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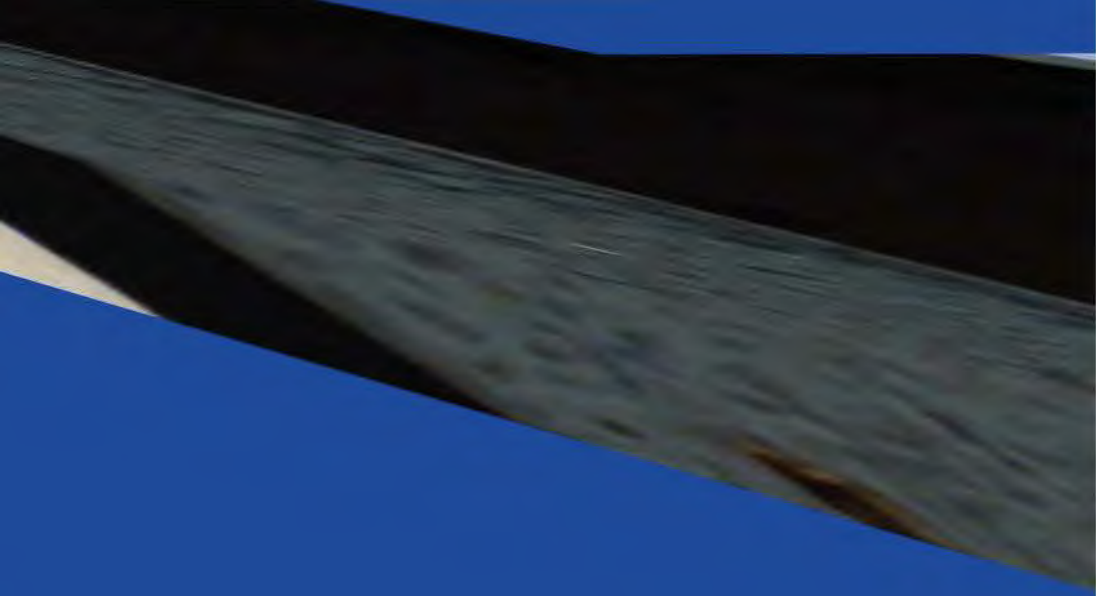

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With the approval of the President and Fellows of Yale University, a series of volumes has been prepared by a number of the Professors and Instructors, to be issued in connection with the Bicentennial Anniversary, as a partial indication of the character of the studies in which the University teachers are engaged.

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THE ELEMENTS OF EXPERIMENTAL PHONETICS

BY

EDWARD WHEELER SCRIPTURE

WITH THREE HUNDRED AND FORTY-EIGHT ILLUSTRATIONS AND TWENTY-SIX PLATES

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PREFACE

THIS book is an attempt to collect the most valuable experimental data concerning the voice in song and speech. I believe that the science of phonetics cannot be confined to a study of the physics and physiology of speech sounds, and that the problems of speech perception, of the psychology of language, of rhythm and verse, etc., can all be treated by experimental methods and must be included.

The book owes much to many friends. Prof. Hanns OERTEL (philology, Yale Univ.), Prof. J. GEDDES (modern languages, Boston Univ.), Prof. E. C. SANFORD (psychology, Clark Univ.), Prof. W. H. BURNHAM (pedagogy, Clark Univ.) and Dr. F. M. JOSSELYN (experimental phonetics, Boston Univ.) have made many suggestions that were incorporated into Part II. Prof. H. L. SWAIN (laryngology, Yale Univ.), Prof. H. B. FERRIS (anatomy, Yale Univ.) and Mr. C. C. CLARKE (French, Yale Univ.) have aided in Part III. Dr. Jonathan WRIGHT (laryngology, Brooklyn) has furnished many valuable suggestions for the chapters on the larynx. Prof. C. H. GRANDGENT (Romance languages, Harvard Univ.), Prof. A. M. ELLIOTT (editor of Mod. Lang. Notes, Johns Hopkins Univ.), Prof. E. S. DANA (editor of Amer. Journ. Sci., Yale Univ.) and Dr. T. R. FRENCH (laryngology, Brooklyn) have permitted me to use blocks from their publications. Prof. E. B. BARKER (translator of SPALTEHOLTZ'S anatomy, Chicago Univ.) consented to the

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reproduction of some plates. W. B. SAUNDERS (publisher of the Amer. Textbook of Physiology) furnished electrotypes for Figs. 51 to 56, and GINN & Co. (publishers, Boston) those for Plates XVII to XXVI. Many of the illustrations in this book are to be credited to the *Studies from the Yale Psychological Laboratory*, Vols. VII and X.

My deepest obligation is to Mr. E. H. TUTTLE (Yale Univ.). His wide acquaintance with the phonetics of various languages has enriched the book with many examples. During the preparation of the manuscript and the correction of the proof I have relied constantly on his technical knowledge and rare critical skill.

E. W. SCRIPTURE.

YALE UNIVERSITY,
NEW HAVEN, CONN., April, 1902.

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ELEMENTS OF EXPERIMENTAL PHONETICS

PART I

CURVES OF SPEECH

CHAPTER I

VIBRATORY MOVEMENT

VIBRATORY movement can be most conveniently studied by considering the motion of a single particle under certain hypothetical conditions. Suppose a particle to be drawn to its position of equilibrium *O* (Fig. 1) by some force that increases as the particle is moved from *O*. When displaced from this position in the direction + *Y* by a momentary blow, it will move a certain distance with steadily decreasing speed until it comes to rest, and then on account of the force acting toward *O* will return to its starting-point. In doing this it will have acquired a velocity that will drive it beyond the original position toward −*Y*. This movement will be opposed by the tendency toward the position of equilibrium, and the particle will be again stopped and drawn back, whereby it will gain new momentum and will pass the point *O* again, but in the opposite direction. At *O* it will again have its maximum velocity. The momentum with which it passes *O* will carry it toward + *Y* and the movement will begin over again. It will thus continue to oscillate across its center of equilibrium.



FIG. 1.

Since the distance *y* of the particle above or below the center of equilibrium varies with the time *t*, it is said to be a function of *t*; this is indicated by the expression $y = f(t)$.

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If the center of equilibrium in Fig. 1 is supposed to travel from left to right at a definite rate, it will describe a straight line representing the time that has elapsed. The oscillating particle will describe a wave-line showing its position at each moment. The shape of the wave and the form of the function will depend on the nature of the force acting on the particle.

The attraction of a particle to its position of equilibrium may vary directly as its distance from that position. If we make the additional suppositions that the actual movement is small and that there are no forces of viscosity or friction tending to dissipate the energy, it is not difficult to get an expression for the movement.

Let y be the position of the particle at any moment t; then, on the suppositions made, the equation of movement can be shown to be

$$y = a \cdot \sin 2\pi \frac{t}{T},$$

where a is the *amplitude*, or the maximum value assumed by y, and T is the *periodic time*, or the time required for y to pass through one complete set of its values. A vibration of this kind is said to be 'harmonic' or 'sinusoidal;' a curve expressing it is called a 'sinusoid.' When the vibrating particle moves without being affected by external forces, its period T is said to be its 'period of free vibration,' or its 'natural period.'

t	$p = \frac{t}{0.5}$	$q = 180° \times p$	sin q	20 sin q	t	$p = \frac{t}{0.5}$	$q = 180° \times p$	sin q	20 sin q
0.00	0.0	0°	0.00	0.0	0.55	1.1	198°	− 0.31	− 6.2
0.05	0.1	18	+ 0.31	+ 6.2	0.60	1.2	216	− 0.59	− 11.8
0.10	0.2	36	+ 0.59	+ 11.8	0.65	1.3	234	− 0.81	− 16.2
0.15	0.3	54	+ 0.81	+ 16.2	0.70	1.4	252	− 0.95	− 19.0
0.20	0.4	72	+ 0.95	+ 19.0	0.75	1.5	270	− 1.00	− 20.0
0.25	0.5	90	+ 1.00	+ 20.0	0.80	1.6	288	− 0.95	− 19.0
0.30	0.6	108	+ 0.95	+ 19.0	0.85	1.7	306	− 0.81	− 16.2
0.35	0.7	126	+ 0.81	+ 16.2	0.90	1.8	324	− 0.59	− 11.8
0.40	0.8	144	+ 0.59	+ 11.8	0.95	1.9	342	− 0.31	− 6.2
0.45	0.9	162	+ 0.31	+ 6.2	1.00	2.0	360	0.00	0.0
0.50	1.0	180	0.00	0.0					

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As an example we may take the curve $y = 20 \sin 2\pi \frac{t}{0.5}$; here the amplitude is 20^{mm} and the period 0.5^{s}. To express this as a curve we calculate the foregoing table.

The curve may be conveniently drawn by plotting on millimeter paper. On a heavy horizontal line a convenient distance is chosen to indicate 0.10^{s}. For example, let $60^{mm} = 1.00^{s}$, whence $3^{mm} = 0.05^{s}$, $6^{mm} = 0.10^{s}$, etc. For y the most convenient arrangement is to let 1^{mm} on the paper represent 1^{mm} of amplitude. At $x = 0$ a point is placed on the line for $y = 0$. At $x = 3^{mm}$ (representing $t = 0.05^{s}$) a point is placed just above $y = 6^{mm}$ (representing $y = 6.2^{mm}$). In a similar manner the points of the curve indicated in the table are marked on the paper and they are then joined by a smooth line. The curve evidently continues to repeat the same form, and further waves can be plotted directly from the same table; the result will be a curve like that shown half-size in Fig. 2.

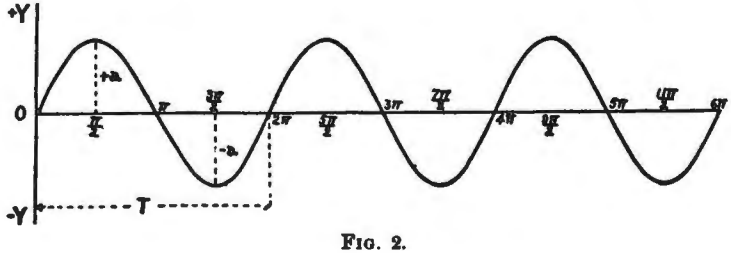

FIG. 2.

The curve crosses the horizontal axis whenever $y = 0$, that is, wherever $\sin 2\pi \frac{t}{T} = 0$; this occurs for sin 0°, sin 180°, sin 360°, etc., that is (since $\pi = 180°$), for sin 0°, sin π, sin 2π, etc., or at the moments $t = 0$, $t = \frac{1}{2}T$, $t = T$, etc. The curve will be at its maximum or minimum for sin 90°, sin 270°, etc., that is, for $\sin \frac{\pi}{2}$, $\sin \frac{3\pi}{2}$, etc., or at the moments $t = \frac{1}{4}T$, $t = \frac{3}{4}T$, etc.

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The sine vibration is also expressed by $y = a \cdot \sin 2\pi nt$ where $n = \frac{1}{T}$ is the *frequency*, or the number of vibrations in the unit time. The relation between T and n is readily understood by considering that when the particle makes a complete vibration in $T = 0.01^s$, it must make $n = 100$ vibrations in one second.

It is also useful to know that the vibration may be expressed by

$$y = a \cdot \sin \sqrt{\frac{s}{m}}\, t,$$

where s is the amount of the central force and m the mass of the particle. The period of the vibration is thus

$$T = 2\pi \sqrt{\frac{m}{s}};$$

the period varies directly as the square root of the mass of the particle and inversely as the square root of the strength of the central force.

The condition of movement of the particle at any moment is called its *phase*. Two vibrations are in the same phase when the particles are at the same stage of the movement at the same time. In the case of the sinusoid curve the phases are repeated at intervals of 2π (Fig. 2).

It is evident that the particle is moving with its least velocity at the moment it changes its direction; that is, its velocity is zero at $\frac{\pi}{2}$, $\frac{3\pi}{2}$, etc. It moves with its greatest velocity as it passes its center of equilibrium, that is, at multiples of π. The moment of greatest elongation is thus the moment of least velocity, and the moment of no elongation is that of greatest velocity.

The vibration of a particle of air is communicated to the neighboring particles and the disturbance travels in dry air at the rate of 330.7^m per second at the sea-level pressure of 760^{mm} and a temperature of 0° C. The successive particles in a line of propagation will be in different phases

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of movement at any given moment (Fig. 3); the distance between two particles in the same phase is known as the



FIG. 3.

wave-length. The wave-length l can be found from the period T by the known relation $l = 330.7\,T$, and from the frequency n by

$$l = \frac{330.7}{n}.$$

The wave-lengths are directly proportional to the periods and inversely proportional to the frequencies. Thus, the wave-length of a vibration with the period 0.01^{s}, or the frequency 100, is $l = 330.7^{m} \times 0.01 = 3.307^{m}$, and that of a vibration with the period 0.02^{s}, or the frequency 50, is $l = 330.7^{m} \times 0.02 = 6.614^{m}$.

A material point set in motion under the circumstances described above would continue to vibrate indefinitely about its position of equilibrium if there were no forces of a dissipative character to be overcome. There are, however, always forces of this character which modify the movement; such forces can be grouped under the term *friction*.

The effect of friction is to reduce the motion of the particle so that instead of vibrating indefinitely it gradually comes to rest. The simplest supposition in regard to friction is that its force is proportional to the velocity of the moving particle. This supposition is in general well adapted to the cases of actual experience. On this supposition it can be shown that the amplitude of the vibration will steadily decrease at a rate expressed by dividing the initial amplitude by the factor e^{kt} where e is the number 2.71828, k the factor of friction, and t the elapsed time. The amplitude at any moment t will thus be $\frac{a}{e^{kt}}$ or $a \,.\, e^{-kt}$, and the curve of vibration will be

$$y = a \,.\, e^{-kt} \,.\, \sin 2\pi \frac{t}{T_k},$$

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where y is the displacement of the point at the moment t, a the amplitude, e the constant 2.71828, k a factor depending on the relation between the mass of the point and the amount of the friction, and T_k the period under the given circumstances. The period T_k depends only in a very slight degree on the friction, and for nearly all purposes it can be regarded as the same as the period without friction; that is, in general we may use T (p. 2) for T_k, and we thus have

$$y = a \cdot e^{-kt} \cdot \sin 2\pi \frac{t}{T}$$

as the expression for the movement when friction is present. The amplitude a is subjected to a steady decrease by the divisor e^{kt}, for in the expression $a \cdot e^{-kt} = \frac{a}{e^{kt}}$ the amplitude will have its greatest value only when $k = 0$ or when there is no friction. Any friction will give a positive value to k and this will reduce the value of a. When there is friction the value of e^{kt} will increase proportionately as time elapses; thus a will be steadily reduced. A vibration with decreasing

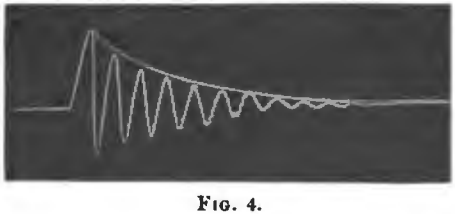

FIG. 4.

amplitude is shown in Fig. 4; the line along the tops of the waves indicates the decrease according to the divisor e^{kt}.

A model comprising a light flat wooden bob suspended between two springs is of value in illustrating the laws of vibration. The bob is moved to one side and then released; it executes vibrations of a definite period with slowly decreasing amplitude. The effect of the mass of the particle can be shown by adding lead weights to the bob and the effect of the amount of the central force by increasing the tension of the springs. A pair of light mica or cardboard vanes, adjustable

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at various angles to the direction of movement, render the model available for illustrating the effects of friction.

Many of the phenomena of vibrating bodies can be accurately studied in the action of vibrating springs or reeds. A steel spring *B* (Fig. 5) clamped tightly in a small vise *D* on the frame *IJ* bears at its end a recording point *N* of thin steel ribbon. The frame also carries an adjustable electromagnet *M* clamped in place by *L* and a felt damper *G* adjusted as desired by the clamps *F* and *H* with their rod *E*.

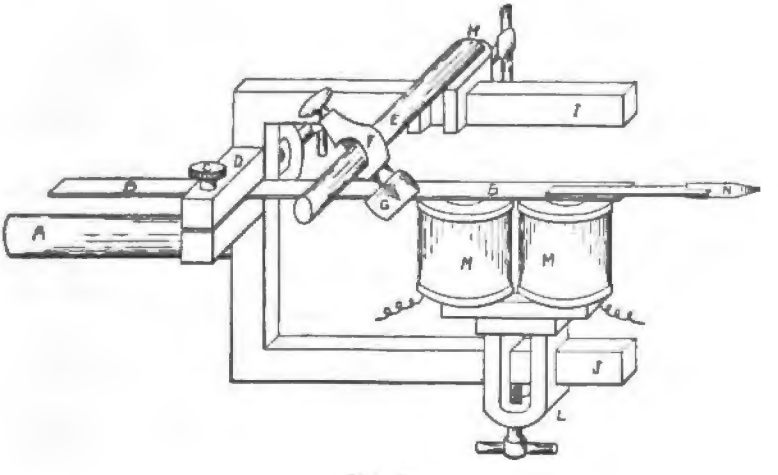

FIG. 5.

The rod *A* is placed in a supporting standard (Fig. 6) which is so adjusted that the recording point rests against the surface of a smoked drum.

One of the most useful forms of a smoked drum is that shown in Fig. 6. It is a light cylinder of metal with an axle made so as to receive any of a set of pulleys or gears. A sheet of glazed paper of the correct size to fit the drum receives a little paste along one edge; it is stretched smoothly around the drum and the paste-edge is lapped over. A gas flame is then held close under it while the drum, with its axle horizontal, is rotated against the direction of the flame;

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in this way an even coating of soot is deposited all over the surface (light brown for ordinary work, black for reproducing curves by photography).

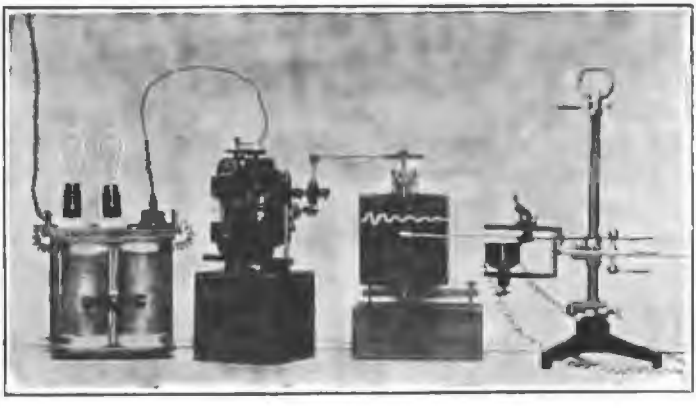

FIG. 6.

Several of these drums may be smoked and kept ready for use. Long strips of paper may be used over two drums. The continuous-paper drum shown in Fig. 7 is suitable for very long records. Two plates *DE* are held together by cross-rods. At any points on the edges of these plates metal shafts may be clamped, and two drums *A*, *B* with hollow axles placed on them. A band of paper *CC* is fastened evenly around the drums and tightened after the paste is dry by ad-

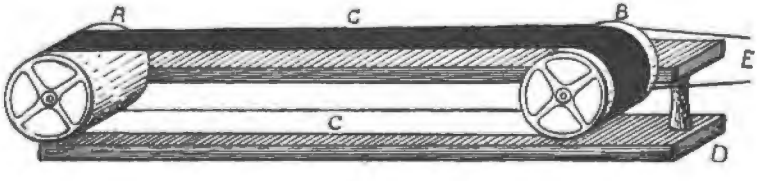

FIG. 7.

justing one of the shafts; it is then smoked as usual. To rotate the drums a loose pulley may be placed on one of the shafts before or after the drum is on the support; this pulley

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has a spring that catches one of the spokes of the drum. The drums may be used horizontally as in Fig. 7; or vertically by tipping the pair of plates on their edges.

Graphic records may also be made on a rotating glass wheel, smoked over a candle flame. One form of such a wheel, shown in Fig. 8, is adapted for use with a projection lantern.

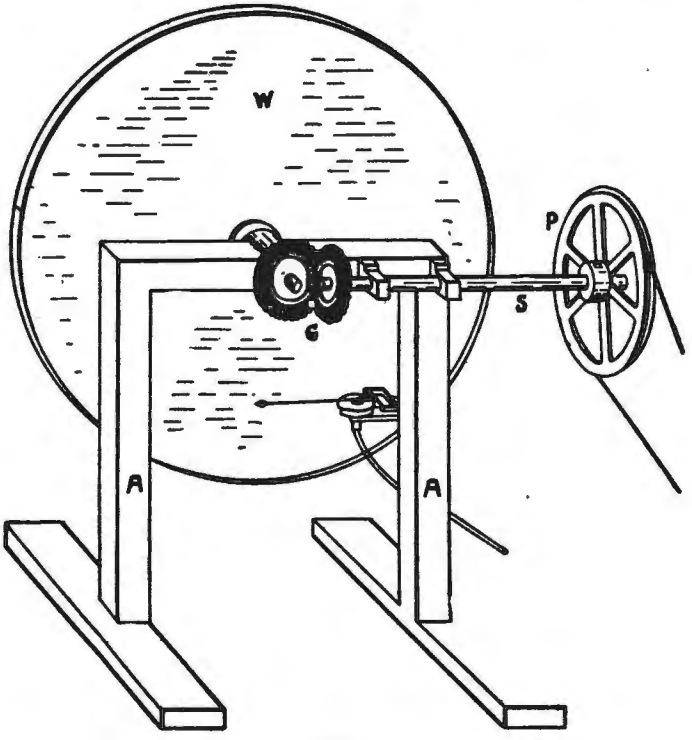

FIG. 8.

The shaft of the glass wheel *W* is connected to the pulley shaft *S* by the bevel gear *G*; the belt from the pulley *P* passes to the motor. The legs *AA* are adjusted to fit over the projection lantern in a manner to bring the lower part of the glass wheel just in front of the condenser. The tracings appear on the screen as they are made while the apparatus itself can be seen through the smoked surface.

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The drum is rotated by a small electric motor whose speed is regulated by an appropriate resistance; Fig. 6 shows both a lamp resistance for large changes in speed and an adjustable wire resistance for smaller changes. A clockwork motor may also be used.

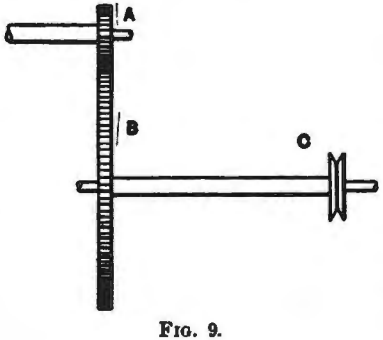

FIG. 9.

An adjustable countershaft fastened to the base of the motor allows the speed to be reduced in transmission. For very high speeds the belt from a pulley on the drum runs directly to a small pulley on the motor axle. For more moderate speeds the countershaft is used with a spur gear *A* on the motor axle and another *B* on the countershaft (Fig. 9); the pulley *C* on the countershaft runs at a lower speed on account of the reduction *AB*. For very low speeds a worm *W* is placed on the motor axle and a worm gear *V* or a spur gear on the countershaft (Fig. 10). When the drum is used with its axis horizontal, a spur gear *S* (Fig. 11) may, if preferred, be placed on its axle and made to connect with a spur gear *T* of any desired size on the countershaft, which is run by a worm *W* on the motor axle. For very low speeds the spur gear *S* (Fig. 12) is run by a worm *X* on the countershaft, which is turned by the worm gear *V* in connection with the worm *W* on the motor axle. A collection of various sizes of pulleys and gears makes it possible to get almost any speed desired; the finer gradations are accomplished by the resistances and by slightly pressing or loosening the motor brushes against the commutator.

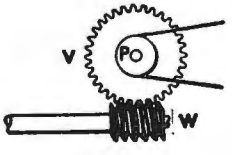

FIG. 10.

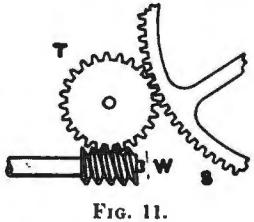

FIG. 11.

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These types of recording apparatus are of constant use in the most varied forms of phonetic work — the drums for investigation and laboratory practice, the glass recorder for class-demonstrations.

A blow on the spring *B* (Fig. 5) will cause it to draw a sinusoidal line on the drum; the waves, however, slowly decrease in amplitude owing to loss of energy by friction (p. 5). A quicker decrease due to additional damping can be obtained by placing the surface of the felt damper (*G*, Fig. 5) more or less tightly against its edge. A curve of vibrations dying away by friction due to damping was shown in Fig. 4; it was made by the damped spring struck by a blow.

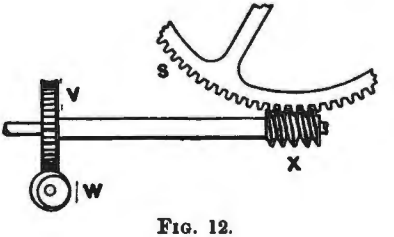

FIG. 12.

A vibratory body may receive a series of impulses. The results of different natural periods of the vibratory point,

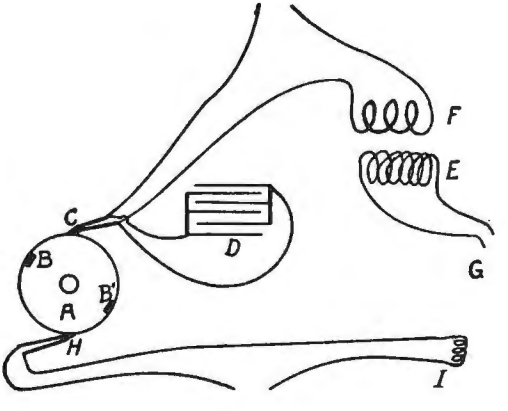

FIG. 13.

of frictional factors, of various strengths of impulse and of different intervals of repetition, can be studied by means of the vibrating spring. A series of impulses may be imparted

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to the spring *B* (Fig. 5) by brief electric currents sent through the magnet *M*. In a study of the action of such impulses on a spring these impulses were obtained and recorded in the following way. A hard rubber contact wheel *C* (Fig. 13) carried on its rim two pieces of metal *BB'*. A pair of copper brushes *H* bearing against the rim were the poles of a circuit through the magnet *M* (Fig. 5), indicated by *I* in Fig. 13. As *B* or *B'* passed across *H*, it closed the circuit and sent a magnetic impulse to the spring. This had the effect of a sharp blow. The strength of the blow could be readily adjusted by varying the current or displacing the magnet *M*. As it was desirable to have an indication of the exact moment at which the impulse was sent to the spring, a spark coil was made to register directly on the line drawn by the vibrating point. A pair of copper brushes *C* formed the poles of a circuit through the primary coil *F* of a spark coil, whose secondary coil *E* was connected by the wires *G* to the metallic spring and the base of the recording drum. A condenser *D* was connected around the break at *C*. Whenever a metal piece *B* or *B'* passed under the brushes *C*, the circuit was closed. With an appropriate adjustment of the current, a spark passed from the recording point through the paper to the drum, removing the smoke and making a white dot when the circuit was closed and also when it was broken. The two pairs of brushes were so adjusted that the sparks registered exactly the moments at which the impulses were sent through the magnet and those at which they ceased.

A record of an experiment in which the contact wheel was revolved with steadily increasing rapidity is reproduced in Fig. 14. The waves were drawn by the point *N* (Fig. 5); the pairs of dots marked the beginning and end of each impulse. The figure shows that each impulse started a vibration which died away by friction. If one impulse followed the preceding one before the vibration was entirely gone, its effect was increased or diminished according as the phase of movement in which it occurred was the same as or

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opposed to the movement started by the impulse. When the impulses occurred quite close together and at exactly the right phases, the summation of effects made the vibrations very strong. In all such cases an increase occurred in amplitude whenever the period τ of the impulses became a multiple of the natural period T of the spring. In all cases the spring vibrated with the period T; only the amplitude was affected by the variations of τ.



FIG. 14.

The condition of equal lengths of impulse could not be illustrated with the arrangement just described, as the contacts through B and B' (Fig. 13) lasted a constant fraction of a revolution and the length of the impulse decreased proportionately as the speed of revolution increased. The impulses were weaker as they came faster. Nevertheless the increase in amplitude whenever τ was a multiple of T appears strikingly in Fig. 14. This increase in amplitude for harmonic relations (that is, according to the simple ratios, 1 : 2 : 3 : etc.) between a natural period and impressed force is known as 'resonance.'

Resonance decreases with increase in damping, with deviation from a harmonic relation and with distance apart in the harmonic series.

The principles of resonance are of considerable importance. Some of them can be readily illustrated by the use of acous-

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tical resonators. The spherical resonator (Fig. 15) is a hollow globe of glass or brass with a small opening arranged to fit the ear and a larger one to receive the vibrations of the air. When the resonator is placed in the ear, it will be heard to respond loudly whenever a certain tone occurs in its neighborhood. This tone is approximately the same as that found, by tapping or blowing, to be its natural tone. The adjustable resonator (Fig. 16) can be made to answer to any tone within its limits. Resonators respond not only to vibrations of their own period but in less degrees also to those of longer periods in the harmonic series. They respond slightly or not at all to vibrations not in this series. The natural period of a resonator depends on its volume. The shape of the cavity is of little influence. The size and shape of the opening are of great effect. The resonance period of a bottle is altered by filling it with water; it does not change when the bottle is tipped, but does change with any change of the size of the opening. The resonance period of the mouth in speech probably depends mainly on the size of the cavity and on the size and shape of the labial, lingual and nasal apertures.



FIG. 15.

Owing to the unavoidable presence of friction all vibratory bodies execute movements of decreasing amplitude unless the



FIG. 16.

loss of energy is replaced. For vibrating springs this may be conveniently accomplished by having the spring regulate a series of magnetic impulses sent to it; this is the principle of

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the constantly used self-interrupting electric fork. One of the many forms is shown in Fig. 17. The fork *AA* is held in the block *G* by a nut *H* on its stem. The block *G* is on a rod attached to the clamp *D* by which it can be adjusted on any rod *F*. An electric current is brought to the binding post *B* connected with the magnet coil *M*; it passes from the magnet to the platinum disc *P*, from which it goes by a small piece of platinum wire to the prong *A* and from another binding post at *G* or elsewhere on the base of the fork back to the battery. The current passing through the coil *M* makes it magnetic, and the prongs *AA* are drawn inward. This movement

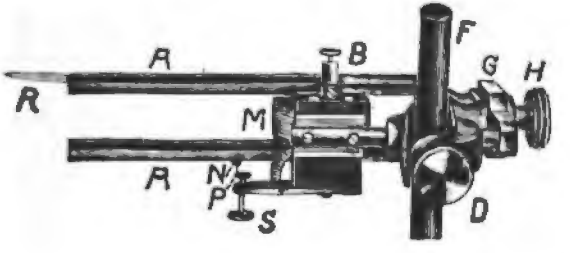

FIG. 17.

breaks the circuit at *P*, the magnetism ceases, the prongs fly back, the circuit is again made, etc. Owing to self-induction in the circuit the passing of the current through the magnet is slightly retarded when the contact is made at *P* as the prong flies outward, and is somewhat prolonged when it is broken at *P* as the prong flies inward. The pull of the magnet inward is therefore somewhat longer when the prong is moving in the direction of the pull than when it is moving against it; this furnishes the extra energy required to compensate the loss by friction and keep the fork vibrating indefinitely.[1] When the point *R* is placed on the recording drum, it draws a sinusoidal curve (Fig. 2) whose wave-length corresponds to

[1] RAYLEIGH, Theory of Sound, § 64, 2d ed., London, 1894; DVOŘAK, *Ueber verschiedene Arten selbstthätiger Stromunterbrecher und deren Verwendung*, Zt. f. Instrumentenk., 1891 XI 423; *Zusatz zu der Mittheilung, 'Ueber versch. Arten selbstth. Stromunterbrecher,'* Zt. Instrumentenk., 1892 XII 197.

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the period of the fork. The period is lengthened by a rise in temperature, but for the usual room-temperatures the differences are small. Increased pressure of N against P very slightly shortens the period. The friction of the point R on the record surface reduces the amplitude but does not appreciably affect the period (p. 6).

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CHAPTER II

PHONAUTOGRAPH CURVES AND MANOMETRIC FLAMES

THE first attempt at recording speech was made by SCOTT in 1856. SCOTT was a proof-reader; noticing a picture of the ear in the proof-sheets of a text-book of physics, he believed that he could get a record of speech by imitating the structure of the ear.[1] In SCOTT'S phonautograph a large parabolic receiving trumpet carried at its end a thin membrane whose movement caused a small recording lever to write upon the smoked surface of a cylindrical drum. The sounds of the voice passing down the receiver agitated the membrane and caused the lever to draw the speech curve on the drum. The instrument as improved by KŒNIG was used by DONDERS and others.[2] It is the prototype of the later machines that make speech records by registering the vibrations of a diaphragm on a moving surface by means of a lever.

The logograph of BARLOW consisted of a trumpet or mouthpiece ending in a thin membrane of rubber. A thin lever of aluminum carrying a point dipped in color wrote the speech curves on a band of paper.[3]

[1] SCOTT, Inscription automatique des sons de l'air au moyen d'une oreille artificielle, 1861; *Phonautographe*, Annales du Conservatoire des Arts et Métiers, Oct. 1864; *Phonautographe et fixation graphique de la voix*, Cosmos, 1839 XIV 314; LIPPICH, *Studien über d. Phonautographen von Scott*, Sitzb. d. Wien. Akad., Math.-naturw. Kl., 1864 L (II. Abth.) 397.

[2] DONDERS, *Ueber d. Natur der Vokale*, Arch. f. d. holländ. Beiträge z. Natur- u. Heilk., 1858 I 157; *Zur Klangfarbe der Vokale*, Arch. f. d. holländ. Beiträge z. Natur- u. Heilk., 1861 III 446; *Zur Klangfarbe der Vokale*, Ann. d. Phys. u. Chem., 1864 CXXIII 527; De physiologie der spraakklanken, Utrecht, 1870; SCHWAN UND PRINGSHEIM, *Der französische Accent*, Arch. f. d. Studium d. neueren Sprachen, 1890 LXXXV 203.

[3] BARLOW, *On the pneumatic action which accompanies the articulation of sounds*

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An improved phonautograph was used by SCHNEEBELI ;[1] it carried two points, one fixed to aid in comparison and the other moving with the membrane. The inscription was made on a strip of glass covered with a light coating of smoke and drawn on a carriage rapidly in front of the recording points. The tracings were measured with the aid of micrometric screws. SCHNEEBELI gave a number of the characteristic curves of the vowels. Various similar methods have been employed with constantly better results. The ear drum has been used for the membrane by C. BLAKE.[2] PREECE and STROH used a thin membrane of rubber stretched by a cone of paper. The cone was made to move a fine glass tube supplied with an aniline ink, the record being taken on a band of paper.[3]

HENSEN'S[4] phonautograph consisted of a membrane of goldbeater's skin in a conical form produced by molding it over a shape while moist and allowing it to dry before removal. A single light lever attached to the center of the membrane carried a fine glass thread as a recording point. It wrote the curve on a thinly smoked strip of glass. The curves were studied with a microscope.

WENDELER'S curves,[5] obtained with HENSEN'S phonautograph, were observed through a microscope and copied by hand.

by the human voice, as exhibited by a recording instrument, Proc. Roy. Soc. Lond., 1874 XXII 277 ; *On the articulation of the human voice as illustrated by the logograph*, Proc. Roy. Soc. Dublin, 1880 N. S. II 153.

[1] SCHNEEBELI, *Expériences avec le phonautographe*, Arch. des Sciences phys. et nat. de Genève, 1878 (Nouvelle période) LXIV 79 ; *Sur la théorie du timbre et particulièrement des voyelles*, Arch. des Sciences phys. et nat. de Genève, 1879 (III. période) I 149.

[2] BLAKE, *The use of the membrana tympani as a phonautograph and logograph*, Archives of Ophthal. and Otol., 1876 V No. 1.

[3] PREECE AND STROH, *Studies in acoustics*, Proc. Roy. Soc. Lond., 1879 XXVIII 358.

[4] HENSEN, *Ueber die Schrift von Schallbewegungen*, Zt. Biol., 1887 XXIII 291 ; first described by GRÜTZNER, *Physiologie d. Stimme u. Sprache*, 187, Hermann's Handb. d. Physiol., I. Bd., II Theil, Leipzig, 1879.

[5] WENDELER, *Ein Versuch d. Schallbewegung einiger Consonanten u. anderer Geräusche mit d. Hensen'schen Sprachzeichner graphisch darzustellen*, Diss., Kiel, 1886 ; also in Zt. f. Biol., 1887 XXIII 303.

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The curve of r was found to consist of small vibrations with rather regular fluctuations of amplitude having long periods; the resemblance to the familiar curves of two tones forming beats suggested the term 'pseudobeats' for the fluctuations of intensity observed in the r-curves. The curves of r were similar to those afterwards obtained by HERMANN (see Chap. III below). The terminal portions of r were thought to resemble the curves of the adjacent vowels; the r was defined as a rhythmically repeated weakening of the vowel sound of the syllable to which the r belonged.

WENDELER also noted the vowel-like character of the curves of l, m and n. The vibrations in a vowel curve were observed not to remain constant in form but to undergo gradual changes; these he attributed to changes in the pitch of the resonance tone, assuming that the cord tone remained constant. This view is inadequate. These changes should be attributed rather to the changes in the relations among the various resonance tones and the cord tone; they appear in all vowel curves and indicate that a vowel sound never remains constant. I believe it is safe to say that a vowel cannot be treated as a sound whose character is the same throughout its duration. The various component tones are continually changing both in pitch and intensity, and it is highly probable that every typical vowel has typical forms of change, and that these forms of change are as important characteristics as the pitches and intensities of the component tones.

MARTENS,[1] with curves obtained by HENSEN'S phonautograph, observed and charted the changes in the cord tone in speech. The cord tone is continually changing, and it may be said that a vowel is not spoken on a tone of a certain pitch but on a slide that may be quite extensive and complicated.

MARTENS, like WENDELER, observed gradual changes in the form of the vowel curve; but he attributed them to the

[1] MARTENS, *Ueber das Verhalten von Vokalen und Diphthongen in gesprochenen Worten*, Diss., Kiel, 1888; also in Zt. f. Biol., 1889 XXV 289.

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changes in the cord tone. As stated above, the changes are due to the changes in the *relations* between the various tones of the vowel.

Curves of the German diphthongs **au** and **ai** showed gradual changes extending throughout the sound. Such curves show that the diphthong recorded is not to be considered as the sum of two sounds united by a glide but as one sound of a changing character. It is undoubtedly true that in **ai**, for example, various stages in the development of the first portion might be picked out that resemble various forms of the **a**-sound, and that similarly various forms of the **i**-sound might be picked out at various moments in the later portion; possibly resemblances to even other sounds could be found at various moments. The attempt to lump the whole effect into two portions leads to conflicting opinions, of which all are partly, and none completely, correct. Diphthongs of this character differ from long vowels only in undergoing somewhat more change. The long vowels themselves are not constant; a sharp division between diphthongs of this kind and long vowels cannot be made. The tendency of long vowels to diphthongize is a familiar phenomenon [1] that has made some of them, like **o** and **e**, as strongly dipthongal as **au** and **ai** in Southern English.[2] The unification of the elements of a diphthong may go so far that it becomes, in the history of the sound, a long vowel; it depends on circumstances [3] just what portion of the diphthong will remain as the fundamental portion of the vowel.

An improvement was made in HENSEN'S recorder by PIPPING, who replaced the glass thread by a small diamond which scratched the curve directly on the glass strip. With this instrument PIPPING has made a series of investigations, chiefly on the vowels.[4] The curves on the glass strip were measured with a microscope and analyzed.

[1] SWEET, *History of English Sounds*, § 63, Oxford, 1888.
[2] SOAMES, *Introduction to Phonetics*, § 87, London, 1899.
[3] SWEET, as before, §§ 70, 71.
[4] PIPPING, *Om klangfärgen hos sjunga vokaler*, Diss., Helsingfors, 1890; also

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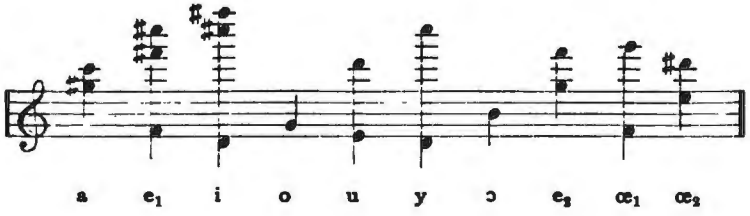
The curves of the Swedish vowels sung and spoken by PIPPING were found[1] to contain resonance tones that lay for **a** at about $g^{2\sharp}$ and c^3; for $\mathbf{e}_1$ (Swedish close *e*) about f^1, $f^{2\sharp}$ and $c^{4\sharp}$; for **i** about d^1, $c^{4\sharp}$ and $f^{4\sharp}$; for **o** about g^1; for **u** about d^1 to f^1 and about d^3; for **y** about d^1 and c^4; for **ɔ** (*å*) about b^1; for $\mathbf{e}_2$ (*ä*) about g^2 and f^3; for $\mathbf{œ}_1$ (close *ö*) about f^1 and g^3; for $\mathbf{œ}_2$ (open *ö*) about e^3 and $d^{3\sharp}$. In musical notation these results are:



The Finnish vowels[2] found in the words '*A*amu,' '*E*erik,' '*v*iisas,' 'ta*l*oon,' '*k*uusi,' '*p*yy,' '*s*ää,' and '*T*öölö' were all sung on $g^{0\sharp}$ by two tenor-barytones, one bass-barytone and two bass voices, also all on c^0 and on $g^{-1\sharp}$, and **e** again on $g^{0\sharp}$ by one of the bass voices. A registration of words spoken by one of the tenor-barytone voices included 'satama,' 'saadaan,' 'kuopio,' 'houreet,' etc.

The eight vowels sung on $g^{-1\sharp}$ showed a maximum resonance near $g^{0\sharp}$ or c^1. Since the Swedish vowels i, y and a tested by resonators (p. 14) also showed a maximum resonance near c^1 and the eight German vowels of HERMANN

as *Zur Klangfarbe d. gesungenen Vokale; Untersuchung mit Hensen's Sprachzeichner*, Zt. f. Biol., 1890 XXVII 1; *Nachtrag zur Klangfarbe der gesungenen Vokale* Zt. f. Biol., 1890 XXVII 433; *Om Hensen's fonautograf som ett hjälpmedel för språkvetenskapen*, Helsingfors, 1890; *Fonautografiska studier*, Finländska Bidrag, till Svensk Språk- och Folklifsforskning, 99, (Helsingfors, 1894); *Zur Lehre v. d. Vokalklängen*, Zt. f. Biol., 1895 XXXI 524; *Ueber d. Theorie d. Vokale*, Acta Societatis Scientiarum Fennicæ (Helsingfors), 1894 XX No. 11; *Zur Phonetik d. finn. Sprache, Unters. mit Hensen's Sprachzeichner*, Mém. de la Soc. finno-ougrienne, XIV, Helsingfors, 1899.

[1] PIPPING, as before, Zt. f. Biol., XXXI.

[2] PIPPING, as before, Mém. Soc. finno-ougrienne.

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(Chap. III) gave like results, PIPPING concluded that this resonance tone must arise from some portion of the acoustical apparatus not influenced by the movements for the different vowels. This constant resonance was attributed by PIPPING to the chest cavity. Since the tones to which the chest resonates best in a male adult are nearly an octave below c^1 and since the capacity of the chest cavity is continually changing during respiration, this supposition can hardly be accepted; the resonance may preferably be attributed to the trachea which is of a fairly constant capacity with an aperture adapted to such a tone.

PIPPING'S computations and interpretations of the Finnish vowels gave three resonances, which he attributed to the chest, throat and mouth in the order of rising pitch as shown in the accompanying table ($\ddot{a}\,[y]$ indicates $\ddot{a}$ when followed by y).

			Chest	Throat	Mouth
a	(a)	sung by bass voice	$g^{0}\sharp$	$b^1 - c^2$	c^3
e_2	($\ddot{a}$)	" " "	"	"	e^3
o	(o)	" " "	"	$g^{1}\sharp$	$a^2 - c^3$
œ	($\ddot{o}$)	" " "	"	"	e^3
e_1	(e)	" " "	"	"	$f^3 - f^{3}\sharp$
u	(u)	" " "	"	about $g^{1}\sharp$	$f^2 - a^{2}\sharp$
y	(y)	" " "	"	"	$f^3 - f^{3}\sharp$
i	(i)	" " "	"	"	$g^3 - g^{3}\sharp$

			Chest	Throat	Mouth
a	(a)	spoken by tenor-barytone	d^1	$f^2 - f^{2}\sharp$	$d^3 - d^{3}\sharp$
e_2	($\ddot{a}$)	" " "	"	$d^{2}\sharp - e^2$	$f^{3}\sharp - g^3$
e_2	($\ddot{a}\,[y]$)	" " "	"	$f^{2}\sharp$	$g^{3}\sharp$
o	(o)	" " "	"	$b^{1}\sharp - c^2$	$a^2 - c^3$
œ	($\ddot{o}$)	" " "	"	$b^1 - c^2$	$g^3 - g^{3}\sharp$
e_1	(e)	" " "	"	$a^{1}\sharp$	$a^3 - b^3$
u	(u)	" " "	"	about d^1	$g^2 - b^2$
y	(y)	" " "	"	"	a^3
i	(i)	" " "	"	"	$a^{3}\sharp - c^4$

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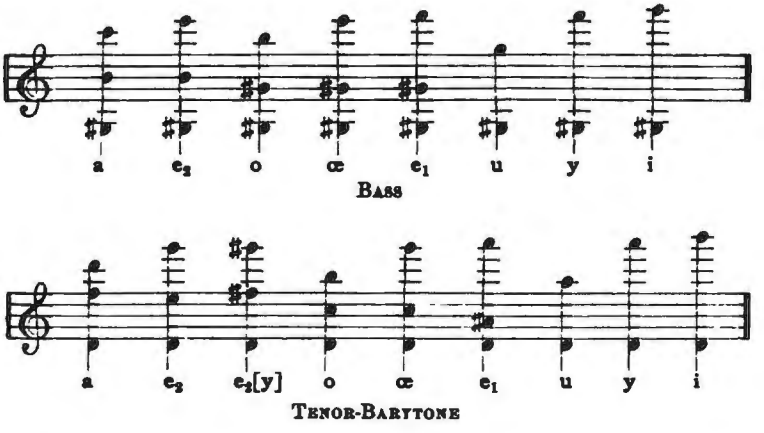
In musical notation the results are:



The vowels sung by one of the bass voices *N* and the vowels spoken by one of the tenor-barytones *E* — as given in the list above — ' form in a way the extremes between which the other investigated sounds lie. Trustworthy exceptions are almost exclusively the e_2-sounds of *W* and *L*. The e_2 of *W* has a throat resonance $f^{2\sharp}$ which otherwise occurs only in e_2[y]. The e_2 of *L* has a still lower mouth resonance, $d^{3\sharp}$, than that of *N*, e^3. The mouth resonance in u of *A* appears to lie below the lowest step otherwise found, f^2; perhaps this is also the case in u of *W*.

' As long as we confine ourselves to one individual and do not compare sung vowels with spoken ones, the vowels may be easily distinguished by their resonance tones. But when we consider sung and spoken vowels of different persons, the variations become considerable, so that the ranges of fluctuation of different vowel resonances not seldom overlap. The i of *N* has a mouth resonance that is not only deeper than the i resonance of *E* but is in fact deeper than his y resonances. Since the vowels i and y belong to the same group in respect to throat resonance, we may ask in what they are to be distinguished from each other. The vowels œ and e cannot be confused with y and i on account of the higher

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throat resonance, but how does it happen that the mouth resonance of **e** with *N* lies lower than the resonance of **œ** with *E*? Can the resonances of **a** sink to c^3 and c^2 (*N*) without the vowel changing into an **o**?' PIPPING'S answer is that the vowels that are designated by the same name are really a group differing considerably from each other. Thus, the **a** of a bass voice at a low pitch resembles an **o**. Again, according to PIPPING, the pitch of the maximum resonance tone is not the only essential to the character of a vowel; the range through which the mouth can resonate to the impulses from the cords is a special characteristic of each vowel.

PIPPING found that in the word 'houreet' the number of flaps of the **r** was always 3, and in 'kiura' 2; in 'houreet' the resonance tone e^2 during the **r** differed from the preceding g^2 for the **u** and the following g^3 for the **i**; in 'kiuru' the resonance tone during the **r** was lower than that for the preceding and the following **u**. The **r** in these cases seems to have been different from that of WENDELER (p. 19). In the word 'keihäitä' there was no interruption of the cord vibrations at the time of the **h**; it was thus a sonant **h**, corresponding probably to the sonant **h** of the Sanskrit grammarians and of later observers [1] and seemingly related to the usual whisper sound which has been shown to possess a slight degree of sonancy.[2]

The hindrances due to the inertia of material levers and to the friction of a recording point were avoided by E. W. BLAKE, who attached a mirror to a telephone plate in such a way that a beam of light was deflected by each movement. A ray of light from a heliostat was reflected through lenses upon a photographic plate moving with a constant velocity. The sound wave recorded a line on the plate.[3] RIGOLLOT and CHAVANON covered the wider end of a paraboloid with a very thin membrane of collodion, to the center of which was

[1] MEYER, *Beiträge zur deutschen Metrik*, numbers 13 and 15 of *Tafel*, Neuere Sprachen, 1899 VI 1; MEYER, *Stimmhaftes H*, Neuere Sprachen, 1900 VIII 261.

[2] OLIVIER, *De la voix chuchotée*, La Parole, 1899 I 20.

[3] BLAKE, *A method of recording articulate vibrations by means of photography*, Amer. Jour. Sci., 1878 XVI 55; also in Nature, 1878 XVIII 338.

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fixed a small mirror working on an axis of fine thread.[1] The ray of light was thrown on a rotating mirror and observed on a screen. LEBEDEFF substituted a membrane of cork in a similar apparatus.[2]

SAMOJLOFF[3] used a phonautograph with a 1^{mm} thick cork membrane to which a lever with a mirror was attached. The deflections of the mirror were recorded by a ray of light fall-

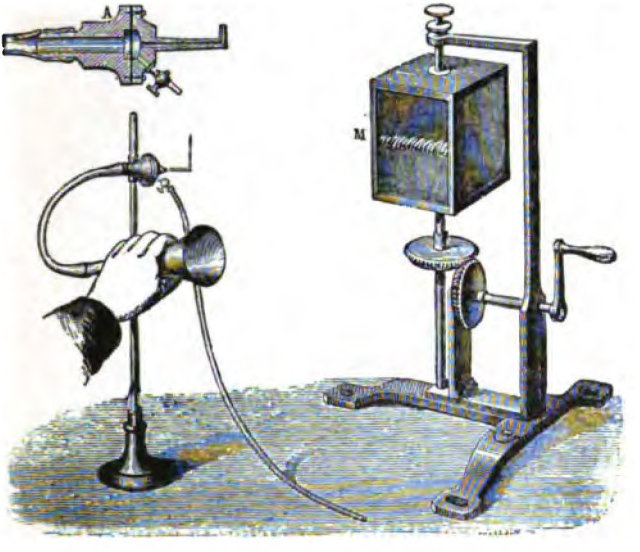

FIG. 18.

ing on a photographic plate. The characteristic tones of the vowels (Russian) were found to vary from a^2 to g^2 for a, b^1 to d^2 for o, c^1 to g^1 and c^2 to e^2 for u, b^1 (?) to d^2 (?) and b^3 to d^4 for e, c^1 (?) to g^2 (?), and finally c^2 (?) to e^2 (?) and d^4 to e^4 for i.

A modification of the phonautograph idea is found in the magnetic and carbon transmitters of the telephone and in the various voice keys. These are used mainly for determining

[1] RIGOLLOT ET CHAVANON, *Projection des phénomènes acoustiques*, Journal de physique, 1883 (2) II 553.

[2] LEBEDEFF, Journal d. russ. physik.-chem. Ges., 1894 XXVI 290, mentioned by SAMOJLOFF, *Zur Vokalfrage*, Arch. f. d. ges. Physiol. (Pflüger), 1899 LXXVIII 4.

[3] SAMOJLOFF, *Zur Vokalfrage*, Arch. f. d. ges. Physiol. (Pflüger), 1899 LXXVIII 1, 27; *Graphische Darstellung d. Vokale*, Physiologiste Russe, 1900 II 62.

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the tone from the vocal cords; accounts will be found in future chapters.

The manometric flame method was devised by KŒNIG.[1] The vowel is sung or spoken into a trumpet leading to a small box known as the 'manometric capsule.' This box is divided in two parts by a thin rubber membrane. The details of its construction are shown in Fig. 18 *A*. One part is a

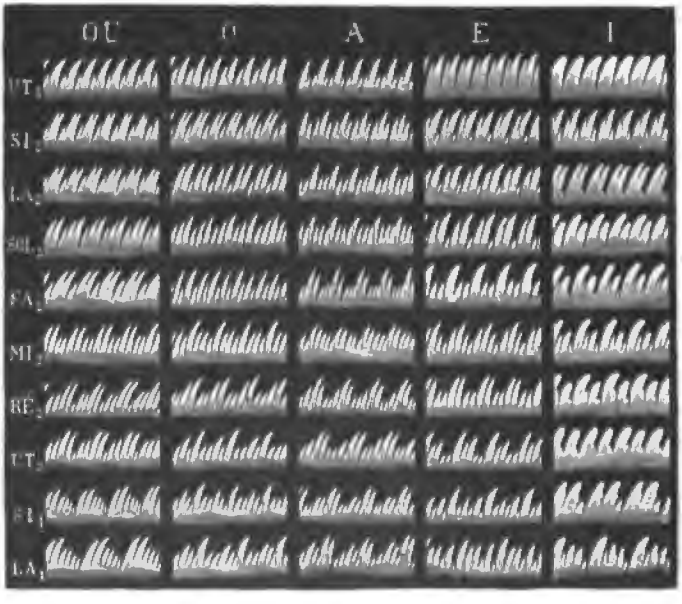

FIG. 19.

tight chamber through which illuminating gas is flowing; the gas is lighted at the end of the small jet. As the sound waves descend they strike the rubber membrane, set it in vibration and thus produce movements of the gas analogous to those of the air in the sound waves. The vibrations of the flame can be seen when the eye is suddenly moved sidewise; owing to the lag of sensation the image remains in the eye and the successive vibrations appear simultaneous. They are conveniently

[1] KŒNIG, *Die manometrischen Flammen*, Ann. d. Phys. u. Chem., 1872 CXLVI 161; Quelques expériences d'acoustique, 56, Paris, 1882.

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studied, like other vibrating bodies, by means of revolving mirrors; the best form is a cube with mirrors on four sides set in rotation by a handle (Fig. 18 *M*). The curves of the five French vowels obtained with this apparatus and carefully drawn by KŒNIG are shown in Fig. 19. The pictures of m and n (no difference detected) are given in Fig. 20. The picture of r is given in Fig. 21.

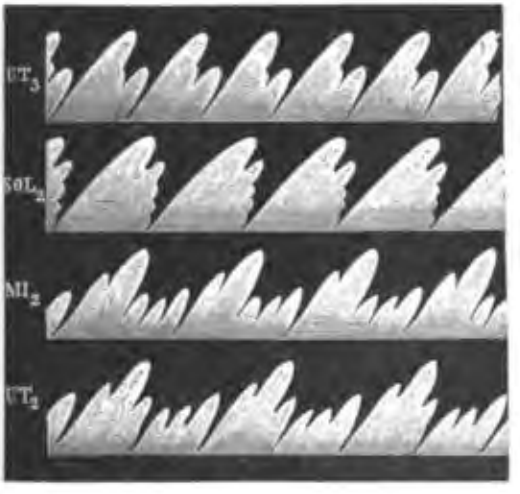

FIG. 20.

The manometric flames can be photographed[1] by selecting the right composition of the illuminating gas. Cyanogen gas has been used. A mixture of hydrogen (or ordinary illuminating gas) and acetylene burning in a chamber of oxygen gives brilliant flames.[2] The first two gases are mixed in a

[1] STEIN, in MAREY, La méthode graphique, 647; DOUMER, *Mesure de la hauteur des sons par les flammes manométriques*, C. r. Acad. Sci. Paris, 1886 CIV 340; *Études du timbre des sons, par la méthode des flammes manométriques*, C. r. Acad. Sci. Paris, 1887 CV 222; *Des voyelles dont le caractère est très aigu*, C. r. Acad. Sci. Paris, 1887 CV 1247; HALLOCK, *Photography of manometric flames*, Physical Review, 1895 II 305; MARAGE, *Études des voyelles par la photographie des flammes manométriques*, Bull. de l'Acad. de Med., 1897 XXXVIII 476.

[2] MERRITT, *On a method of photographing the manometric flame, with applications to the study of the vowel A*, Physical Review, 1893 I 166'; NICHOLS AND MERRITT, *Photography of manometric flames*, Physical Review, 1898 VII 93.

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tank and supplied to the capsule *M* by the tube *G*, Fig. 22. The jet *AA*, with a platinum tip *B*, is fixed in an outer tube *T* which receives oxygen at *O*. The flame *F* thus burns in an atmosphere of oxygen with a strongly actinic light. The image of the flame is focused on a photographic plate in a camera. When this plate is moved rapidly sidewise, the flame traces a curve showing its vibrations. MERRITT'S results with a number of records of the vowel **a** sung by different voices on different notes, varying from a frequency of 102 with a bass voice to 667 with a soprano, showed a resonance tone averaging 736, practically independent of the pitch of the voice.

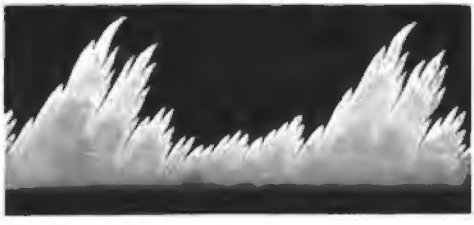

FIG. 21.



a

In the experiments by NICHOLS and MERRITT the image of the flame was focused upon a sensitive celluloid film mounted on a wheel *D* with a circumference of nearly 1^m inside a light-tight box (Fig. 23). The wheel was rotated at a surface speed of 1^m in a second. The vibrations of the gas flame *F* were thus photographed on the film. The curves may be reproduced by a photogravure process; as the reproductions sometimes shrink, the measurements should be made in the original films. I have found it convenient to print the curve on blue prussiate paper, trace the

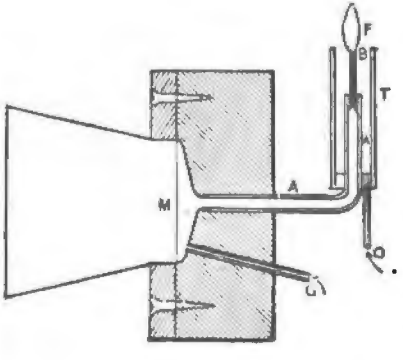

FIG. 22.

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outline in Chinese ink and clear off the blue color by washing-soda. Fig. 24 shows o of bo reproduced in this way.

NAGEL and SAMOJLOFF[1] used the ear in the head of a freshly killed animal as a manometric capsule. The gas was

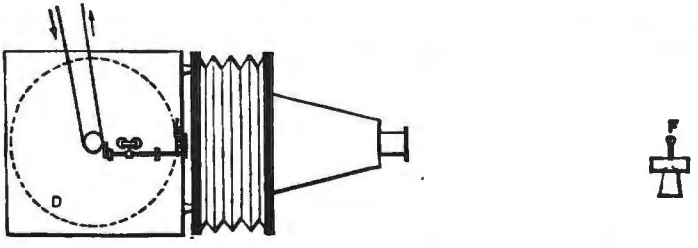

FIG. 23.

passed through the Eustachian tube into the middle ear and out through a hole in the bone; it burned in a small flame at the end of a platinum point. The tympanic membrane formed the membrane between the two compartments. On speaking into the outer ear the sound waves agitated the tympanic membrane, and this caused the flame to vibrate exactly as in the usual manometric capsule. The flames have been photographed.[2]



FIG. 24.

In concluding this chapter it is necessary to consider a few facts that concern all speech-recording machines.

Records on such machines have certain advantages over those obtained by instruments attached to the speaker, as the vocal organs act with less interference. When speaking into a machine, a person may depart to a certain extent from

[1] NAGEL UND SAMOJLOFF, *Einige Versuche ü. d. Uebertragung v. Schallschwingungen auf d. Mittelohr*, Arch. f. Anat. u. Physiol. (Physiol. Abth.), 1898, 505.

[2] SAMOJLOFF, *Zur Vokalfrage*, Arch. f. d. ges. Physiol. (Pflüger), 1899 LXXVIII, Tafel I.

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his conversational voice unless the records are made with the proper precautions. It is highly desirable to have no one in the room except the experimenter and the subject, as a person, even in ordinary conversation, has a tendency to speak somewhat differently when he feels himself observed. With some informal conversation beforehand, almost any person can be so put at his ease that when he turns to speak into the phonautograph or phonograph he feels quite at home and does not change his voice in any way. Much experience with the phonograph has shown that it requires only a little knack to put people at ease with the machine and lead them not to think of it. The result may be compared to that of the views of a kineto-camera (cinematograph) taken when the person is not thinking about it. An unskilful or nervous experimenter may get results to be compared rather with the usual photograph; still, even such results give the fundamental facts in good approximation to the truth. With the latest form of gramophone apparatus, records can be made while the subject is unconscious of the fact.

It is sometimes said that the speech machines do not faithfully record the vibrations of the air; this is true to a certain extent. The speaking-tube and the diaphragm reinforce or weaken some of the tones, but the influence is chiefly on the very high ones. The modification of the finer details has been studied in a series of curves of the same sound made with different diaphragms.[1] The friction of the recording point greatly reduces the size of the vibrations and modifies them chiefly by rounding off the corners. The inertia of the recording levers also has some influence. Just how much detail has been lost and just how much distortion has occurred cannot be known with machines of the phonautograph type because the records cannot be turned back into speech. It is in any case a question of the degree of approximation, which is to be discussed and specified as

[1] HERMANN, *Phonophotographische Untersuchungen, I.*, Arch. f. d. ges. Physiol. (Pflüger), 1889 XLV 582.

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in all scientific work. No measurements can ever be exact; the progress in accuracy consists in increasing the degree of approximation. The degree of approximation in the HENSEN phonautograph is far greater than in that of SCOTT; that of the manometric flame is still unknown. In any case it is a matter of scientific detail, and the remark sometimes made to the effect 'that most of the characteristics of a speech curve may be due to the apparatus' shows a lack of comprehension of instrumental methods equalled only by that of a critic who supposes the phonograph to be able mysteriously to add the very strongest tones to a record and — practically — to be able to change a vocal solo into an orchestral performance. The student of experimental phonetics should endeavor to learn the degree of accuracy in the action of each part and of the whole apparatus and should ever bear in mind that it is a *machine* whose every action is a matter of mechanics.

REFERENCES

For the SCOTT phonautograph and for manometric flame apparatus: KŒNIG, Paris. For the HENSEN phonautograph: ZWICKERT (care of Prof. Dr. V. HENSEN), Kiel.

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CHAPTER III

PHONOGRAPH RECORDS

THE original machine for reproducing speech seems to have been the phonograph of EDISON.[1] The tin-foil phonograph was afterwards superseded by the wax-cylinder form (Figs. 25, 26).

When a person talks into the speaking-tube of the phonograph, the air vibrations from the mouth are hindered from spreading and are conducted along the tube to the recorder at the further end. In the recorder (Fig. 27) they pass down the channel *E* to the thin diaphragm of glass *A* held in the frame *F* between thin rings of rubber *J*. This diaphragm follows the pressure by bending and possibly in some cases by moving as a whole also. A metal head *D* cemented to the center of the diaphragm transfers the vibratory movement by means of the link *C* to the lever *B* which ends in the sapphire recording knife *K*. The recording knife cuts a groove in a surface of a special wax composition. The action of the sapphire knife in cutting the surface of the cylinder is shown in Fig. 28. The depth of this groove depends on the vibrations of the diaphragm. A portion of the groove of the vowel a in the Dutch word 'daar' by BOEKE[2] is shown in Fig. 29. The vibrations should never be so great as to remove the knife entirely from the wax. The work of



FIG. 25.

[1] Patent of November, 1877.

[2] BOEKE, *Mikroskopische Phonogrammstudien*, Arch. f.d. ges. Physiol. (Pflüger), 1891 L 297.

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cutting the wax naturally modifies the movement of the knife. With the best wax composition this modification consists almost entirely in a reduction of amplitude.



FIG. 26.

To reproduce the sound the recorder is replaced by a reproducer (Fig. 30) which has a round sapphire point instead of the sapphire knife, but which is otherwise closely like the recorder in structure.

The rotation of the cylinder causes the round point to follow the rise and fall of the groove, whereby it repeats the movement of the recording knife. The glass diaphragm connected to the reproducing point is set in vibration and arouses air vibrations similar to the original ones in the spoken sounds.

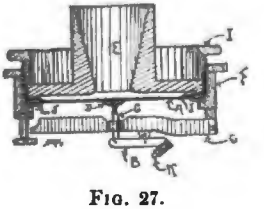

FIG. 27.

The changes of the cylinder under the fluctuations of temperature are so great that the reproducer must have considerable sideplay in order that the stylus may keep in the groove. The usual relation between the size of the cutting edge of the recording sapphire, 1^{mm}, and the diameter of the spherical reproducing sapphire, 0.9^{mm}, has been shown to be the most favorable one.[1]

The accuracy with which the phonograph reproduces the

[1] HERMANN, *Fortgesetzte Untersuchungen über die Konsonanten*, Arch. f. d. ges. Physiol. (Pflüger), 1900 LXXXIII 6.

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original sound depends on a series of factors that need careful consideration.

In the first place the sound may be modified by the speaking-tube. A narrow cylindrical tube with perfectly hard

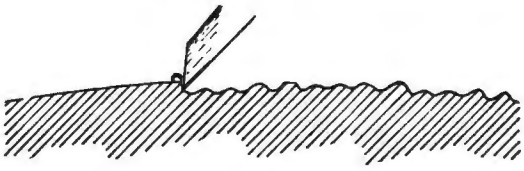

FIG. 28.

walls will conduct the vibrations practically unchanged in character, except when harmonic — or resonance — relations (p. 14) occur between the natural period (p. 2) of the tube and the periods of the voice vibrations; a very short tube has such relations only to the high partials of the voice. Most voice records are made with a flexible mohair tube. A soft-walled tube is unfavorable to the reflection of very high tones; this is possibly the reason why some voice records seem 'muffled;' in such a case a metal horn, conical or flaring, may be tried, the best one being a perfectly conical horn 20 to 26 inches long and not more than 6 inches across the end. The speaking-tube is a necessity as the vibrations of the diaphragm would otherwise be too weak.

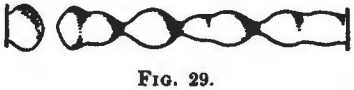

FIG. 29.

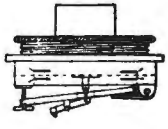

FIG. 30.

The glass diaphragm of the recorder is from 0.003 in. to 0.009 in. in thickness (0.08^{mm} to 0.23^{mm}). The thinner the diaphragm, the more sensitive it is. A loud voice makes the diaphragm execute such great excursions that the recording knife leaves the wax at times; this results in a rattling sound, or 'blast,' when the record is reproduced. Some voices produce rattling records with a certain diaphragm, but not with a thicker one or a thinner one. If the rubber

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washers become hardened, the vibration of the diaphragm will be hindered. The washers should not be pressed too tightly or too loosely by the screw ring *I* (Fig. 27); in the former case the diaphragm will lose sensitiveness, in the latter it will rattle. If the metal head *D* is not firmly fixed, the record will give a dull, raspy sound. To remove this head from a diaphragm, allow one drop of water to remain upon it for ten or fifteen minutes, remove the screw on the edge and lift up the weight *G*. If the glass diaphragm has been broken, the metal head should be scraped clean. Both head and glass should be thoroughly cleaned with benzine. To fasten the head apply a very small drop of stratena to it and lower it upon the diaphragm exactly in the center; if it is found to twist the link *C* when dry, loosen the ring *I* and turn the diaphragm.

The best glass diaphragms for reproducing are 0.004½, 0.005, 0.005½ and 0.006 inch in thickness. They should be of uniform thickness. It is well to try several sizes when first adjusting a phonograph.

The sapphire recording knife should be handled with great care; in order to preserve its sharp even cutting edge it should never come into contact with any hard surface. It should be examined with a magnifying glass, if the records seem to be in any way poor.

A diaphragm favors certain tones by resonance (p. 30). A diaphragm whose lowest period of free vibration (p. 2) is very high is able to favor only the very high partials of a note. For this reason a stiff or tightly stretched diaphragm records with greater accuracy. The strong damping caused by the knife cutting in the wax eliminates most of the influence of the free period of the diaphragm in the phonograph.

The wax cylinder is composed mainly of stearate of soda. To make the surface of the cylinder as smooth as possible, it is shaved by running it at a very high rate of speed and turning it off by a sapphire shaving knife. Chips and dust are cleared off by a camel's hair brush. The surface should never be touched by the finger or blown upon. Any rough-

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ness of the surface will appear as a strong noise in the record. Large cylinders take better records than small ones; owing to the greater speed at which the surface travels under the knife, the waves in the groove are more extended and the sapphire ball of the reproducer can more readily follow the finer fluctuations.

The machinery of the phonograph should be well oiled, free from dust and in perfect order, as any noise from friction transfers itself to the record. Records taken in a perfectly bare room have a loud resonant quality; those taken in a room with a few hangings are mellower but fainter. In making a record the speaker should stand or sit immediately in front of the instrument and should speak directly into it. The articulation should be distinct but natural. In the case of singing, the head should be drawn back when very high or loud notes are sung. The speaker should be put at ease as much as possible (p. 30).

The final test of the truthfulness of a record is made by hearing it. The words spoken by the machine represent what is on the record with close approximation. When a record is found that speaks clearly in a natural voice, it can be trusted for what it says, since it cannot say anything more than is on it and cannot improve its own tracing. The speech represented by a tracing from a record is the speech of the record itself. How nearly this reproduces the original speech can only be determined by comparing it by the ear with the words of the original speaker. By skilful manipulation records can be made whose speech cannot be distinguished from that of a living person except by their weakness and by the scratching noise due to the friction of the tracing point in the groove. Curves correctly traced from such a record give exactly the curve of the speech spoken into it.

From the known velocity of rotation of the cylinder, lengths on the surface can be translated into time. The rotations may be counted for a number of seconds. For m rotations in n seconds the time of one rotation is $T = n/m$ seconds. For a diameter of d millimeters the circumference is πd

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($\pi = 3.1416$). The time represented by 1^{mm} is $T/\pi d$. Thus, if the cylinder rotates 122 times in 60 seconds, $T = 0.49^{s}$, a figure that is accurate owing to the long time during which the rotation was counted. With an outside diameter — measured by calipers — of 53^{mm} the circumference (use table for πd) is $53 \times 3.1416 = 229.3363^{mm}$. The time represented by 1^{mm} circumference is then $\frac{0.49}{229.34} = 0.0021^{s}$, a figure that for a good phonograph is generally reliable to half a thousandth of a second when the spring is kept at about the same tension or the motor is run by a tested storage battery. The constancy of the speed can be roughly tested by sounding into the recorder from time to time the note of some musical instrument of known pitch, for example, a telephone connected with an electric fork.

The tracings on the phonograph have been observed through a microscope and sketched.[1]

The groove of a phonogram may be conveniently examined[2] by a corneal microscope, having a side illuminating tube that concentrates the light of a small incandescent lamp on the record. Measurements may be made by an ocular micrometer.

Measurements of phonograph tracings have been made by BOEKE.[3] The widths of the grooves were measured by a microscope with an ocular micrometer; the shape of the cutting surface of the recording sapphire being known, the depths could be at once calculated.

The records on the phonograph cylinder may be enlarged by amplifying levers recording on a smoked drum.[4]

[1] MARICHELLE, La parole d'après le tracé du phonographe, Paris, 1897; MARICHELLE ET HÉMARDINGER; *Études des sons de la parole par le phonographe*, C. r. Acad. Sci. Paris, 1897 CXXXV 884; GELLÉ, L'audition, Paris, 1897.

[2] MEYER, *Zur Tonbewegung d. Vokals*, Neuere Sprachen, 1897 IV, Beiblatt.

[3] BOEKE, *Mededeeling omtrent onderzoekingen van klinkerindruskels op de wasrollen van Edison's verbeterden fonograaf*, De natuur, 1890, July; *Mikroskopische Phonogrammstudien*, Arch. f. d. ges. Physiol. (Pflüger), 1891 L 297; *Mikroskopische Phonogrammstudien*, Arch. f. d. ges. Physiol. (Pflüger), 1899 LXXVI 497; M'KENDRICK AND GRAY, *On vocal sounds*, Schaefer's Text Book of Physiology, II 1227, 1229, London, 1900.

[4] MAYER, *Edison's talking machine*, Nature, 1878 XVII 469; FICK, *Zur Phonographik*, Beiträge zur Physiologie LUDWIG gewidmet, 23, Leipzig, 1887;

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Highly accurate tracings of phonograph records have been made by HERMANN.[1] The desired record is made on the phonograph and tested by reproducing. Owing to the changes of the wax with the temperature, the tracing must begin immediately; to keep the centering the wax must not be removed from or displaced on the metal barrel. In place of the reproducer a system of levers is so brought to bear that a fine glass knob travels in the record and deflects a mirror with every movement. For consonants three successive levers are used, for vowels only two levers. It is well to have the bearings jeweled.

Above the system of levers a weak convex lens is fastened with its center exactly over the mirror. The phonograph is

JENKIN AND EWING, *The phonograph and vowel theories*, Nature, 1878 XVIII 167, 340, 394; *On the harmonic analysis of certain vowel sounds*, Trans. Roy. Soc. Edinb., 1878 XXVIII 745; LAHR, *Die Grassmann'sche Vokaltheorie im Lichte des Experiments*, Diss., Jena, 1885; also in Ann. d. Phys. u. Chem., 1886 XXVII 94; WAGNER, *Ueber d. Verwendung d. Grützner-Marey'schen Apparats u. d. Phonographen zur phonetischen Untersuchungen*, Phonet. Studien, 1890 IV 68; M'KENDRICK, *On the tone and curves of the phonograph*, Jour. Anat. and Physiol., 1896 XXIX 583; M'KENDRICK, MURRAY AND WINGATE, *Committee report on the physiol. application of the phonograph and on the form of the voice curves by the instrument*, Rept. Brit. Ass. Adv. Sci., 1896 669; M'KENDRICK, *Observations on the phonograph*, Trans. Roy. Soc. Edin., 1897 XXXVIII 765; *Demonstration of an improved phonograph recorder*, Proc. Roy. Soc. Edin., 1896-97 XXI 194; Sound and Speech Waves as revealed by the Phonograph, London, 1897; M'KENDRICK AND GRAY, *On Vocal Sounds*, Schaefer's Text Book of Physiology, II 1229, London, 1900.

[1] HERMANN, *Phonophotographische Untersuchungen, I.*, Arch. f. d. ges. Physiol. (Pflüger), 1889 XLV 582; *Ueber d. Verhalten d. Vokale am neuen Edison'schen Phonographen*, Arch. f. d. ges. Physiol. (Pflüger), 1890 XLVII 42; *Phonophotographische Untersuchungen, II.*, Arch. f. d. ges. Physiol. (Pflüger), 1890 XLVII 44; *Phonophotographische Untersuchungen, III.*, Arch. f. d. ges. Physiol. (Pflüger), 1890 XLVII 347; *Bemerkungen zur Vokalfrage*, Arch. f. d. ges. Physiol. (Pflüger), 1890 XLVIII 181, 543; *Phonophotographische Untersuchungen, IV., Untersuchungen mittels des neuen Edison'schen Phonographen*, Arch. f. d. ges. Physiol. (Pflüger) 1893 LIII 1; HERMANN UND MATTHIAS, *Phonophotographische Mittheilungen, V., Die Kurven d. Konsonanten*, Arch. f. d. ges. Physiol. (Pflüger), 1894 LVIII 255; HERMANN, *Phonophotographische Untersuchungen, VI., Nachtrag zur Untersuchung der Vokalkurven*, Arch. f. d. ges. Physiol. (Pflüger), 1894 LVIII 264; *Weitere Untersuchungen ü. d. Wesen d. Vokale*, Arch. f. d. ges. Physiol. (Pflüger), 1895 LXI 169; *Fortgesetzte Untersuchungen über die Konsonanten*, Arch. f. d. ges. Physiol. (Pflüger), 1900 LXXXIII 1; *Ueber d. Zerlegung von Kurven in harmonische Partialschwingungen*, Arch. f. d. ges. Physiol. (Pflüger), 1900 LXXXIII 33.

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tipped till the mirror is vertical. A vertical slit in front of an arc lamp permits a ray to strike the mirror and be reflected so that its image, obtained by means of the lens, falls across a horizontal slit in the recording box. As the mirror is deflected back and forth sidewise, the vertical beam of light swings along the horizontal slit, so that the eye on the opposite side sees a bright point vibrating along a horizontal line. Inside the light-tight recording box a cylindrical drum is arranged to rotate on a horizontal axis so that sensitive paper on its surface receives the point of light. As the phonograph and the drum are set in motion, the point of light traces the speech curve upon the sensitive paper. The result is developed in the usual photographic manner.

Since the curve on the phonograph cylinder and the set of levers travel axially, the point of light would soon fall one side of the horizontal slit; to avoid this the phonograph is placed on rails and slowly moved sidewise by the hand.

Curves of the German vowels sung by HERMANN (born in Berlin, 1838) are given in Figs. 31 and 32. The vowel is indicated by the phonetic letter and the note (physical scale) by the letter in parentheses.

Analyses of the curves show that they are composed of several tones; that in most vowels (a, ɔ, o, . . .) there is no sinusoid (p. 2) corresponding to the tone on which the vowel is sung; that in all there are one or more frictional sinusoids (p. 6) which remain constant for each vowel regardless of the tone on which it is sung; that in some cases (i, y, . . .) the vowel shows a sinusoid for the tone on which it is sung, the other vibrations having no relation to its period.

The tone of constant pitch for each vowel — independent of the tone on which it is sung — is termed by HERMANN its 'formant.'

The cord tone itself is seen in the vibrations for i and y, but otherwise seldom appears in the vowels. It seems evident that in most cases the cords act by emitting a series of more or less sudden explosions that set the air in the resonance cavities in free oscillation. The periodical changes from

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strong to weak in these oscillations produce the cord tone as heard, just as a series of sharp noises from a card held

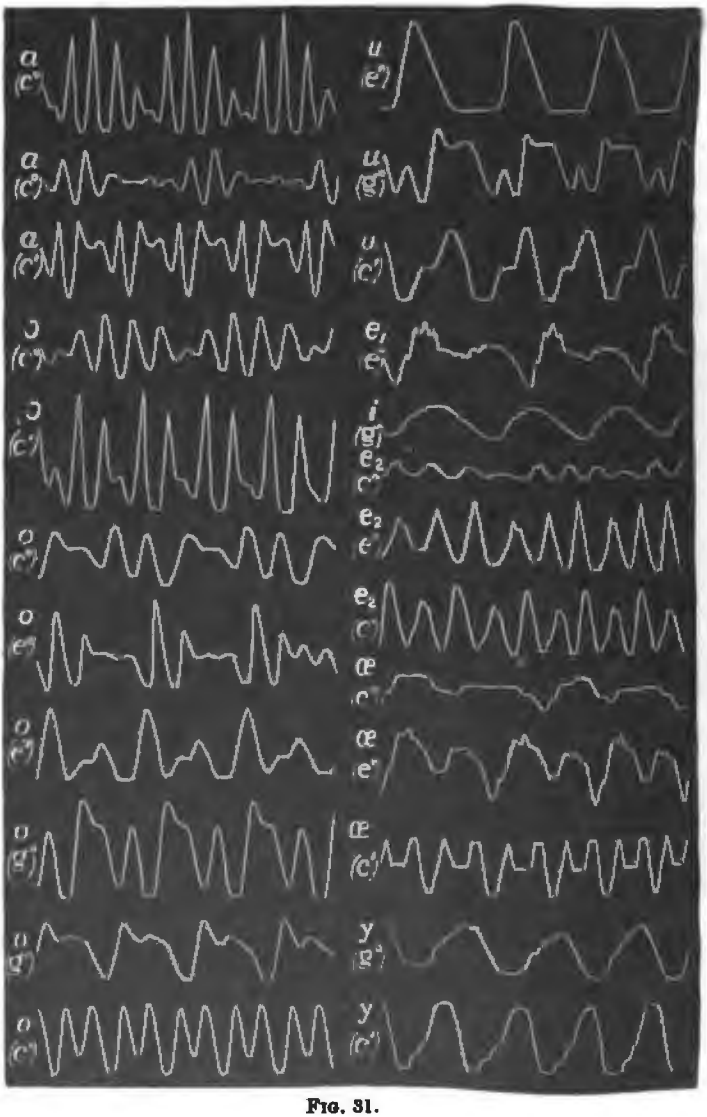

FIG. 31.

against a toothed wheel or puffs from a siren will produce a note. The groups of similar vibrations indicate separate

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puffs from the cords. Thus the curve a (c^0) in Fig. 31 shows three groups of vibrations that represent the free vibrations of the resonance cavity, each aroused by a puff from the cords. That there is no sinusoid for the cord tone in most of the vowels does not mean that the phonograph is 'deaf to the cord tone,' as has been absurdly stated, for the phonograph will speak the vowel on that tone; but it does

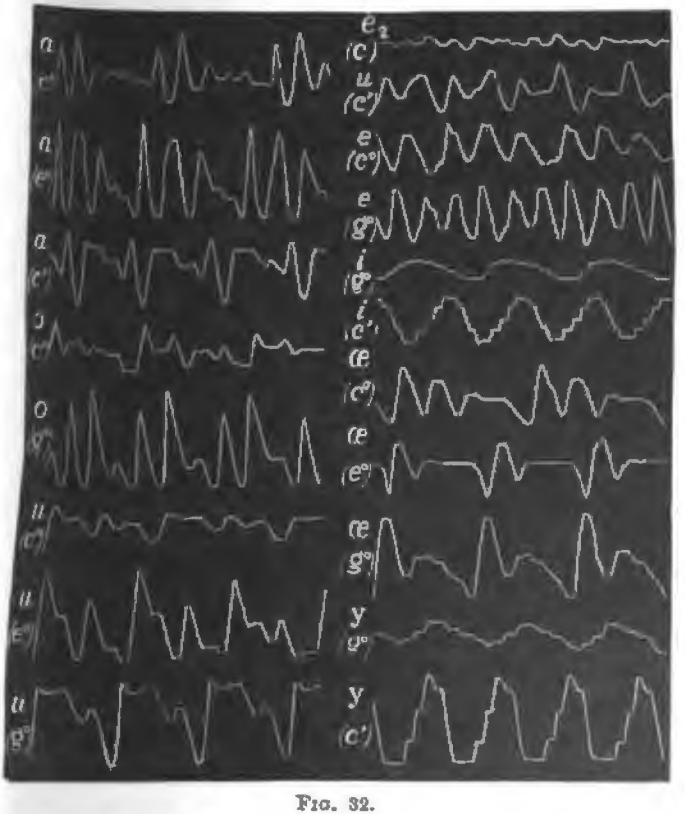

FIG. 32.

mean that the cord tone from the human mouth is not produced by a sinusoid vibratory movement but by a series of puffs. The series of puffs act on the air in the resonance cavity just as the series of magnetic impulses act on a spring (p. 11). The curves of some vowels (o, e, œ . . .) seem to indicate that

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the puffs occur with an explosive abruptness quite like that of the magnetic impulses (Fig. 14); those of other vowels (a) indicate puffs with more gradual beginnings, while still others (i, y) indicate puffs of so gradual rise and fall of intensity that the curve of explosion is like a distorted sinusoid.

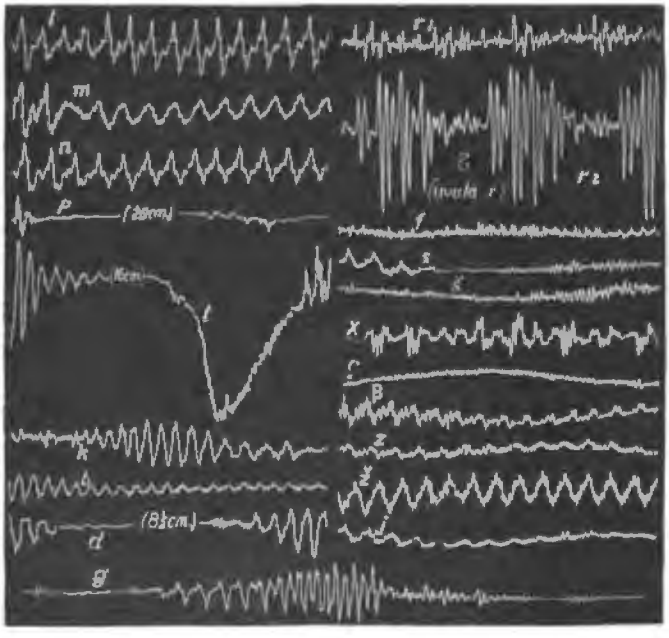

Fig. 33.

The short vowels in an, en, etc., alter their tones as they are about to change into the following consonants. The explanation is, I suggest, that the mouth starts on its movements from the vowel position to the consonant position before the vowel ends.

The so-called 'short' vowels are in ordinary German generally not briefer 'long' vowels, but are really other sounds, as appears clearly in Hermann's curves (Fig. 32). The short e in 'Helm' is much more like e_2 (ä) than like e_1. In fact no difference could be heard in pronouncing 'Hälm' and 'Helm.' Short o in 'Wort' resembles long ɔ much more

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than long o. Short i as in 'Bild' appears quite different from long i. Essential differences are also found between long and short u, œ (ö), y (ü). Short œ (ö) can be heard to resemble a form of long œ not usual in Germany but very common in France. The short a differs least from the long a, but with some persons it can be heard to somewhat resemble ɔ or æ.

HERMANN'S curves show that the cord tone is not constant but continually fluctuating to a slight degree; similar minute fluctuation will also probably be found in the resonance tones if they are studied.

With a triple recording lever working in jeweled bearings HERMANN has obtained highly magnified curves of several consonants (Fig. 33).

The l curve resembles that for short i with no intervals of weakening or cessation of the vibrations (pseudobeats, p. 19). At the point where a vowel borders on l there is regularly a weakening or a pause; in very rapid speech this does not occur. The shortest l, occurring in 'Allallal,' lasted 0.075^s to 0.100^s. The main vibration of the l has sharp points at the extremes of oscillation with one extra oscillation on the ascending portion. Aside from this extra oscillation the curve bears some resemblance to the curve given by KŒNIG[1] for the series of partial tones 1, 2, 3, 4, 5, 6, 7, 8 with the respective amplitudes 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, $\frac{1}{64}$, $\frac{1}{128}$ but without difference of phase. An excessive amplitude given to the second partial would perhaps produce the form seen in the l. If this should happen, the curve of the l might be interpreted to indicate a cord action producing such a set of partials. The first partial, or fundamental (that is, the cord tone) appears strongly in l. On this main vibration there appear regular small sharply pointed oscillations with a constant period independent of the note on which the l is sung; these represent the resonance tone of the mouth cavity. It shows no influence of a preceding or following vowel. The characteristic resonance tone of

[1] KŒNIG, Quelques expériences d'acoustique, 228, Paris, 1882.

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the l lies near f^3. The cord tone with its octave is prominent in l.

The main fluctuations in the curve of m resemble somewhat those of l but do not have the extra oscillation from the second partial and do have a slightly different incline. The resemblance to KŒNIG'S curve of the series of partials of decreasing amplitude and of identical phase as given above is a fairly close one; it would be rather close to that of the same series with slight differences of phase. The small vibrations arise from the resonance of the mouth cavity. Harmonic analysis of the curves of m sung on the note e^0 indicates a very strong first partial, or fundamental (cord tone), a strong fourth or fifth partial at e^2 to $g^{2\sharp}$ and a strong eighth or ninth partial at e^3—$f^{3\sharp}$ and not a geometric decrease in amplitude. The constant resonance tone has a pitch of b^3 to $c^{4\sharp}$. The cord tone (without its octave) is prominent.

The curve of n appears to closely resemble that of m. Harmonic analysis shows that the first partial, or fundamental, is relatively not so strong and that the fourth or fifth partial is much stronger than for m, while the eighth or ninth partial and the resonance tone are the same as in m. The cord tone (without its octave) is prominent.

The depressions in amplitude (pseudobeats) need not be numerous in the middle of a word in order to produce the r-effect. The depression often becomes complete, showing complete interruption of the sound. The characteristic form of the vibrations during the r remains the same and is independent of the degree of depression. The form of the r-vibration may be one peculiar to the r and not derived from the preceding vowel. A vowel tinge can, however, be purposely given to the r. The vibrations between a vowel and an r show intermediate forms that indicate the change. In rapid speech the r may perhaps partake largely of the vowel-sounds bounding it. The characteristic tone for the lingual r of two German voices lies at b^2, that for the uvular r of HERMANN at about f^3. All HERMANN'S rs were continuous rolled sonants, no records of unrolled or of surd rs having been made.

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With p, t and k the durations of the silence and the following explosion vary. In the cases where the explosive noise is lacking (p followed by m and sometimes by n, or t followed by m or n) the phonograph curves show no record during the speaking of these consonants, and HERMANN'S conclusions concern only the full consonants with explosions. Their chief characteristic is the long period of silence; this was never less than 0.1^s, very seldom less than 0.2^s in ordinary speech, and generally about 0.3^s to 0.4^s for p and a trifle longer for t and k. In groups like pĭpĭp, păpăp and tĕtĕt without special stress on either syllable, the pause after the second vowel is much longer than after the first one. The time is lengthened unconsciously when stress is given to the consonant. The explosion of these consonants is recorded as a noise curve, irregular in its vibrations, and also often as a strong excursion due to the increased air pressure.

The record of increased pressure is more marked for p than for t and k. The pressure curve is very steep, the explosion being very sharp for p and less sharp for t and k; it is also longest for p (0.03^s to 0.1^s). The explosion is not necessary to the hearing of these consonants; in several cases there was no record of an explosion in the phonograph and yet the sounds of p, t and k were heard from it as well as usual. Just what makes the acoustic distinction between these sounds in such a case HERMANN does not suggest; it is presumably the noise made by the breath as the closure is formed, since this will differ for each kind of closure. At the end of a syllable before a pause the noise curve is more prominent than before a vowel. The small vibrations during some of the occlusions suggest that sometimes the closure is not perfect and that they have a slight breathiness.

In the case of p the following vowel usually occurs immediately after the explosive noise; the noise curve and the vowel curve often begin on the line of recovery from the explosion; this may, I suggest, be due to the fact that the explosion of the p has pressed the glass diaphragm so far inward

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that its inertia prevents its recovery as a whole before it vibrates for the vowel. Regularly in t and k and occasionally in p there is a very short silent period between the noise and the vowel. This second silent period varies according to the vowel, being shorter in kă than in kĭ although in kĭ it is less than 0.02^s. Apparently, I may suggest, the mouth organs require more time to change from the t and k positions to a vowel position than from the p position, and the time varies with the resemblance between the consonant position and the vowel position.

The noise curves of the explosions are very irregular, yet they show certain periodic prominences that presumably cause tones to be heard. For HERMANN'S voice the tones were near a^0 or d^1 for p, near f^3 for k and near $f^{3\sharp}$ (in one case b^3) for t.

In the case of two successive stops or occlusives as in atka a considerable silent interval occurs between them, — in one case about 0.15^s.

The curve for HERMANN'S χ (*ch* as in *ach*) shows vibrations often as strong as those of vowels. In many cases the entire long χ curve consists of almost regular equidistant points whose amplitude, however, rises and falls. The frequency of these vibrations lies near 1000, or $b^2-d^{3\sharp}$. At many places more frequent vibrations (near 1300, or e^3-f^3) are mixed with the others. The fluctuations of amplitude occur often at fairly regular periods of about 200 a second; these oscillations sometimes appear to have a periodic alteration in strength occurring about 30 to 40 times a second. In the latter case the curve bears a resemblance to the r-curve, as might be expected from a certain resemblance between χ and uvular r.

The curve for š shows very fine sharp oscillations, the frequency varying between $d^{3\sharp}$ and f^4 but chiefly around b^3. Sometimes these fine oscillations are superimposed on coarser ones with a frequency of about 600.

The fainter s curve resembles most that of š, with a frequency mainly between g^3 and b^3, but also sometimes be-

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tween b^2 and $d^{3\sharp}$. The finest oscillations (3000 frequency, or g^4) are also here often superimposed on coarser ones (600 frequency).

The curves for ç (*ch* as in *ich*) show intermitting groups of rather large pointed oscillations (about 750–800 frequency, in one case 456) with still finer oscillations upon them (various frequencies: 1100, $d^{3\sharp}$; 2280, d^4; 2736, f^4).

The curve of f, when spoken very energetically, usually shows a very definite periodicity (from 150 to 250 frequency), arising from the tone produced by the vibration of the lips or of the lower lip against the upper teeth. In the ordinary f this periodicity is lacking; the curve is composed of coarse and fine oscillations in which frequencies of 1300 to 1500 ($f^3 - g^3$) and of 1700 to 2000 ($a^3 - c^4$) can be occasionally picked out. Many details have probably been lost in these curves; the very high tones have probably been entirely lost.

In the curves of β, v, z, ž (as in '*L*ogis') and j (as in '*J*ahr') the cord tone appears distinctly. The curves for β and v vary greatly. Being spoken with the two lips only, β produces a curve closely resembling that of u with fine zigzags superimposed. The ordinary v with the upper teeth on the lower lip produces a curve that varies essentially from the sinusoid, rising more rapidly and falling more slowly, with superimposed zigzags of rather irregular period but of an average frequency generally that of $c^4 - d^4$ but not seldom that of $f^{3\sharp} - a^{3\sharp}$. These two tones agree closely with those of the similar sound f. The curve of z shows the cord tone with superimposed zigzags whose mean frequency is about $a^{3\sharp}$ and $c^4 - e^4$. A still higher tone is probably present also. The curve for ž is similar to that for z with tones of $a^{3\sharp} - b^3$ and $c^{4\sharp} - f^4$. The curve for j likewise shows the cord tone; the zigzags represent tones between c^4 and e^4, the same as those of the vowel i. When followed by a vowel, the j always becomes i before the vowel begins.

The curves for b, d and g show waves from the cord vibrations; they are weaker than those for m and n. The fine zig-

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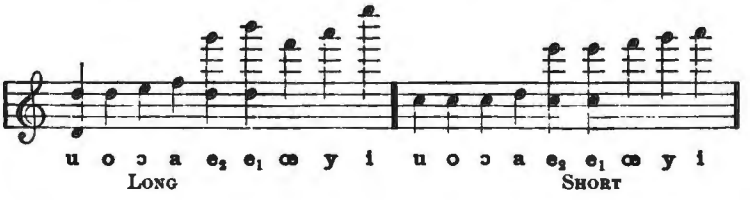
zags on these waves show frequencies between d^3 and a^3 for all three sounds. When passing into a vowel, the **b** curve often shows a small pressure explosion; **d** and **g** never do this. When used as final consonants, as in **bib, did, gig** (spoken distinctly, and not like **p, t, k** as often in German), the curves show at the end of the consonant regular vowel vibrations that indicate lower cord tones for **g** than for **b** and **d** and a resonance tone about $g^3 - a^3$ for **b** and **g** and about $b^3 - c^4$ for **d**.

The following table gives the resonance tones (formants) found by HERMANN:

Speech sounds		Region or regions of resonance tones		Speech sounds	Region or regions of resonance tones	
u	long	$c^1 - f^1$	$d^2 - e^2$	r_1, lingual	b^2	
o	"	$c^2 - d^2\sharp$		r_2, uvular	f^3	
ɔ	"	$e^2 - f^2$		p	$a^0 - e^1$	
a	"	$e^2 - g^2\sharp$		k	d^1	
e_2 ($\ddot{a}$)	"	$c^2 - e^2$	$f^2\sharp - a^2\sharp$	t	f^3 or b^3	
e_1 (e)	"	$d^2 - e^2$	$a^2\sharp - b^3$	χ	$b^2 - d^2\sharp$	$e^3 - f^3$
œ	"	$f^3 - g^3$		š	(a^2)	$d^2\sharp - f^4$
y	"	$a^3 - b^3$		s	$b^2 - d^2\sharp$	$g^2\sharp - b^3$
i	"	$e^4 - f^4$		ç	$b^1 - g^2\sharp$	$d^2\sharp - f^4$
u	short	c^2 (?)		f	$f^3 - c^4$	
o	"	$b^1 - c^2\sharp$		v	$f^2\sharp - d^4$	
ɔ	"	$b^1 - c^2\sharp$		z	$a^2\sharp$	$c^4 - e^4$
a	"	$c^2 - e^2\sharp$		ž	$a^2\sharp - b^3$	$c^4\sharp - f^4$
e_2 ($\ddot{a}$)	"	about c^2	about e^3	j	$c^4 - e^4$	
e_1 (e)	"	"	"	b	$d^3 - a^3$	
œ	"	$e^3 - f^3\sharp$		d	$d^3 - a^3$	
y	"	$f^3\sharp - g^3\sharp$		g	$d^3 - a^3$	
i	"	$a^3\sharp$		b (explosion)	$g^3 - a^3$	
l		f^3		d (explosion)	$b^3 - c^4$	
m		$b^3 - c^4$		g (explosion)	$g^3 - a^3$	
n		$b^3 - c^4$				

With the understanding that there may be considerable range around a note, these results may be indicated approximately as follows:



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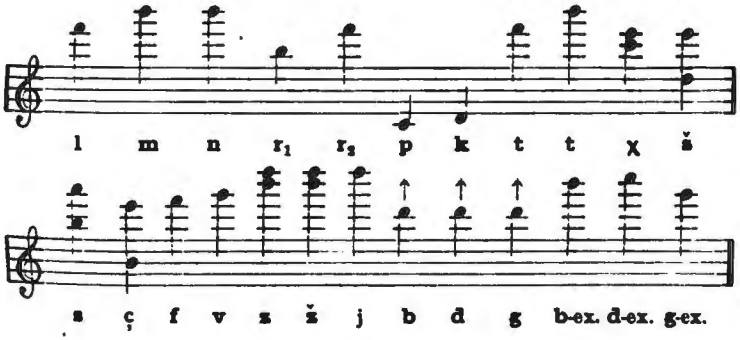

A careful inspection of HERMANN'S curves shows that gradual changes of form occur even in sung vowels. The interpretation is that which I have already given (p. 19), namely, continual changes in the relations among the cord and resonance tones; it is undoubtedly true that *even in* the best singing the *voice* does not remain at

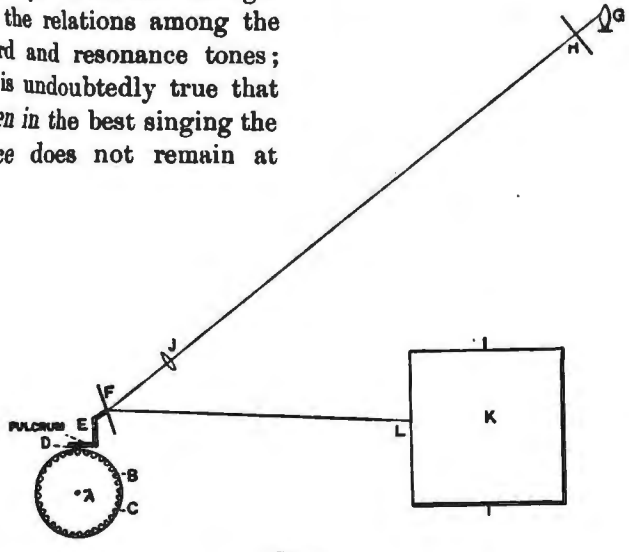

FIG. 34.

exactly the same pitch but fluctuates; it is probably also true that the resonance tones fluctuate likewise.

In some experiments by BEVIER,[1] the diaphragm of a

[1] BEVIER, *The acoustic analysis of the vowels from a phonographic record*, Physical Review, 1900 X 193; *Acoustic analysis of the vowel A*, Neuere Sprachen, 1900 VIII 2, 65.

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phonograph reproducer was removed; a rigid arm *E* (Fig. 34) with an adjustable plane mirror *F* was fastened to the tracing lever *D*; a spring on this arm held the knob of the reproducer against the furrow in the wax. A narrow beam of light *H* reflected from the mirror and focused by the lens *J* on bromide paper around the drum *K*, registered the speech curve in great magnification. An improved form of tracing mirror has just been devised by BEVIER. The sound was

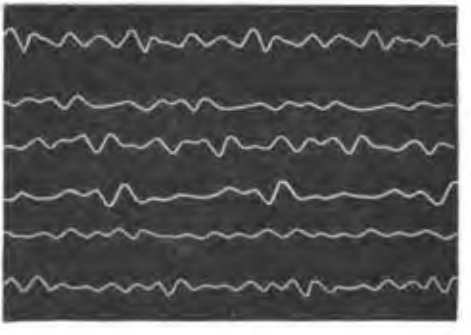

FIG. 35.

recorded on the phonograph; it was tested by reproducing it, and then the above tracing apparatus was immediately put in action. The curves of the vowel a sung on different notes by three adult barytone voices and one child's soprano voice showed after analysis the presence of the fundamental in varying degrees of strength, the first and second overtones very weak, a lower resonance tone averaging about 675, or f^2 (from 575 to 800, d^2 to $g^{2\sharp}$), and a higher resonance tone averaging about 1150, or d^3 (from 1000 to 1300, c^3 to e^3). In musical notation these two tones are as indicated. The curves in Fig. 35 are from three voices, *A*, *B*, *D*; the upper curve is from *A* on a tone of 181 frequency, the second from *B* on 202, the third from *B* on 226, the fourth from *A* on 226, the fifth from *B* on 226 and the sixth from *D* on 240.



a

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MARICHELLE[1] has given a series of drawings of the phonograph grooves for the French vowels.

A new form of speech machine, POULSEN'S telegraphone,[2] may perhaps be available for phonetic purposes. An electrolytic phonograph by NERNST and v. LIEBEN has recently appeared.

REFERENCES

For phonographs: EDISON MANUF. Co., Orange, N. J.; LIORET, Paris. For HERMANN'S lever systems: VALENTINOWYCKS, Königsberg.

[1] MARICHELLE, La parole d'après le tracé du phonographe, Paris, 1897.
[2] *The telegraphone*, Nature, 1901 LXIV 183.

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CHAPTER IV

GRAMOPHONE RECORDS

THE gramophone is a development by BERLINER of the idea contained in SCOTT'S phonautograph in combination with the idea of reproducing the sound in a special manner.[1]

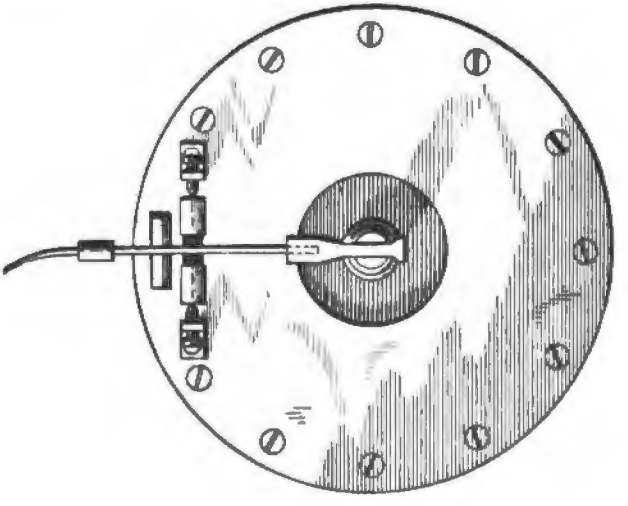

FIG. 36.

One form of the recorder with which the air vibrations are received is shown in Fig. 36. It comprises a thin mica diaphragm held in a frame. The sound waves coming down the speaking tube set the diaphragm in motion; this diaphragm moves one arm of the stylus and the point at the

[1] The following account is condensed from SCRIPTURE, *Researches in experimental phonetics (first series)*, Stud. Yale Psych. Lab., 1899 VII 7.

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end of the other arm repeats this movement. Various modifications of this recorder are used for various kinds of records.

The impression disc is prepared by two methods. In one method (BERLINER) a highly burnished zinc disc 18^{cm} in diameter is flowed with a saturated solution of wax in benzine; the film of wax thus deposited is so thin that the touch of a camel's hair brush marks it perceptibly. The prepared disc is placed on a revolving plate so that its surface is touched by the point of the recording stylus. As the plate revolves, the recorder is made to travel toward the center; thus its point cuts a spiral groove through the wax. The vibrations of the point make deflections in this groove. These deflections are in the plane of the surface of the plate and not dug into it as in the case of the phonograph. The record disc is then placed in an etching bath similar to that used by photo-engravers. The part of the zinc from which the wax has been removed by the stylus is attacked by the acid and a permanent groove is made. A copper matrix is then made from this by electrolysis.

In still another method (BERLINER) a glass plate is clamped on an axis by which it can be rotated. The under-surface of the disc is carefully polished and dried and is then covered with a thin film of linseed oil by means of a camel's hair brush. A smoky flame held under the plate deposits a fine layer of lamp-black, thus forming an amorphous ink which covers the glass in an even, exceedingly thin layer. The coating of ink does not flow spontaneously; it requires only a minute force to trace a line in it. The sound line is drawn by the point of the recording stylus in a manner similar to that just described. Copies of the disc are made by placing it over a sensitized photographic plate and proceeding by photo-engraving.

In a later method (CHENEY) the point of the recorder draws a groove in the surface of a viscous substance, from which an electrotype is made as a matrix. The resistance to the vibratory movement is very small and the sound is recorded with increased truthfulness. Records by this process have been called zonophone records.

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The impression disc made in any of these ways is used to form a copper matrix by electrolysis. This matrix contains the sound line in relief. After the matrix thus secured has been backed in order to give it strength and stability, its face is protected by a layer of nickel, which answers the double purpose of protection and also of giving a polish to the final record. A composition made of a combination of shellac and filler (the same material from which doorknobs, billiard balls, etc., are now being made in large quantities), in the form of a stiff board, $\frac{3}{8}$ of an inch thick, is heated to the required consistency. The mold, which is the exact size of the matrix, is also heated, the matrix itself is heated, and then, by a quick process, the matrix is thrown into the mold, the material on top, the face of the die — also heated — is thrown over the whole, and all is subjected to a pressure averaging about 80,000 pounds. Water is then driven into the press for the purpose of cooling the mass, the pressure is removed, the die opened, and the completed record plate taken from the matrix. It is a true copy of the original disc. This is the record known to commerce; it appears as in Fig. 37. The process is repeated, a single matrix sometimes producing 2000 or 2500 hard records before the wear is sufficient to interfere with its efficiency.



FIG. 37.



FIG. 38.

To reproduce the sound, the permanent disc-record is placed on a plate which can be rotated by some motor power. The reproducing sound-box (Fig. 38) is so arranged that the point of its stylus travels in the sound groove. The deviations in the sound groove move the point of the stylus, whereby a mica diaphragm is made to reproduce the sound

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waves. The reproducing sound-box differs only in detail from the recording sound-box. The operation is simply in reverse order from that of the recording box — the sound, when the recorder was used, being conducted first through the tube to the diaphragm, and thence communicated to the needle point, whereas, with the reproducing box, the waves are communicated first to the needle point, thence to the diaphragm, and thence outwardly, through the tube, to the amplifying horn. The complete reproducing apparatus is shown in Fig. 39.



FIG. 39.

The speed at which the plate travels in the record-making machine is about 70 revolutions a minute. This stretches out the curves for the speech sounds so that the variations in amplitude are visible through the microscope only in the case of musical sounds and vowels. The method of direct reading by the microscope is therefore not available. The record must be transcribed in such a way that the relation between length and height, that is, between time and amplitude, shall be changed. In the method about to be described the amplitude was enlarged.

In my first transcribing apparatus (Fig. 40) the gramophone plate was put on a metal disc *E* similar to that of the original record-making machine. This disc was rotated at a speed of 0.1 of a revolution a minute by a system of spur and bevel gears. A miter gear *a* on the axle of the electric motor fitted into another miter gear on the first axle of the speed-reducing machine *B*. The first axle of the reducing machine thus revolved at the speed of the motor, which was 800 revolutions per minute. The second axle carried a large spur gear with 160 teeth which fitted into a small spur gear with 16 teeth on the first axle; thus the second axle made 80 revolutions per minute. In a similar way gear-transmis-

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sion to a third axle reduced the speed to 8 revolutions, and transmission to a fourth axle reduced it to 0.8 of a revolution. This fourth axle carried a spur gear of 20 teeth which fitted into the 160 teeth of the final driving machine of the disc, whose axle thus made 0.1 of a revolution a minute.

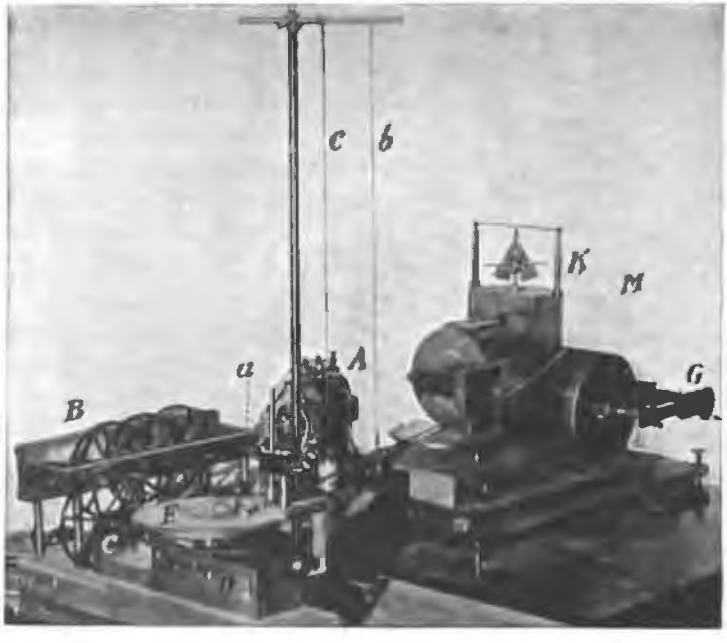

FIG. 40.

The axle of the final driving mechanism carried on one end a tube *C* (Figs. 40, 42) with a slit in it. Within this tube was a rod 1^{cm} in diameter with a thread of 96 turns to the inch on its surface; it was held by a nut correspondingly threaded. A projection from the rod fitted into the slit in the tube; thus the rod was forced to turn with the tube. At the same time the thread on its surface forced it to move lengthwise $\frac{1}{96}$ of an inch for each revolution. The rod bore on its end a carefully centered point and just back of this point a miter gear. The point pressed against the

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disc-carriage. This carriage consisted of a bar of brass running on a pair of rails and carrying the metal wheel *E*. The metal wheel rested on the carriage and its axle projected through it. As the rod travelled forward it pushed the carriage ahead of it. At the bottom of the axle there was a second miter gear *D* bearing against the first one on the rod; this turned the metal wheel in unison with the rod. When a gramophone plate was clamped on the wheel with proper centering, it turned once in 10 minutes and was driven forward radially $\frac{1}{96}$ of an inch per revolution. Thus the speech curve on a plate would travel steadily under a fixed point from beginning to end.

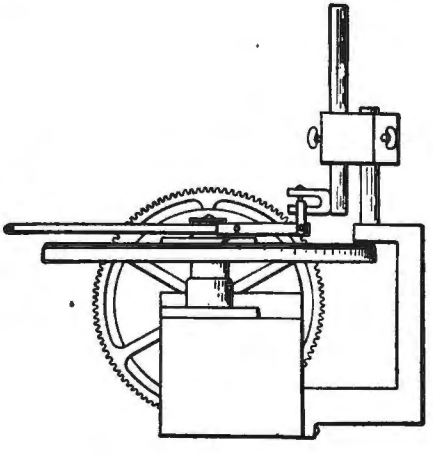

FIG. 41.

Just above the disc the amplifying lever *F* was adjusted so that the soft steel point rested in the sound groove. The arrangement is shown in Fig. 41. The distance from the fulcrum to the point was 22^{mm}. The lever possessed side movement in order to transcribe the curve, and vertical movement in order to follow the changes in the thickness of the plate. The long arm of the lever reached 595^{mm} beyond the fulcrum. The extreme part of it consisted of a recording

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point of pendulum ribbon *M* (Fig. 40) 152^{mm} long. This point traced the side movement on the smoked paper and also yielded to the up and down fluctuations without any noticeable effect on the records. The amplification was approximately 27 times.

The centering of the gramophone plate was not an easy matter. The speech curve was made in the form of a spiral around the center of rotation in the original machine; neither the edge of the rubber disc with the record nor the hole in its center coincided with this center. To center the spiral accurately on the metal plate two methods could be used. The microscope method proved somewhat the more convenient. The metal disc was moved away from the point of the rod. A microscope or a large magnifying glass was fixed so that it was focused on the spiral groove. As the disc was turned the groove passed through the field of vision. If the plate was not centered, it would move to one side or the other during one half a revolution; it was adjusted by the fingers until the groove did not appear to move back and forth with every turn, but to maintain a steady side movement amounting to once the width between lines for one revolution. The other method consisted in turning the disc with the recording point adjusted and noting the deviation to one side for one half a revolution. The disc was then moved radially until the point marked one half the deviation.

The steel point was pressed into the groove of the plate by means of the rubber band on the thread *b*; the verticality of the pressure was assured by the plumb line *C*.

The record was made on smoked paper moved by the BALTZAR kymograph *K* with side movement of the drum by the driving mechanism *G*. To avoid jarring through the floor the table was at a later date suspended from the ceiling by springs. The jarring of the motor was avoided by placing it on sand.

Of the speech curves that were made with this apparatus only three sets have been used in this book: *Cock Robin, Series I; Self Help, Series I; Lord's Prayer, Series I.*

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Greater amplification, accuracy and convenience have been attained by modifications of the preceding arrangement. A worm placed on the motor axle turns a worm gear on the first shaft of the speed-reducing mechanism. A set of lamps of various resistances modifies the speed of the motor. The gramophone disc is rotated about once in 5 hours when a curve appears in the tracing, and very much faster when there is no curve. As the speech curve on a gramophone disc runs around from 100 to 200 times, requiring 500 to 1000 hours of tracing at the low speed, it is desirable to save time by running the plate faster during pauses.

The latest tracing apparatus (Fig. 42) comprises a primary lever *FJ* with a steel point kept in the speech groove by a small weight. This lever is held in a gimbal joint on the block *H* on the support *I* over the plate *E* just as in the original machine (Fig. 40). It is connected with a second lever *Q* by a link and the gimbal joints *L* and *N*. The second lever, with its fulcrum at *O* fixed to the support *P*, carries a fine recording point on an axle. The magnification by successive levers can be raised to almost any amount.

The records are made by a light aluminum point on an axle at the end of the rod *R*; the point writes on a band of smoked paper *S* about 5 meters long stretched over two drums (p. 8). As the drums are run by a belt from the same shaft that turns the gramophone disc, any changes in the speed of the motor affect the disc and the record alike. The gear wheel *Y* by which the plate is driven and the pulley *X* for the belt to the drum are shown in Fig. 42 on the axle within the barrel *C*.

The accuracy with which the machine reproduces the vibrations in the groove on the gramophone plate may be shown by a comparison of repeated tracings of the same curve; the pieces in Fig. 43 were cut from different tracings and were reproduced directly by photography. The tracing is thus done with an accuracy indicated by the likeness of the two records. These differences are so small as to escape anything but microscopic measurement. The fine vibrations

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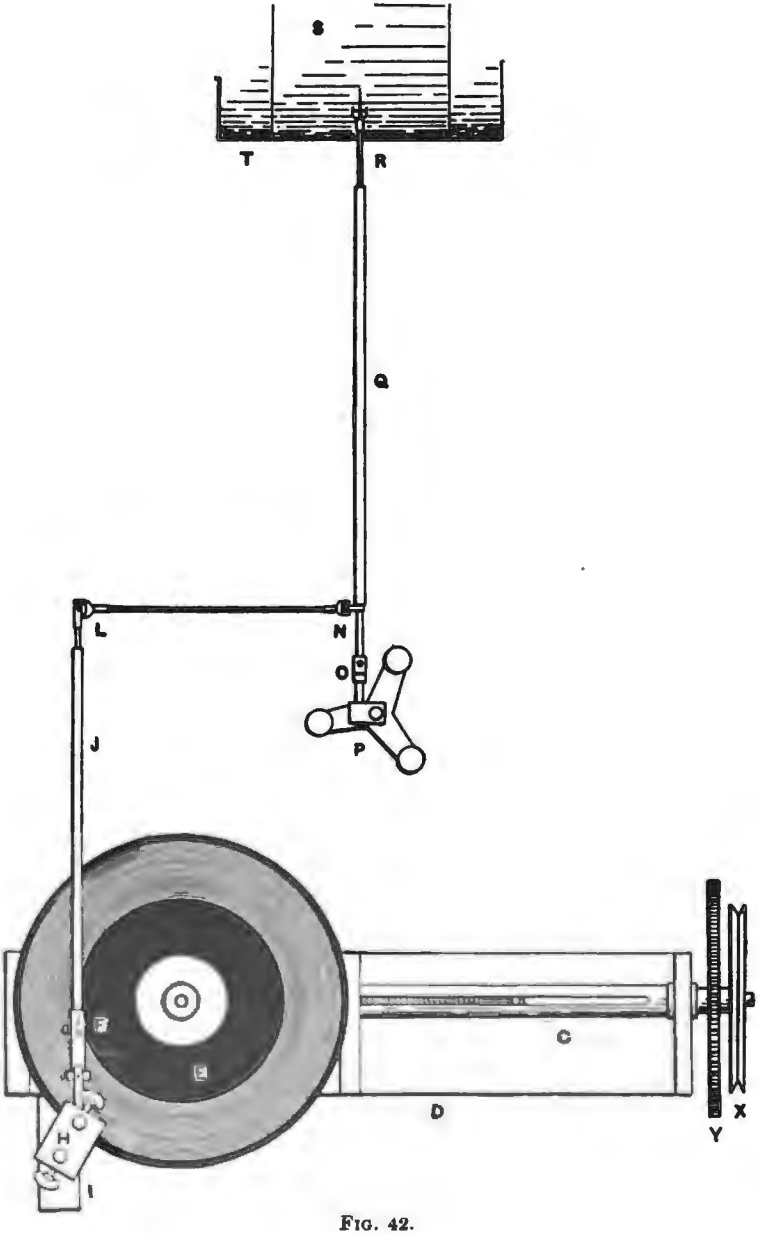

FIG. 42.

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in some of the consonants, which are lost in the tracing, are smaller than these differences.

As this machine can be run continuously day and night with no supervision except for changing the paper, great

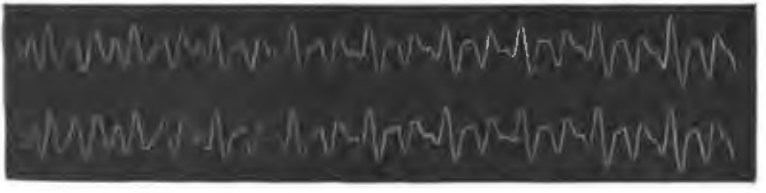

FIG. 43.

quantities of tracings can be accumulated in spite of the low speed. The entire tracing — with long silences omitted — of *Rip Van Winkle's Toast*, spoken by Joseph JEFFERSON, is reproduced in plates at the end of this volume.

The statements (p. 29) concerning the accuracy of talking-machine records apply to the gramophone also.

REFERENCES

For gramophones: NATIONAL GRAMOPHONE CORPORATION, New York. For gramophone tracing machines: PSYCHOLOGICAL LABORATORY OF YALE UNIVERSITY, New Haven, Conn. (The machine belonging to Yale University will as far as practicable be freely placed at the disposal of investigators who wish to have plates traced off.)

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CHAPTER V

IMMEDIATE ANALYSIS OF SPEECH CURVES

A CURVE of speech is at first sight no more intelligible than a line of Chinese ideographs. The knowledge of the speech sounds to which a certain portion of a curve belongs gives the general meaning of the curve but affords little information concerning its details. A careful study of the sound by the ear reveals some of the grosser characters of the sound, but cannot indicate any of the finer details that lie before the eye in the complexities of the curve. The meaning of these details — the very essentials of the speech sounds — is not apparent at first observation; only by patient and persistent unraveling of the tangled curve is an inkling of it obtained.

A set of speech curves (Plate I) from the *Cock Robin* record (p. 58) will be used to illustrate the first steps taken in analysis. The curve reads from left to right; the italicized letters indicate the sounds recorded.[1] The speech curves in the figure would naturally run along horizontal lines. The slow fluctuations seen in the records are due to irregularities in feeding the gramophone plate sidewise. They in no way affect the accuracy of the records. In making measurements of duration, however, the ruler should always be horizontal.

To interpret the details of a sound the grouping of the vibrations is first noticed. In a series of groups of the same general form each group may usually be considered as arising from one puff of the vocal cords. The minor vibrations arise from the vibrations of the resonating cavities and from the overtones of the cords.

[1] This account is from SCRIPTURE, *Speech curves, I.*, Mod. Lang. Notes, 1901 XVI 71.

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Many of the main features of the speech curves can be obtained by inspection without measurement; very much more can be obtained by simple measurements. Long distances may be measured by millimeter scales; the tenths of a millimeter may be estimated by the eye. Finer measurements may be made with a scale graduated in tenths of a millimeter; the work is done with a watchmaker's eyeglass, or under a magnifying glass. When the curves are very small, the measuring may be done by a microscope with a micrometer object table or a micrometer eye-piece.

The calculations are all done by books of tables or with a slide rule. The investigator should become familiar with various books containing extensive multiplication tables, tables of reciprocals, etc. A Chinese abacus is also very convenient in adding.

The speech curves are frequently of such a nature that the period of the cord tone may be found by measuring the distance between two like points in two successive groups of vibrations.

The distance in millimeters is translated into time according to the equation valid for the tracing. For all the curves in Plate I except that of 'draw your' the relation is $1^{mm} = 0.0016^{s}$; for this curve it is $1^{mm} = 0.0007^{s}$. Thus, the distance between the two high points in the last vibration in the fourth line is 3.2^{mm}; at 1^{mm} for 0.0016^{s} (use ZIMMERMANN'S table for 16); this gives a period of 0.01536^{s} for the cord vibrations at that instant. A period of 0.01536^{s} is the same as a frequency of $1 \div 0.01536$ (use BARLOW for reciprocals) or 65.1.

To illustrate the details a complete analysis will be given of the words 'saw him' which occur in the phrase 'Who saw him die?' The words are run together in speech on the gramophone so that the result is sɔim rather than sɔhim, the h not being heard, and the two vowels being fused like a diphthong. The record shows no trace of the s. The first vibrations of the curve differ from the rest, and show changing relations between the resonance (or mouth) tone and the cord tone; they indicate that the cords have begun to vibrate

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while the mouth is still changing from the s position to the ɔ position. After this the grouping of the vibrations in threes indicates a cord tone with a resonance tone a duodecime higher; this general relation is maintained throughout the diphthong. That still other resonance tones are present is indicated by the subordinate modifications of the small vibrations. The sound ɔ increases slowly in intensity, but diminishes again as it changes into i (middle of first line). The i is quite strong but falls quickly as the sound changes to m. The m vibrations slowly fade away. The relations between ɔ and i in this diphthong somewhat resemble those between a and i in ai discussed in a later chapter; they differ in the fall of amplitude at the end of ɔ before the i begins, whereby the separation of the elements of the double sound is slightly marked.

The accompanying table shows the way in which the course of the cord tone in reference to pitch is calculated. It illustrates several important principles used in computing and interpreting results.

A. Period in millimeters.	B. Period in seconds.	C. Frequency.		A. Period in millimeters.	B. Period in seconds.	C. Frequency.
3.8	0.0061	167		4.8	0.0077	130
3.8	0.0061	167		5.0	0.0080	125
3.9	0.0062	161		5.1	0.0082	122
4.0	0.0064	156		5.0	0.0080	125
4.0	0.0064	156		5.1	0.0082	122
2.6	0.0042	238		5.2	0.0083	120
4.2	0.0067	149		5.1	0.0082	122
4.2	0.0067	149		4.7	0.0075	133
4.1	0.0066	152		4.6	0.0074	135
4.0	0.0064	156		4.7	0.0075	133
4.2	0.0067	149		4.8	0.0077	130
4.3	0.0069	145		4.7	0.0075	133
4.3	0.0069	145		4.4	0.0070	143
4.2	0.0067	149		4.5	0.0072	139
4.3	0.0069	145		4.5	0.0072	139
4.3	0.0069	145		4.5	0.0072	139
4.3	0.0069	145		4.7	0.0075	133
4.1	0.0066	152		4.5	0.0072	139
4.2	0.0067	149		4.7	0.0075	133
4.3	0.0069	145		4.5	0.0072	139
4.5	0.0072	139		4.6	0.0074	135
4.5	0.0072	139		4.4	0.0070	143
4.5	0.0072	139		4.6	0.0074	135

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The figures in column A give the distances in millimeters from apex to apex of the strongest vibrations in the successive groups. The measurements were made by an assistant who did not know the nature of the problem investigated. It is very important to note the following:

1. The determination of the exact point to be called the apex may be indefinite to the extent of one or two tenths of a millimeter, owing (*a*) to the roundness of the apex, (*b*) to the fact that the apex is sometimes slightly displaced by interfering resonance tones.

2. The general character of muscular action indicates that the changes in the voice proceed with some regularity; this would indicate that the unusual figure 2.6 for the sixth period does not give the proper period at that point but shows something else.

Using ZIMMERMANN'S table for 16, the figures in column A are turned into time as shown in column B. These are the lengths of successive periods in the cord tone. Using a table of reciprocals (BARLOW or ZIMMERMANN) these are turned into the frequencies as in column C.

The curve of frequency is now to be plotted. This is best done by supposing the speech curve to be laid off along the horizontal or X axis, so that the first vibration is at zero. From zero the proper number of millimeters is counted upward to indicate the frequency of the cord tone at the start. Thus, if the duration of the first group is 0.12^{s}, the frequency will be 83; if 100^{mm} have been assigned to each 100 of frequency, the dot will be placed at 83^{mm} above the X axis. Above the point on the X axis at which the second group of vibrations would begin if the curve were laid upon it, the frequency of the cord tone at this moment is indicated by a dot at the proper height. In this manner a series of dots is obtained, indicating the frequency of the cord tone at a succession of moments.

In the diagram of frequency the successive dots might be connected by straight lines. We probably come nearer to the true curve of frequency (see 1. and 2. above) by drawing a

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smooth curve that evenly distributes the dots on either side. This may be done with the free hand, by means of draughtsman's curves or by a flexible rubber rule; the more general reasons for this procedure may be found in works on the methods of science.[1] The curve of frequency of ɔi, plotted from the table on p. 64, is shown in Fig. 44.

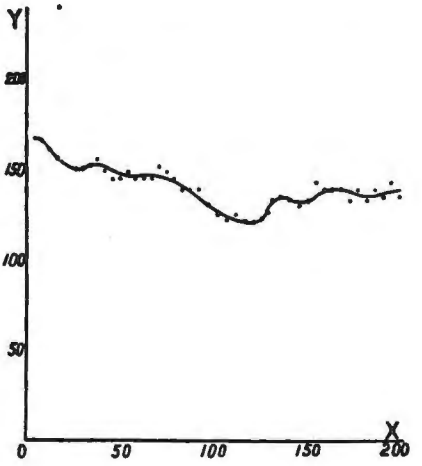

FIG. 44.

The curious interruption of the regular course of figures in the table by 2.6 arises from the fact that the series of the strongest vibrations used to mark off the groups is replaced at this point by a series arising from one of the weaker vibrations. In the first part of the curve there is some vibration of a changing character that causes a change in the moment of strongest vibration. The unusual figure indicates this latter fact and not any sudden break in the cord tone. A similar occurrence may be seen in the o of 'bow' at the middle of line 2 (Plate I) and in ɔ of 'draw' as indicated below.

The periods of the smaller, or resonance vibrations can frequently be obtained by direct measurement. This occurs most readily when these vibrations are of a simple form or of a pitch much higher than the cord tone. The result becomes more accurate when several successive resonance vibrations

[1] JEVONS, Principles of Science, Chap. XXII.

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can be measured together. When the resonance vibrations are simple in form and a place in the curve can be found where a number of them exactly fill out a group period, the length of the group period divided by the number of vibrations will give the length of the resonance period.

At the beginning of the record of sɔim (the 'glide' from s to ɔ) the smaller vibrations show a period of 0.0032^s or a frequency of 313. This resonance tone quickly changes to one of 0.0024^s period, or 417 frequency. It remains at this figure throughout most of its course but becomes 0.0028^s or 357, toward the end of ɔ. During the i it is 0.0032^s.

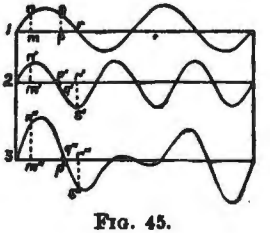

FIG. 45.

The other curves in Plate I are described in Appendix II.

The analysis of speech curves might be greatly facilitated by an inspection of curves produced by compounding vibrations of known characters.

Vibrations of any character may be compounded by tabulating them or by plotting them separately, adding the results and plotting the sums. The synthesis of sinusoid curves of the same amplitude and the same phase at the start but of the periods T and $\frac{2}{3}T$ is shown in Fig. 45. The ordinates of the constituent curves 1 and 2 are added at each moment to give the ordinate of the resultant 3; thus, $m''n'' = mn + m'n'$, $p''q'' = pq + p'q'$ ($p'q'$ having a negative value), etc. A synthesis of two vibrations of the periods T and $\frac{1}{2}T$ with the same amplitude a and with the phase differences at the start of 0, $\frac{1}{4}T$, $\frac{1}{2}T$ and $\frac{3}{4}T$ is shown in Fig. 46.

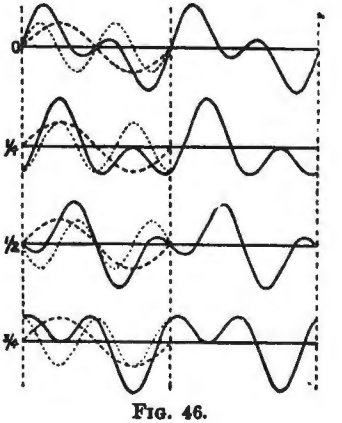

FIG. 46.

The sum of two curves of any kind with any relations of

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period, amplitude and phase can be drawn automatically by PEARSON'S curve-adder.

The composition of two sinusoid vibrations can be performed mechanically by moving the recording point of one fork over a smoked plate attached to another fork. The arrangement consists of two large forks, one fixed and the other movable in the direction of its axis by sliding its support along a guide. The fixed fork carries a narrow strip of thin glass coated with soot or covered with smoked paper. Both forks are set in vibration and the movable fork is rapidly drawn back. The periods of the forks can be altered by weights. The results of the syntheses for several relations of pitch[1] are shown in Fig. 47. The relations are indicated by the figures at the left-hand side. In the first line the speed with which the fork is drawn along decreases from left to right, in the other lines it increases.



FIG. 47.

To avoid the labor of computing the synthesis of several sinusoids in a harmonic series (p. 13), machines have been devised to add such vibratory movements mechanically.[2]

1 KŒNIG, Quelques expériences d'acoustique, 13, Paris, 1882.

2 DONKIN, *On an instrument for the composition of two harmonic curves*, Proc. Roy. Soc. Lond., 1874 XXII 196; BLAKE, *A machine for drawing compound*

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Only the machine of PREECE and STROH has been used to imitate speech curves. The artificial curves thus produced can hardly be said to bear any close resemblance to the actual vowel curves.

Sinusoids not in a harmonic series may be added by plotting, by the curve-adder, by adjusting one of two vibrating bodies (second curve in Fig. 47) or by inserting inharmonic discs into a curve-producing machine.

It is quite doubtful if either harmonic or inharmonic syntheses of simple sinusoids can give close approximations to speech curves. It is quite certain that the component tones in most speech sounds do not belong to a harmonic series. Moreover, it is highly probable that each component represents a vibratory movement of a more or less explosive character and not a harmonic of constant amplitude; its equation is (p. 2)

$$y = a \,.\, e^{-kt} \,.\, \sin 2\pi \frac{t}{T}$$

rather than (p. 5)

$$y = a \,.\, \sin 2\pi \frac{t}{T}.$$

These considerations have suggested the synthesis of free frictional sinusoids. A free sinusoid is understood to express the movement of a body displaced by a sharp blow and allowed to vibrate in its natural period; its amplitude will decrease according to the amount of friction present. A synthesis of two such frictional sinusoids may be accomplished by the arrangement shown in Fig. 48. The spring *B* is the spring *B* of Fig. 5 (p. 7). Upon it there is placed the slide *V* carrying the spring *U* and another slide *R* with the electro-magnet *S*. The movement of *B* is recorded on a smoked drum by the point *N*, that of *U* by the point *T*. The magnet *M* of the spring *B* (Fig. 5) and *S* of the spring *U*

harmonic curves, Amer. Jour. of Otology, 1879 I 81; abstract in Nature, 1879 XX 103; PREECE AND STROH, *Studies in acoustics, I. On the synthetic examination of vowel sounds*, Proc. Roy. Soc. Lond., 1879 XXVIII 358; MICHELSON AND STRATTON, *A new harmonic analyzer*, Amer. Jour. Sci., 1898 (4) V 1.

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(Fig. 48) are connected with the contact wheel *A* (Fig. 13). When the current passes through *M* alone, both points *N* and *T* draw the curve of vibration for *B* as in Fig. 14. When sent through *S* alone, the point *T* draws the curve of vibration of *U*. In both cases the vibration is a free frictional sinusoid. When the curve is sent through both *M* and *S*, the point *T* draws the curve of the sum of the vibrations of *B* and *U*.

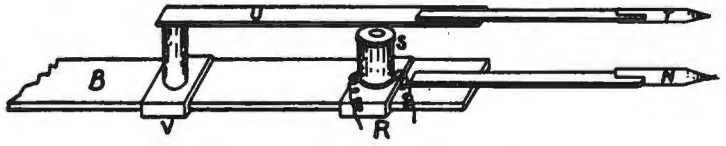

FIG. 48.

The relations of period may be altered by changing the lengths of *B* and *V*, those of amplitude by shifting the magnets, those of damping by adjusting the dampers. When the curve drawn by *T* is like that found in a speech curve, it can be assumed that the speech curve is the result of two vibratory movements simultaneously aroused by a sudden blow, which have relations of pitch, amplitude and damping like those in the springs. The sudden blow is the puff from the cords heard in the cord tone and the two free vibrations are those of the vocal resonance cavities. Tables of typical combinations would be useful. A third sinusoid might be added by placing another spring and magnet on *U* in the same way as *U* and *S* on *B*. Work on these problems is now in progress; tables of curves may be expected at some future date.

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millimètres' for 20 francs). For slide rules and similar calculating instruments: DENNERT & PAPE, Altona; W. F. STANLEY, London; BEYERLEN & Co., Stuttgart; TAVERNIER-GRAVET, Paris; KEUFFEL & ESSER, New York.

For microscopes with micrometer eye-pieces: ZEISS, Jena; BAUSCH & LOMB, Rochester, N. Y. For micrometer object tables: ZIMMERMANN, Leipzig. For adding machines: FELT & TARRANT, New York City. For calculating machines (most advantageous for multiplication and division): BURKHARDT, Glashütte i/S; BRÜCKNER, Dresden; GRIMME, NATALIS & CIE., Braunschweig. For the curve-adder: CORADI, Zürich.

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CHAPTER VI

HARMONIC ANALYSIS

THE tones represented in a period of a speech curve may be determined to a certain extent by the harmonic, or FOURIER, analysis.[1]

The hypothesis on which this analysis rests can be readily illustrated. A stretched string — that of a tonometer, a violin, etc. — is made to sound. The edge of a piece of blotting paper, the tip of the finger or any narrow object is then applied exactly to its middle point. The main tone of the string ceases at once, but the octave is heard to continue. Careful inspection shows that the string has ceased to vibrate as a whole but continues to vibrate in halves. After the experiment has been repeated a number of times, the unaided ear can hear the octave in addition to the fundamental when the string vibrates freely. Similar results occur when the string is touched at $\frac{1}{3}$, $\frac{1}{4}$, . . . of its length. The note from the violin string can thus be analyzed into a series of *partial tones* consisting of a *fundamental tone* and its *overtones*. It is assumed that these partial tones correspond to vibrations of the sinusoid form (p. 2) with different periods and that the complex tone of the violin is made up of a sum of these sinusoids. The series of tones thus found in the complex tone from a violin have periods in the relations of 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, . . . and frequencies in relations of 1, 2, 3, 4, . . . They form a harmonic series (p. 13). No tones outside of the harmonic series can be detected.

The analysis of a musical tone into such a series of har-

[1] FOURIER, Théorie analytique de la chaleur, Ch. III, Paris, 1822.

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monics can be accomplished on the principle of resonance (p. 13). A resonator will respond loudly to a tone of its own pitch. Resonators tuned to different tones are held to the ear in succession while the tone is sounding. The periods of the resonators that respond are taken as giving with fair approximation the periods of the partial tones present. Spherical resonators (Fig. 15) answer very accurately to the partials; when they are used, the tone to be tested is adjusted to the pitch of one of the set. Adjustable resonators (Fig. 16) can be accommodated to any tone; they can also indicate inharmonic partials, that is, partials whose frequencies do not stand in simple relations to that of the fundamental. The application of the resonators to the ear requires the tone to be prolonged unchanged for a long time, or to be repeated unchanged if many partials are to be determined. The resonators may be connected to manometric flames and may be mounted in sets.[1]

Although an analysis by resonators is useful for demonstration, it is practically valueless in the study of speech because 1. speech sounds are not constant long enough for the adjustment of the apparatus; 2. a resonator responds in some degree to other tones than its own (p. 14); 3. the harmonic analysis of speech tones can at best be only an approximation.

When a vibration is registered in the form of a curve that can be accurately measured, it can be resolved into a series of harmonics by means of the FOURIER analysis.

To apply this method the heights of a series of ordinates are measured at equidistant points along a base line parallel to the axis of the curve. When the records are very large, the base line may be drawn directly on the record-sheet and all the measurements made with a ruler graduated in tenths of a millimeter. Smaller records may be enlarged by the precision-pantograph of CORADI. A camera lengthened by a wooden tube projecting in front and bearing a lens of short focus — for example, a 20-diopter lens from an optician's test

[1] KŒNIG, Quelques expériences d'acoustique, 73, Fig. 31, Paris, 1882.

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case — may also be used for enlarging. The lens is covered with a card containing a circular hole of 1^{cm} diameter to increase the sharpness of definition. The record is placed in front of the lens. If desired, a photograph may be obtained in the usual way. To simply trace off the enlarged curve, the ground glass of the camera is replaced by a sheet of clear glass on which a piece of tracing paper is laid. When the record may be cut out, a micrometer object table under a microscope may be used. A piece of the tracing is cut out, placed between glass plates and focused under the microscope. The measuring is done by micrometer screws that move the curve horizontally and vertically.

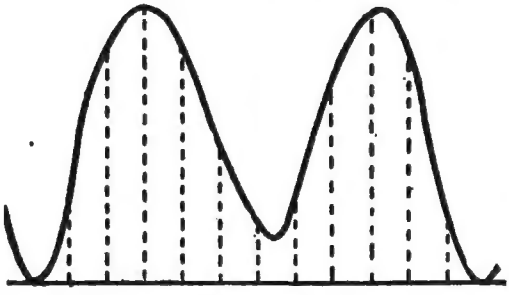

FIG. 49.

For the analysis of a curve so many ordinates must be measured that the piece of curve cut off between any two ordinates can be considered as a straight line, whereby it is implied that no maxima or minima (no points or turns) of the curve lie between two ordinates. Very smooth curves can be handled with only 12 ordinates; these will give the first few partials with fair accuracy. A portion of a speech curve, enlarged 20 times by a camera, is shown with 12 ordinates in Fig. 49. More complicated curves require 20, 24, 36 or 40 ordinates. The utility of the method depends upon the success with which the measuring and computing can be kept within reasonable limits of time.

The measurements of the ordinates, when inserted into certain formulas, give values that indicate the relative am-

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plitudes of the sinusoids into which the given curve may be analyzed. An analysis of the curve in Fig. 49 gave the relative amplitudes as indicated in Fig. 50.

On the supposition that the original curve (Fig. 49) represents a tone composed of harmonic partials the analysis shows that the second partial (2, Fig. 50) was the predominant tone, that the third and first were much weaker and the others very weak. For speech curves we cannot make the preceding supposition, and the results of the analysis do not indicate the presence of component harmonic partials, but do indicate the presence of tones in certain relations to one another. A tone that is not harmonic to the fundamental appears by the FOURIER analysis to reinforce neighboring harmonics. The diagram in Fig. 50 thus seems to indicate the presence of a tone slightly higher than the second partial. The FOURIER analysis is often the only way of locating the tone or tones in a complex, even though they do not stand in harmonic relations.

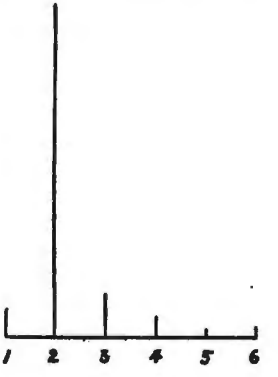

FIG. 50.

The preceding account is probably sufficiently detailed for an understanding of the objects of the FOURIER analysis; full instructions for performing the analysis will be found in an Appendix.

The resolution of an empirically obtained speech curve into a series of harmonics by the FOURIER analysis seems to have been first performed by SCHNEEBELI (p. 18); it was used by PIPPING (p. 20), BOEKE (p. 37), HERMANN (p. 38) and BEVIER (p. 49) in obtaining their results.

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PART II

PERCEPTION OF SPEECH

CHAPTER VII

THE ORGAN OF HEARING

THE auricle (*1* in Fig. 51) in man is of little aid in hearing sounds. It strengthens them slightly by reflecting more

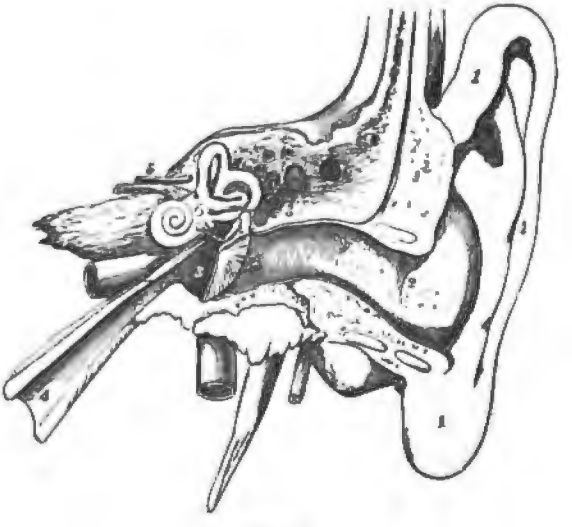

FIG. 51.

of the wave into the ear canal (*2*, Fig. 51); it favors those from the front; by resonance it modifies slightly the partial tones of a complex sound; and it favors the hissing tones of sounds like s.

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The vibration of the air traveling down the external canal (*2*, Fig. 51) reaches the ear-drum, or tympanum, *membrana tympani* (*3* in Fig. 51; *1* in Fig. 52). This membrane consists mainly of radiating fibers in the central portions and of circular fibers in the peripheral portions; it thus has great possibilities of adjustment and damping. It is of slightly conical form. Its structure of radiating and circular fibers,



FIG. 52.

its conical shape and its damping by the ear-bones attached to it (Fig. 52) permit it to repeat vibratory movements of various pitches without reinforcing any of them greatly by resonance (p. 13). At the tympanum the vibratory movement of the air is transformed into vibratory displacements of the tympanic membrane. Weak sounds are most favored by the shape and position of the tympanum.

The cavity beyond the tympanum is known as the middle ear (*3*, Fig. 51). It communicates with the pharynx by the

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Eustachian tube (*4*, Fig. 51). The middle ear is shown in Fig. 52 with the cavity *b*, the ear-bones *2*, *5*, *7*, the tympanum *1*, and the oval window *d* to the inner ear *c*. The inner side of the tympanum is attached to the end of a small bone, the hammer, or *malleus* (*2–3*, Fig. 52), which rotates on an axle and thereby repeats the movements of the tympanum. The anvil, or *incus* (*5–6*, Fig. 52), is a small bone fitting on the head (*3*, Fig. 52) of the hammer and pivoted in such a way that its long arm repeats the movement of the handle of the hammer with a somewhat lessened amplitude. The stirrup, or *stapes* (*7*, Fig. 52), attached to the long arm of the anvil, fits loosely into an oval opening, *fenestra ovalis* (*d*, Fig. 52), between the middle ear and the inner ear (*c*, Fig. 52). It is held in this opening by a ligament running around on all sides. In repeating the movements of the anvil it is forced to twist because the ligament is more tense on the side below than above. The movement executed by the tympanum and ear-bones is indicated by the white line in Fig. 52. The ear-bones together form a lever arrangement for transforming the air vibrations into a movement of the liquid behind the oval opening. As the arms of the lever are in the relation of $1\frac{1}{2}$ to 1, and as the tympanum is nearly twenty times the size of the oval opening, the movement is reduced in amplitude but increased in energy to the extent of $1\frac{1}{2} \times 20 = 30$. The movements of the stirrup are communicated to the membranous sac, or labyrinth, of the internal ear.

Two muscles act upon the chain of ossicles. The *tensor tympani* from the handle of the malleus (at *4* in Fig. 52) serves to pull it inward (→ in Fig. 52) thereby stretching the tympanum and pushing the stirrup more strongly against the internal ear. The former action reduces the amplitude of the vibrations of the tympanum and, by shortening its period of free vibration, makes it better fitted to transform those of various periods with less resonance-effect. The latter action stretches the membrane of the oval window and thus produces more opposition to the movement of the stirrup, the other bones and the tympanum; the effect is to reduce the

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amplitude of the vibratory movement. The *stapedius* muscle attached to the stirrup twists it in a way to relieve the internal ear from pressure and to oppose the action of the *tensor tympani*. It thus renders the tympanum, the ear-bones, and the liquid of the labyrinth more sensitive to vibrations.

The internal ear consists of a complicated membranous labyrinth (*1*, *2*, *3*, *4*, Fig. 53) inclosed in a bone labyrinth

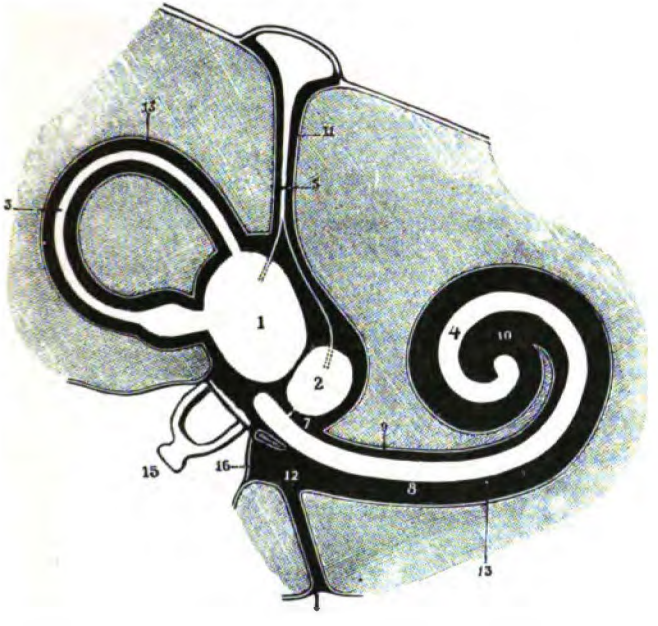

FIG. 53.

(*7*, *8*, *9*, *10*, *12*). The portion belonging to the cochlea (*4*) is specifically concerned in hearing; the utricle (*1*) and saccule (*2*) are of doubtful function; the semicircular canals (one shown at *3*) are not concerned in hearing.

The cochlea comprises a long canal (*4*, Fig. 53) wound around a cone (Fig. 54) and divided longitudinally through nearly its whole length by a partition partly of bone and partly of membrane. One portion of the canal (*A* in Fig. 55) is connected with the oval opening, the other (*B*) with the

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round one (*16*, Fig. 53). The bone division between them (*1*, Fig. 55) is continued across by a membrane, *membrana*



FIG. 54.

basilaris (*7*), to the opposite wall. The membrane of REISSNER (*5*) is stretched across the canal *B*. The whole labyrinth is filled with a liquid. The pressure of the stirrup on the liquid connected with one side (*A*) of the canal will



FIG. 55.

press the membrane to the other side (*B*). The basilar membrane is composed of transverse bands of different lengths and presumably of different periods of free vibration (p. 2).

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Being light in mass these bands are readily set in vibration; as they are well damped, the vibrations quickly die away on account of friction (p. 5). A diagram of one of the bands of the basilar membrane and its annexes is given in Fig. 56.

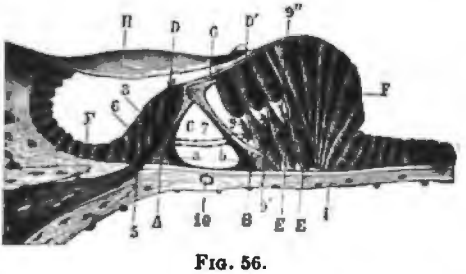

FIG. 56.

The band *I* carries on it sets of supporting cells *F* and *E*, the rods of CORTI *A B*, and the hair cells *D D'*; these last are held in place in the membrane *G*.

The vibratory movements of the liquid in the cochlea will thus readily set in motion those bands whose periods of free vibration are harmonic to its period or to the period of any of its components. For musical notes the action of the membrane is thus somewhat like that of a series of harmonic resonators responding to a sound (p. 14). For vibrations of the character of voice curves a similar principle of analysis by resonance may be applied. The whole membrane is forced to move very slightly in a manner corresponding to the curve of vibration, but any fibers whose periods correspond to the periods of impulses contained in the original vibration will be made to vibrate strongly.[1] Each fiber of the membrane carries on it a set of cells (*D D'*, Fig. 56) with hairs that rub[2] against a floating membrane (*H*) when the fibers vibrate. This causes deformation of the cells and irritation of the nerve endings (*9*, *9'*, *9''*) around them. The irritation is transmitted along the nerve fibers (*3*, Fig. 55) to the brain. The number of fibers in the membrane, that of the hair cells,

[1] HELMHOLTZ, Lehre v. d. Tonempfindungen, 5. Aufl., 235, Leipzig, 1896.

[2] TER KUILE, *Die Uebertragung d. Energie von d. Grundmembran auf d. Haarzellen*, Arch. f. d. ges. Physiol. (Pflüger), 1900 LXXIX 146.

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and that of the nerve fibers is greater than that required for the number of tones that can be distinguished by the ear.[1] Other theories of the action of the basilar membrane and the stimulation of the nerve endings have been proposed but have failed of general acceptance.

A complicated vibratory movement arriving in the internal ear is probably analyzed into a series of simultaneous nerve-irritations that proceed to the brain. These irritations change at every instant. On the supposition (which may have to be modified) that the irritation passing along a nerve can change only in its intensity, all variations in the vibratory movement of the air result in variations in the intensity and number of the nerve irritations aroused. Every change in the air-wave produces changes in these irritations. Arriving in the central nervous system these irritations are combined with others from other parts of the body and from various nerve cells. The manner of analysis by the nerve endings in the internal ear is largely unknown; tones like those from some musical instruments are supposed to be analyzed into a harmonic series (p. 72) on the principle of resonance. The complicated vibrations in speech sounds, especially in the consonants, present difficulties to such a harmonic analysis; these difficulties may not be fatal and the theory is still a plausible one. Just what happens to the irritations when they reach the central nervous system is still entirely unknown.

From every sound the brain receives impulses of different strengths that arrive along different nerve fibers. The activities of the brain cells connected with sensations of sound bear no resemblance whatever to the physical vibrations that arouse them, although the two sets of phenomena are related by definite laws. The sensations of sound in consciousness, moreover, in no way resemble the activities of the nerve cells, although most intimately connected with them.

[1] SNODGRASS AND M'KENDRICK, in Schaefer's Textbook of Physiology, II 1184, Edinburgh and London, 1900.

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The integrity of a relatively definite region of the outer layer (*cortex*) of the left cerebral hemisphere is necessary for the correct understanding and use of speech in its usual forms.

The centers for controlling combinations of vocal movements in speech are in the region (BROCA'S convolution) indicated by 'Motor words' in Fig. 57. The centers for memories of word-movements are mainly in the anterior portion of the speech region. The region connected with the hearing of sounds is in the first temporal convolution ('Hearing,'

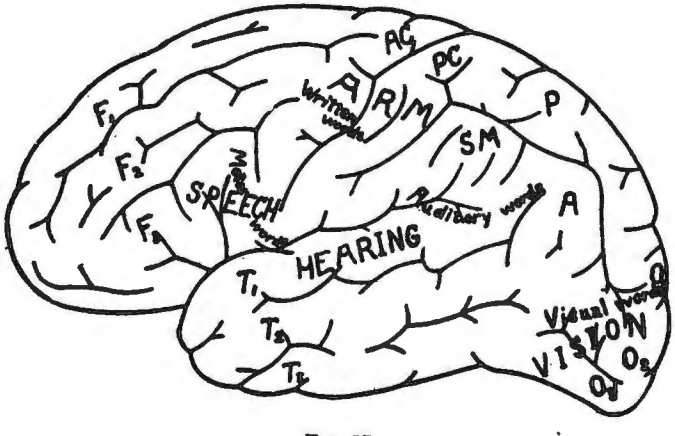

FIG. 57.

Fig. 57), that for the perception of speech sounds in WERNICKE'S convolution ('Auditory words'). The region for the perception of visual objects lies in the occipital lobe ('Vision'). When printed signs take on the character of intelligible words through association with other speech elements, they probably involve the activity of portions of the brain in the fore part of the visual region ('Visual words,' also *A*). The region for arm movements lies in the middle portions of the two central convolutions ('Arm'), that for the corresponding motor ideas probably near the same place ('Written words').

Differing from those of other activities the centers of

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speech all lie on one side, on the left in right-handed persons, although the muscles and sense organs lie on both sides; it has been suggested that such an arrangement arises from the necessity of exact coordination of the movements and impressions from the two sides.

Four fundamentally different types of disturbance occur in the brain. The more elementary ones appear as disturbances in movement and sensation on one side of the body, for example, the inability to move the right arm as the result of a lesion in the arm center on the left side of the brain. Another group is characterized by the loss of definite, complicated associations of movements and sensations; for example, the inability to perform the movements involved in sewing, drawing, etc. A third group involves the loss of highly complicated associations like those involved in speech. Finally, the disturbance may involve the most complicated of all associations, such as those of logical thought, language, etc.

The special characteristic of speech disturbances in the surface of the brain lies in injury to or loss of the ability to use the common language of expression, such as words, letters, notes and other symbols, although the general ability to use ideas is not notably gone and the action of the ear and vocal organs is not seriously injured. Such disturbances are generally grouped under the term 'aphasia.' The mildest forms of aphasia appear in the difficulty of finding the correct (though familiar) word to express an idea (this weakness of word-memory occurs regularly in old age, in conditions of fatigue, etc.); or in the difficulty of understanding spoken or written words.

Motor aphasia, or word-dumbness, is the term applied to a condition in which the voluntary control of the speech muscles is in general fairly complete and the production of sounds and even of single monosyllabic words or syllables is possible, but in which the speech names for the most common things and conditions cannot be found and used and the words heard by the patient cannot be repeated. It results

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from injury to the motor speech center ('Motor words,' Fig. 57).

Auditory aphasia, or word-deafness, is characterized by retention of hearing with loss of understanding of spoken words. A word appears to the patient as a meaningless noise or a word from an unintelligible language. The disturbance is connected with lesions in WERNICKE'S convolution ('Auditory words,' Fig. 57); it may be due to resistances in the conduction in the brain, whereby single portions of words do not appear in consciousness with sufficient rapidity, clearness or completeness to be grasped, or whereby they cannot be held long enough in memory to be united with the following ones. Word-deafness may be chiefly perceptive or chiefly associative, according as there is difficulty in grasping the elements, or in recognizing them by assimilation to past experiences. The understanding of words is seldom completely lost; specially familiar words are generally still understood. The difficulties of conduction occasion exchanges of words (paraphasia). The word-deaf person gets the meaning imperfectly or not at all of what he hears; nevertheless he answers every question with alacrity but quite inappropriately. He has no full consciousness of his errors and generally shows indifference to them. His thoughts need not be in any wise incorrect, but he misunderstands and misuses words.[1]

Agraphia ordinarily occurs whenever motor aphasia is present; it is not known to occur alone. It is characterized by inability to write words, while the other arm movements are still completely under control. It is connected with deficiencies in the ideas of speech movements and speech sounds, and not with special lesions of the arm center. Agraphia occurs regularly with auditory aphasia. Generally it is a word-agraphia, the power to write single letters being retained though they do not correspond to the sounds which they are supposed to indicate. In cases of complete auditory aphasia the hand makes only irregular, meaningless strokes and signs, a proof that the chief guidance of the hand in writing is not

[1] v. MONAKOW, Gehirnpathologie, 523, Wien, 1897.

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from the visual memories of the letters or from the motor memories and sensations of the arm and hand, but from the auditory ideas with which these movements are connected.[1]

Alexia is characterized by the inability to understand words. It is of two forms. The one is usually connected with auditory aphasia; the other arises independently. The former results from disturbances in the temporal convolutions and the *gyrus angularis* (*A* in Fig. 57), the other from subcortical lesions.

It can be considered as definitely established[2] that the control of the individual muscles occurs in the spinal cord and the pons, whose centers can operate them for combined action; that the cortical centers are those of group action, the separate muscles being represented only when they are often used singly; that the arrangement of the group centers in the cortex does not occur by chance or in reference to anatomical relations but according to definite, varied, fundamental movements; that each form of use of a muscle-group in this or that act is represented by a different center. This latter fact may be illustrated by a case in which injury to a portion of the cortex was followed by loss of the ability to extend the right thumb alone, while the ability to do so in combination with other movements remained.

This principle of group representation in the cortex presumably holds good for speech volitions and speech perceptions; no other principle seems to agree with the phenomena that appear in disturbances of language functions.

The diagram in Fig. 58, a development of one by LICHTHEIM,[3] indicates the supposed functional connections of the speech centers. Repetition of a word heard involves the transmission to the hearing center and stimulation of the motor speech center by the associating fibers. Reading aloud involves the translation of the visual words into auditory words and then into spoken words. It does not occur by direct

[1] v. MONAKOW, as before, 518.

[2] v. MONAKOW, as before, 382.

[3] LICHTHEIM, *Ueber Aphasie*, Deut. Arch. f. klin. Med., 1884–85 XXXVI 204.

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connection between the visual and motor speech centers except in the case of the deaf. In spontaneous writing the ideas are first put into speech form and then translated into writing movements, and are not expressed by the arm directly. In writing from dictation the perceived words first arouse the center for speech action and this arouses the writing center. In copying by sight there is direct connection between the reading center and the writing center. Although used to indicate the accepted theory of the action of the cortical

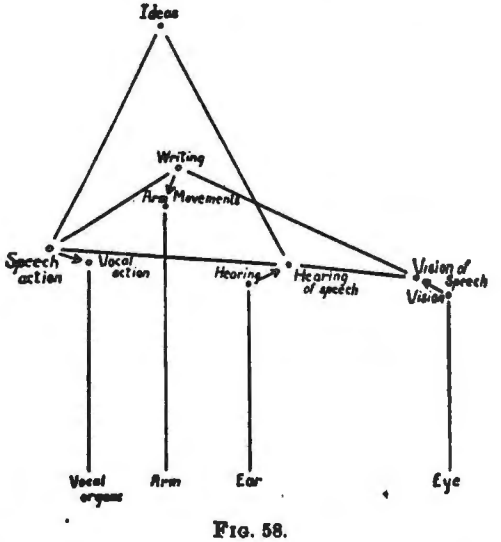

FIG. 58.

centers, the diagram is essentially a scheme of the mental processes involved; it cannot be fitted with any closeness to the actual brain action.

Beyond this point our knowledge of what occurs in the brain is limited. A study of the cases of disturbance of the language functions of mind has been carefully made with reference to brain action, and certain fundamental facts have been established. The attempts of various psychological writers to state the phenomena of consciousness — particularly 'the marginal or fringe processes that are seldom if

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ever within the scope of introspective observation' — 'in neural terms' are pure figments of the imagination whose hypotheses are incompatible with the familiar facts of physiological action.

Systematic application of experimental methods to determine the laws of speech disturbance has not yet been extensively undertaken.

The motor functions of the brain in controlling the vocal organs will be considered in detail in Chap. XV.

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CHAPTER VIII

PERCEPTION OF SOUNDS

SOUNDS are purely mental experiences, most of which are the results of vibratory movements reaching the ear through the air. 'Tone' and 'noise' are the two extremes of a mental arrangement of sounds according to likeness. A pure tone can be obtained from a well made tuning fork; a vowel sung by a good voice can be made nearly a pure tone without admixture of noise; a whispered vowel combines tone and noise; f and s are mainly noises, but nevertheless resemble tones to some extent and are heard to vary in pitch. Every ordinary sound appears to have more or less of each element in it.

Tones have three necessary properties: pitch, duration, and intensity. Other properties such as timbre, objectivity, emotional tinge, etc. may be added.

Many of the fundamental facts concerning tones can be illustrated by a siren.[1] In its simplest form the siren consists of a carefully balanced and trued disc with a circle of holes pierced through it. When such a disc (*A*, Fig. 59) is rotated through a jet of air from a tube *E*, the holes produce a series of puffs at intervals depending on the speed of the disc. This disc may be mounted on any rotating axle *B*; it is most conveniently placed directly on the axle of a small electric

[1] CAGNIARD-LATOUR, *Sur la sirène, nouvelle machine d'acoustique destinée à mesurer les vibrations de l'air qui constituent le son*, Ann. de chim. et de phys., 1819 XII 167; SEEBECK, *Beobachtungen über einige Bedingungen der Entstehung von Tönen*, Ann. d. Phys. u. Chem., 1841 LIII 417; *Ueber die Sirene*, Ann. d. Phys. u. Chem., 1843 LX 449; DOVE, *Beschreibung einer Lochsirene f. gleichzeitige Erregung mehrerer Töne*, Ann. d. Phys. u. Chem., 1851 LXXII 596; HELMHOLTZ, Lehre v. d. Tonempfindungen, 5. Aufl., 269, Leipzig, 1896.

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motor whose speed is regulated by an appropriate resistance (p. 10). As the speed of the siren disc is increased, the puffs come more rapidly and finally change into a tone that continues to alter in its property of pitch.

Since a series of puffs, as known mentally, gradually changes to a tone of rising pitch as the frequency of the puffs increases, we may say that a tone is composed of puffs and that the property of pitch depends on the frequency of the puffs. We may not be able to detect the puffs in a tone and the tone may appear to us as a simple phenomenon, yet we are quite justified in considering it as a compound of the more elementary

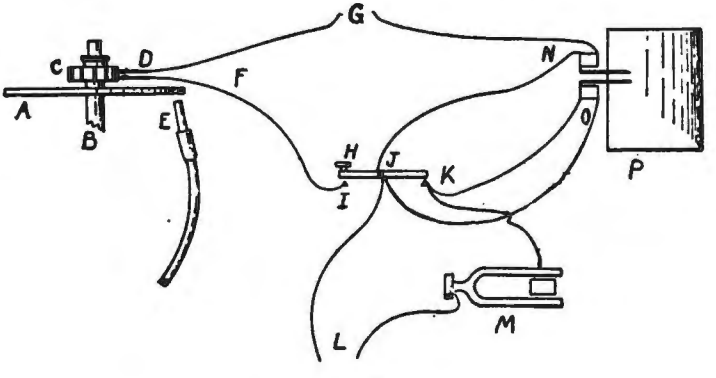

FIG. 59.

sensations termed puffs. The numerical expression for the pitch of a tone may be derived from the number of puffs that compose it. With a siren it can be readily demonstrated that at low frequencies one puff corresponds to the passage of one hole before the blast tube; this correspondence can be followed as long as the puffs can be heard separately. When the puffs fuse into a tone, we may assume that the correspondence still remains; the number of jets of air a second can thus be taken as the figure for the pitch of a tone. The pitch of a tone and the frequency of the puffs are thus correlated.

The property of pitch may be varied by changing the speed of the disc, and making the holes pass the jet at different

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rates. With a small number of holes the pitch is said to be 'low' or 'grave;' with a large number it is said to be 'high' or 'acute.' These terms are metaphors, having no physical, physiological or psychological meaning except what has been derived by association.

The property of duration in a tone can be illustrated by changing the time during which the tone is produced; the property of intensity by making it louder or weaker.

The pitch of the tone from the siren at any moment can be determined by placing on the axle of the motor a contact *C* (Fig. 59) consisting of a gear wheel with spaces filled by vulcanized rubber, and adjusting a pair of copper brushes *D* on its rim. A battery current *G* is sent through the brushes, a make-key, *IJ*, and a magnetic marker *N*; whenever the knob *H* is pressed, the circuit is closed at *I* and each closure at *D* will register a check in the line of the marker-point *N* on the drum. To get a registration of the time the marker *O* is connected to a fork *M* (p. 15) in such a way that the breaking of the circuit at *K* sets it vibrating. This can be conveniently done by using the key as a shunt around the marker in a circuit coming from the fork. A comparison of the checks in the line from the marker *N* with the waves of known frequency from the marker *O* will give the time between contacts at the brushes *D*; from this the speed of the disc and the number of puffs can be readily calculated.

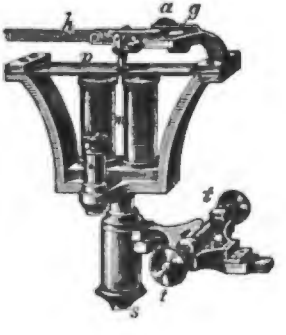

FIG. 60.

The magnetic marker referred to appears in various forms. The PFEIL marker is shown in Fig. 60. A current passing through the coils *m* draws down the steel spring *p* and causes the lever *h* (only partly shown in the figure) to record on the drum. This marker in connection with an electric fork can produce smooth waves of the sinusoid form, which is

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well adapted for time-comparisons; by adjusting the weight *g*, it may be tuned to the harmonic series of which the fork-period is a member. The screw *s* moves the cores of the magnets to and from the spring *p* and thus regulates the amplitude of the action. The side screws *t t* are for adjusting the point of *h* accurately on the drum. The DEPREZ marker (Fig. 61) is a form adapted to quick action on account of the light mass of its armature *V*. The magnets *U U* are connected to the binding posts *S S*. The armature is held back against the cone *C* by the spring *R*, whose tension is regulated by a movable arm *Y*. The distance of the armature from the magnet is regulated by moving the cone *C* axially by means of the knob *T*. With appropriate adjustments of the strength of the current, the tension of the

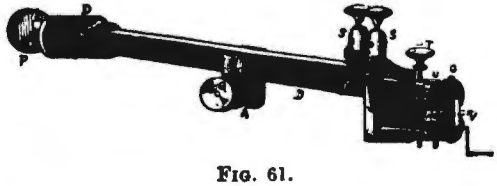

FIG. 61.

spring and the position of the armature, the rapidity of action can be made so great that the marker loses only a few ten-thousandths of a second in responding to a magnetic impulse; it may be used to record 500 impulses a second. The marker is held on a rod by the screw *P* through the barrel *D*; its stem is lengthened or shortened by the knob *Q* moving the rack *B* by means of the pinion *A*.

The latent time of a marker should be measured frequently when it is of importance. This is best done by placing on the axle of the drum a rubber or fibroid wheel with a strip of metal on its edge around half the circumference; the two poles of the circuit are rested against the wheel as indicated in Fig. 62; the marker is placed in the circuit, its point being against the drum; the drum is brought to rest just as the contact is closed, whereby a check is made on the smoked surface; the same is done for the point where

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the circuit is broken. The drum is now turned rapidly; the marker responds to each make and break by a check on the line on the drum; the distance between the check made by bringing the drum to rest and that made while it is moving represents the time lost by the marker; with a time line (p. 15) on the drum this latent time can be measured. It is convenient to have such simple contact wheels with brushes on all drums; the determination of the latent time then takes only a few moments before or after the experiments are made. In the experiment with the siren this measurement is not required.

The puff produced by the siren is accompanied by considerable noise. Most of this noise can be avoided by using a vibrating steel reed. When such a reed is clamped in a vise, it can be set vibrating by the finger. When its length is adjusted so that its frequency is sufficiently high, a tone is heard. As the length is increased, the tone begins to rumble and finally breaks up into puffs of sound almost entirely unaccompanied by noises. Still clearer results may be obtained by using large tuning forks with heavy sliding weights.

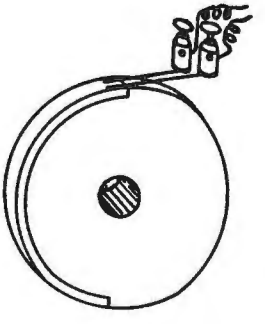

FIG. 62.

The rise in pitch may be continuous between the lowest and the highest limits. The changes by steps as used in music are required neither by the voice nor by the ear.

The psychophysic law for tones in its simplest form as given by ARISTOTLE[1] states that a tone corresponds to the vibrations of a body (the statements of PYTHAGORAS refer to the relation between the length of a string and the pitch of a tone and not to vibrations).[2] The psychophysic law of

[1] ARISTOTELES, Problemata, XIX 27; De anima, II viii 420.

[2] NIKOMACHOS, Harm. introd., I 16 (direct source for the statements regarding PYTHAGORAS); BÖCKH, Philolaos des Pythagoreers Lehren nebst Bruchstücken seines Werkes, 65, Berlin, 1819.

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pitch was first formulated by GALILEI[1] and MERSENNE[2]: the pitch of tones depends directly on the frequency of the impulses.

Using siren discs with holes of different shapes SEEBECK demonstrated[3] a principle whose validity was long overlooked in favor of an erroneous theory of vowel tones. SEEBECK'S principle may be stated thus: a puff recurring with a constant period produces a tone whose pitch is given by that period independently of the character of the puff and of the portion of the period occupied by it. The experiment has been repeated in various developments. A strong tuning fork may be held close behind a rotating disc with large holes so that the tone is heard only when a hole passes the fork.[4] The intermittent tone gives a series of puffs whose frequency is that of the holes passing the fork. When the holes pass rapidly enough, the puffs are heard as a tone of a pitch corresponding to the number of holes passing in a second. The tone of the fork and that of the series of holes are thus heard simultaneously. When regular groups of holes are filled (or omitted) in a siren disc, the changes between tone and silence likewise produce two tones, one with a pitch corresponding to the frequency of the holes within a group and another to the frequency of the group.[5] Similar experiments may be readily made with a card or paper cone held against the teeth of a gear wheel. The intermissions are produced

[1] GALILEI, Discorsi e dimostrazioni matematiche, Leida, 1638.

[2] MERSENNE, Harmonie universelle (Harmonicorum libri XII), Paris, 1636; GOVI, *Su un' antica dimostrazione del numero delle vibrazione che corrispondono ad un suono dato della scala musicale*, Rend. Acc. di Napoli, 1886 XXV 106 (refers to MERSENNE); TAYLOR, *De inventione centri oscillationis*, Phil. Trans. Royal Soc. Lond., 1713, XXVIII 11; Methodus incrementorum, London, 1715; EULER, Tentamen novae theoriae musicae, Petropoli, 1739.

[3] SEEBECK, *Ueber die Erzeugung von Tönen durch getrennte Eindrücke, mit Beziehung auf d. Definition des Tones*, Ann. d. Phys. u. Chem., 1844 LXIII 368.

[4] KŒNIG, *Ueber den Zusammenklang zweier Töne*, Ann. d. Phys. u. Chem., 1876 CLVII 231; Quelques expériences d'acoustique, 139, Paris, 1882.

[5] DENNERT, *Akustisch-physiologische Untersuchungen*, Arch. f. Ohrenheilk., 1886-87 XXIV 171.

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by filling some of the teeth with wax.[1] The tone whose pitch corresponds to the frequency of intermission is always the loudest although the tone whose pitch is that of the number of blows of the teeth on the card may be also heard. When a tone through a telephone is regularly interrupted by breaking the secondary circuit, the interruption tone appears also.[2] The fundamental law demonstrated by the preceding experiments may be thus stated: every periodic change within certain limits of frequency is perceived by the sense of hearing as a tone.

Out of tones regarded as simple, other tones, or notes, can be built up. When two tones are sounded by blowing on two series of holes of widely different frequencies in the siren disc, the result appears different from either tone heard separately. To the uneducated ear this tone appears just as simple as the others though quite different in its character. It may, however, be regarded as a complex or compound tone composed of two simpler tones, just as each of these simpler tones is to be regarded as composed of puffs.

The character of a compound tone varies with the relations of pitch and intensity among its components. When the components are of approximately equal intensity and when they have certain simple relations of pitch, they are called 'chords;' thus, three tones of nearly equal intensity in the relations of 2 : 3 : 5 form a major chord. The chords can be demonstrated by a siren disc with several series of holes, in the desired numerical relations, blown by several jets. A few of the simple tones in compound ones can frequently be picked out by listening for them. The notes of a chord may appear simple to the unaccustomed ear, but the musician can by attention separate them.

When the components have certain simple relations of pitch such as 1 : 2 : 3 : 4 : 5 . . . and the lowest tone is

[1] HERMANN, *Phonophotographische Untersuchungen, III.*, Arch. f. d. ges. Physiol. (Pflüger), 1890 XLVII 386.

[2] ZWAARDEMAKER, *Ueber Intermittenztöne*, Arch. f. Anat. u. Physiol. (Physiol. Abth.), 1900, Supplementband, 60.

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much stronger than the others, the compound tone is said to be 'complex,' or to be composed of a 'fundamental' and its 'overtones.' To illustrate this, several series of holes in the siren may be blown at once, the high tones being made quite subordinate in intensity to the lowest one by using smaller jets. Changes in the relative intensities of the series of overtones produce changes in the character of the complex tone; these are said to be changes in timbre. A series of tones such as

$$1 : 2 : 3 : 4 : 5 : 6 : — : 8 : — : 10,$$

with the relative intensities indicated by the size of the figures, will produce quite a different complex tone from a series such as

$$1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 9 : 10.$$

The character of the tone differs also with the character of its elementary puffs. When puffs of the same frequency are compared, they will be found to differ in properties that may be termed 'loudness,' 'suddenness,' 'smoothness,' 'sharpness,' etc. A single puff in any case is heard with more or less complicated variations of intensity. Explosive puffs like those from the siren and usually from the vocal cords rise and fall suddenly in intensity. Very smooth puffs are obtained from tuning forks.

Tones composed of puffs of different forms appear different to the ear. These differences often resemble those produced by combining tones into compounds and complexes. The puffs from some musical instruments whose tones differ in timbre can be shown to be of forms that would arise from adding harmonic series of sinusoids with regular systems of decreasing amplitudes for the components of shorter periods. The puffs from other instruments are of forms that would not arise in this way. Tones from the voice differ not only in timbre but also in other ways; the puffs have very complicated forms.

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When the puffs are of forms such as would arise from a summation of puffs of the sinusoid form, with periods in a harmonic series, the sound can often be heard as containing a series of tones. This led OHM to assert that each sensation of tone corresponded to a sinusoid vibration and that complex vibrations were analyzed by the organ of hearing into a harmonic series of sinusoids resulting in a mental complex of harmonic tones.[1] Although refuted by SEEBECK, this hypothesis was used by HELMHOLTZ[2] as the basis of his theory of the action of the ear. The hypothesis is certainly incorrect when applied to sensations. To the mind the tone from a violin is just as simple as that from a tuning fork or an organ, yet the analysis of the vibration into a series of sinusoids would give results differing greatly in complexity. Moreover, the mind executes no such analysis; the physical differences represented by combinations of sinusoids appear as the property of timbre. Finally, physical speech vibrations cannot be treated as a series of sinusoids, and yet the ear hears tones in speech. Moreover, the explosive tones from the siren differ with the character of the explosion. When elliptical or triangular holes and mouthpieces are used, the resulting tones differ greatly in character with no apparent presence of overtones.[3]

The range of pitch that can be heard by the ear is confined between fairly definite limits;[4] the lowest limit for a series

[1] SEEBECK, *Beobachtungen über einige Bedingungen der Entstehung von Tönen*, Ann. d. Phys. u. Chem., 1841 LIII 417; OHM, *Ueber die Definition des Tones, nebst daran geknüpfter Theorie der Sirene und ähnlicher tonbildender Vorrichtungen*, Ann. d. Phys. u. Chem., 1843 LIX 497; SEEBECK, *Ueber die Sirene*, Ann. d. Phys. u. Chem., 1843 LX 449; OHM, *Noch ein Paar Worte über die Definition des Tones*, Ann. d. Phys. u. Chem., 1844 LXII 1; SEEBECK, *Ueber Schwingungen unter Einwirkung veränderlicher Kräfte*, Ann. d. Phys. u. Chem., 1844 LXII 289; *Ueber die Definition des Tones*, Ann. d. Phys. u. Chem., 1844 LXIII 353; *Ueber die Erzeugung von Tönen durch getrennte Eindrücke, mit Beziehung auf die Definition des Tones*, Ann. d. Phys. u. Chem., 1844 LXIII 368.

[2] HELMHOLTZ, Lehre v. d. Tonempfindungen, 5. Aufl., 97, Leipzig, 1896.

[3] SEEBECK, *Ueber d. Erzeugung v. Tönen durch getrennte Eindrücke*, Ann. d. Phys. u. Chem., 1844 LXIII 375.

[4] SAUVEUR, Mém. de l'acad. roy. des sciences, Paris, 1700, p. 140; CHLADNI, Akustik, 2, 36, 294, Leipzig, 1802; SAVART, *Note sur la limite de la perception des*

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of puffs from the siren depends on the intensity. A very low limit of 16 to 30 frequency can be reached by large and powerful forks. The upper limit of pitch can be determined by striking bars or forks of known frequencies [1] or by the GALTON whistle.[2] The ordinary upper limit lies near a frequency of 30,000 for moderately strong tones;[3] it is lowered

sons graves, Ann. de chim. et de phys., 1831 XLVIII 69; DESPRETZ, *Observations sur la limite des sons graves et aigus*, C. r. Acad. Sci. Paris, 1845 XX 1214; MOOS, *Beitrag zur Helmholtz'schen Theorie der Tonempfindungen*, Archiv. f. path. Anat., 1864 XXXI 125; *Patholog. Beobacht. über d. Töne*, Arch. f. Augen- und Ohrenhk., 1872 II (2) 139, Arch. f. Ophth. and Otol., 1873-74 III 113; MAGNUS, *Ein Fall von partieller Lähmung des Corti'schen Organs*, Archiv für Ohrenheilkunde, 1867 II 268; PREYER, *Ueber die Grenzen der Tonwahrnehmung*, Jena, 1876 (also in PREYER's Sammlung physiol. Abhandlungen, I 1, Jena, 1877); TURNBULL, *The limit of perception of musical tones by the human ear*, Boston Medical and Surg. Journ., 1879 C 741; STEFANINI, *Dell' energia minima che è necessaria a produrre la sensazione del suono*, Atti della r. Acc. lucchese, 1888 XXV 239; LOVE, *The limits of hearing*, Journ. Anat. Physiol., 1888 XXIII 336; APPUNN, *Akustische Versuche über die Wahrnehmung tiefer Töne*, Jahresb. d. Wetterau'schen Gesellsch., 1889; HELMHOLTZ, Die Lehre von den Tonempfindungen, 5. Aufl., 290, Leipzig, 1896; BATTELLI, *Sur la limite inférieure des sons perceptibles*, Arch. Ital. de Biol., 1897 XXVII 202; SCHÄFER, *Die Bestimmung d. unteren Hörgrenze*, Zt. f. Psych. u. Phys. d. Sinn., 1899 XXI 161.

[1] KŒNIG, Catalog, Paris, 1889; Ann. d. Phys. u. Chem., 1899.

[2] GALTON, Inquiries into Human Faculty, 38, London, 1883; STUMPF UND MEYER, *Schwingungszahlbestimmungen bei sehr hohen Tönen*, Ann. d. Phys. u. Chem., 1897 LXI 760; SCHWENDT, *Exper. Bestimm. d. Wellenlänge u. Schwingungszahl höchster hörbarer Töne*, Arch. f. d. ges. Physiol. (Pflüger), 1899 LXXV 346, also in Verh. d. naturf. Ges. Basel, 1900 XII 149; EDELMANN, *Fortschritte in der Herstellung der Galtonpfeife*, Zt. f. Ohrenheilkde., 1900 XXXVI 330; *Studien über d. Erzeugung sehr hoher Töne vermittelst d. Galtonpfeife*, Ann. d. Phys. u. Chem., 1900 II 469.

[3] CHLADNI, Die Akustik, 24, Leipzig, 1802; SAUVEUR, Mém. de l'acad. roy. des sciences, Paris, 1700, p. 140; SAVART, *Notes sur la sensibilité de l'organe de l'ouïe*, Ann. de chim. et de phys., 1830 XLIV 337; DESPRETZ, *Observations sur la limite des sons graves et aigus*, C. r. Acad. Sci. Paris, 1845 XX 1214; SCHWARTZE, *Totaler Verlust des Perceptionsvermögens f. hohe Töne nach heftigem Schalleindruck*, Archiv f. Ohrenh., 1864 I 136; GOTTSTEIN, Ueber den feineren Bau und die Entwickelung der Gehörschnecke beim Menschen und den Säugethieren, Bonn, 1871; BLAKE, *Summary of the results of experiments on the perception of high musical tones*, Trans. Amer. Otol. Soc., 1872-74; *Diagnostic value of high musical tones*, Trans. Amer. Otol. Soc., 1873 118; *Audibility of high musical tones*, Amer. Journ. Otol., 1879 I 274; BURNETT, *Ein Fall von verminderter Hörbreite*, Archiv f. Augen- und Ohrenheilk., 1877 VI 238; RAYLEIGH, *Acoustical observations; very high notes*, Philos. Mag., 1882 (5) XIII 344; PAUCHON, *Sur la limite supérieure de perceptibilité des sons*, C. r. Acad. Sci. Paris, 1883 XCVI

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for weaker tones,[1] by advancing age,[2] etc. When the upper limit is too low, the perception of certain consonants is defective.[3]

When two sinusoid vibrations of the neighboring frequencies n and n' unite, there is a rise and fall of the vibratory movement with the frequency $b = \pm (n - n')$. These fluctuations, or 'beats,' can be readily heard by sounding two neighboring piano strings.

When the beats have a sufficiently high frequency, they are heard as 'difference' tones[4] with a frequency equal to the difference between the frequencies of the two primaries.[5] HELMHOLTZ'S deduction of difference tones from the asymmetrical vibration of the tympanum has been shown to be inconsistent with the facts.[6] Four difference tones can arise from two simultaneous tones under favorable conditions.[7] The first has a pitch of $D_1 = \pm (n - n')$, where

1041; STUMPF, Tonpsychologie, I 414, Leipzig, 1883; LOVE, *The limits of hearing*, Journ. Anat. Physiol., 1888 XXIII 336.

[1] BLAKE, as before, 1872, 1873; SCRIPTURE AND SMITH, *Experiments on the highest audible tone*, Stud. Yale Psych. Lab., 1894 II 105.

[2] BLAKE, as before, 1872, 1873; ZWAARDEMAKER, *Een Wet van ons Gehoor*, Ned. Tydschr. v. Geneeskunde, 1890 737; *Der Verlust an hohen Tönen mit zunehmendem Alter*, Archiv f. Ohrenheilk., 1891 XXXII 53.

[3] MOOS, *Ueber das combinirte Vorkommen mangelhafter Perception gewisser Consonanten, sowie hoher musikalischen Töne und deren physiologische Bedeutung*, Arch. f. Augen- u. Ohrenheilk., 1874 IV 165; MOOS UND STEIBRÜGGE, *Ueber Nervenatrophie in der ersten Schneckenwindung; physiologische und pathologische Bedeutung derselben*, Zt. f. Ohrenheilk., 1881 X 1.

[4] SORGE, Vorgemach musicalischer Composition, Thl. I, Cap. V, § 5, Hamburg, 1745 (this passage is repeated in WINKELMANN, Physik, I, 779, Breslau, 1891); TARTINI, Tratto di musica secondo la vera scienza dell'armonia, Padova, 1754.

[5] HÄLLSTRÖM, *Von den Combinationstönen*, Diss., 1819; also in Ann. d. Phys. u. Chem., 1832 XXIV 438; HELMHOLTZ, *Ueber Combinationstöne*, Monatsber. d. Berliner Akad., 1856, 22 Mai, 279 (reprinted in HELMHOLTZ, Wiss. Abhand., I 256, Leipzig, 1882); *Ueber Combinationstöne*, Ann. d. Phys. u. Chem., 1856 XCIX 497 (reprinted in HELMHOLTZ, Wiss. Abhandl., I 263, Leipzig, 1882); Tonempfindungen, 5. Aufl., 152 and Beilage XII, Leipzig, 1896.

[6] VOIGT, *Ueber den Zusammenklang zweier einfacher Töne*, Nachrichten d. kgl. Ges. d. Wiss. zu Gött., 1890 159; also in Ann. d. Phys. u. Chem., 1890 XL 652; HERMANN, *Zur Theorie der Combinationstöne*, Arch. f. d. ges. Physiol. (Pflüger), 1891 XLIX 499.

[7] KRÜGER, *Beobachtungen an Zweiklängen*, Philos. Stud. (Wundt), 1900 XVI 325.

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n and n' indicate the pitches of the two tones. The second is $D_2 = \pm (n - D_1)$, the third $D_3 = \pm (D_2 - D_1)$, and the fourth $D_4 = \pm (D_3 - D_1)$. A fifth may even occur. It is not yet known if these tones occur in vocal sounds. A summation tone $s = n + n'$ may possibly be present.[1]

When two tones are heard in succession they may appear to be alike; vaguely unlike; unlike in pitch, intensity or quality; or unlike in any two or all three of these properties. Very small differences in one property may be mistaken for differences in another one, as pitch for intensity.

The average amount by which the two tones must differ in order to be generally perceived as unlike is known as the just perceptible difference. To determine the just perceptible difference in pitch, a tone of a certain pitch is first produced, and then another of a slightly different pitch; the hearer states his judgment as to whether the two tones are the same or different.[2] An apparatus for this experiment consists of two forks of the same pitch, with a small weight at the middle of one prong of each fork. Starting with the weights at the middle, whereby both forks give the same tone, one of the weights is moved upward or downward by successive steps. The forks are sounded alternately. When the difference is large enough to be perceived, the two forks are sounded simultaneously, the number of beats giving the number of vibrations by which they differ.

The dependence of the just perceptible difference on the pitch of the tone follows the general rule that the just perceptible difference, expressed in vibrations, is smallest with low tones and largest with high tones without the difference being very great, and that within the range of

[1] HELMHOLTZ, Lehre v. d. Tonempfindungen, 5. Aufl., 254, Leipzig, 1896; KRÜGER, as before, 334.

[2] DELEZENNE, *Mém. sur les valeurs numériques des notes de la gamme*, Recueil des travaux de la Soc. des Sci. de Lille, 1826-27 1; SEEBECK, *Ueber d. Fähigkeit d. Gehörs, sehr kleine Unterschiede d. Tonhöhe zu erkennen*, Ann. d. Phys. u. Chem., 1846 LXVIII 462; PREYER, Akustische Untersuchungen, Jena, 1879.

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the tones usually employed in speech it remains practically constant.[1]

The smaller the difference the greater is the amount of mental work required for its detection. The amount of this work may be measured by 1. the minimum time required to perceive the difference, 2. the time required to respond to the difference, 3. the number of mistakes made in detecting the difference. The first method has been applied to the distinction of visual objects; the two that are to be distinguished are placed behind a screen and exposed for a brief interval, the interval being increased until the difference is perceived. The second method has been applied to visual objects and to sounds. For the latter, two sounds slightly differing in intensity or quality are used. For one of them the person responds in one way, for the other in another way. The number may be indefinitely increased. The greater the number of distinctions required and the smaller the differences, the longer the time required.[2] For the third method the sounds may be given in pairs irregularly in a series with pairs of like sounds. The smaller the difference the greater the number of mistakes.

The sense of hearing is able to distinguish continuous variations in pitch with an accuracy depending on the pitch of the tone varied, its loudness and the rate of variation. Starting with the finger at a certain place on a violin string, we can change the pitch of the tone continuously by sliding it one way or the other.

Following some preliminary observations,[3] the least perceptible change was investigated by STERN.[4] The tone was produced by a current of air blowing over the mouth of a

[1] LUFT, *Ueber die Unterschiedsempfindlichkeit f. Tonhöhen*, Philos. Stud., 1888 IV 511; MEYER, *Ueber die Unterschiedsempfindlichkeit f. Tonhöhen*, Zt. f. Psych. u. Phys. d. Sinn., 1898 XVI 352.

[2] Summary of methods and results in WUNDT, Physiol. Psychol., 4. Aufl., II 362, Leipzig, 1893.

[3] SCRIPTURE, *On the least perceptible variation of pitch*, Amer. Jour. Psych., 1892 IV 580; *Ueber die Aenderungsempfindlichkeit*, Zt. f. Psych. u. Phys. d. Sinn., 1894 VI 472.

[4] STERN, *Die Wahrnehmung von Tonveränderungen*, Zt. f. Psych. u. Phys. d. Sinn., 1896 XI 1, 1899 XXI 30, 1899 XXII 1.

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bottle (*F*, Fig. 63). The change in pitch was brought about by mercury flowing in at the bottom of the bottle and thus, by changing its capacity, raising its pitch. The mercury was sent at a definite rate into the bottle and variator *V* together. The variator had a carefully determined form, such that the rise of the mercury in the bottle produced an even rise of pitch. The various rates at which the tone was altered were produced by different rates of movement of the piston in the reservoir *C*. The tone was begun and gradually raised in pitch until the change was detected. Two types of change were used:

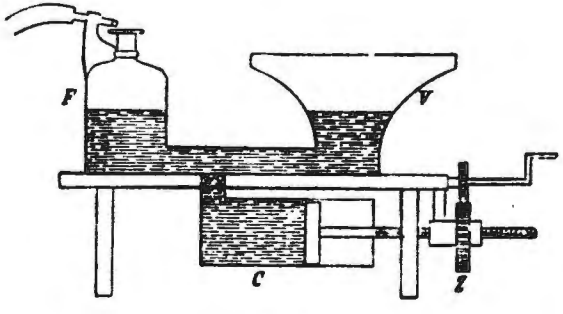

FIG. 63.

the continuous change of pitch _/‾ and the intermitted change (or discrete difference) of pitch _‾. In the former the change from the initial tone to the final one occurred by a slide upward (or downward) in pitch, in the latter there was no sound in the interval. Different rates and extents of change were used with the results: 1. continuous changes were more accurately perceived than the corresponding differences; 2. the clearness with which the change in pitch was perceived increased with the actual extent of change from the initial to the final tone; 3. this increase in clearness was greater for continuous changes; 4. with continuous changes rise in pitch was more clearly perceived than fall in pitch, while the fall in pitch was remarkably well perceived with discrete differences; 5. the accuracy of perception of the likeness of two discrete tones was much less than that of the constancy of pitch of a

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continuous tone; 6. the accuracy of perception of the likeness of two successive tones was less than that of the difference of two successive tones; 7. the accuracy of perception increased as the change in pitch became slower.

The application of these facts to the changes in the cord tone in speech is apparent. For example, the lack of the ability to perceive the variations that may arise in a long sound permits a long vowel to gradually change its nature and finally to become a sound that has an ending quite different from its beginning, that is, a diphthong. This is probably the auditory factor that in Southern British English permits most long vowels to become diphthongs although the spelling remains the same and the diphthongization is unconsciously done; thus, 'so' is pronounced as sou, 'fate' as feit, etc., and even long i and long u show similar tendencies.[1]

Every sound may be said to have its range of likeness or its limits of imperceptible difference. Thus, a tone may vary within certain limits without any perception of its variation. Any one of the resonance tones constituting a vowel may vary in pitch, intensity or duration without a perception that the sound is different. Since each element may change imperceptibly in any direction the timbre, that is, the vowel character, may gradually change to a quite different one.

The judgments of likeness of objects depend upon the coincidence of similar elements. Two tones are judged to be alike in pitch if the two sensations of pitch coincide.

The judgment of likeness is made with a feeling of certainty that varies from absolute certainty to complete uncertainty. One person will feel absolutely sure that two tones are exactly alike in pitch, another will feel less certain about it, still another will feel somewhat doubtful and a third will feel quite uncertain, — all of them feeling the likeness and not perceiving any difference whatever. Similar differences in degree of certainty will be felt by one person on different occasions. This judgment of likeness with different degrees of certainty is quite different from the judgment of closeness of approach to likeness or of the degree of unlikeness.

[1] SOAMES, Introduction to Phonetics, 2d ed., 48, London, 1899.

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Investigations on these points are still lacking. They might be readily carried out with tones according to the method of equality judgments (or of the so-called method of right and wrong cases).[1] The improved method of computation gives definite results.[2]

Large differences of pitch can be judged with considerable accuracy. Equal differences of frequency of vibration appear as equal differences of pitch.[3] For example, the tone 384 is selected as halfway between 256 and 512, or 360 as halfway between 296 and 424, giving the relations 2 : 3 : 4 and 37 : 45 : 53.

Certain special relations of pitch produce the musical intervals. The simpler intervals include the unison (1 : 1), octave (1 : 2), fifth (2 : 3), fourth (3 : 4), major sixth (3 : 5), major third (4 : 5), minor third (5 : 6), minor sixth (5 : 8), minor seventh (5 : 9), major second (8 : 9), major seventh (8 : 15), minor second (15 : 16), also the duodecime (1 : 3), double octave (1 : 4), etc.

The musical intervals can be estimated with a degree of accuracy that depends on the individual and on various conditions.[4]

The just perceptible difference from a simple interval may be determined by comparing two tones, one fixed and

[1] FECHNER, Elemente d. Psychophysik, 2. Aufl., 134, Leipzig, 1889; MÜLLER, Zur Grundlegung d. Psychophysik, Berlin, 1878; WUNDT, Grundzüge d. physiol. Psychol., 4. Aufl., 348, Leipzig, 1893.

[2] BRUNS, *Ueber d. Ausgleichung statistischer Zählung in der Psychophysik*, Philos. Stud. (Wundt), 1893 IX 1; briefly indicated in SCRIPTURE, New Psychology, 269, London, 1897; MOSCH, *Zur Methode d. richtigen u. falschen Fälle im Gebiete d. Schallempfindungen*, Philos. Stud. (Wundt), 1898 XIV 491.

[3] LORENZ, *Untersuchungen über d. Auffassung v. Tondistanzen*, Philos. Stud. (Wundt), 1890 VI 26 (discussed in Zt. f. Psych. u. Phys. d. Sinn., 1890 I 419, 1891 II 266; Philos. Stud., 1891 VI 604, 1892 VII 298); WUNDT, Grundz. d. physiol. Psychol., 4. Aufl., 463, Leipzig, 1893.

[4] DELEZENNE, *Mém. sur les valeurs numériques des notes de la gamme*, Recueil des travaux de la Soc. des Sci. de Lille, 1826-27 1; CORNU ET MERCADIER, *Sur les intervalles musicaux*, C. r. Acad. Sci. Paris, 1869 LXVIII 301, 424; PRETER, Ueber d. Grenzen d. Tonwahrnehmung, 38, Jena, 1876; SCHISCHMANOW, *Untersuchungen über die Empfindlichkeit des Intervallsinnes*, Philos. Stud. (Wundt), 1889 V 558; STUMPF UND MEYER, *Maassbestimmungen über d. Reinheit consonanter Intervalle*, Zt. f. Psych. u. Phys. d. Sinn., 1898 XVIII 321.

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the other varied, with pitch numbers corresponding to the relations of frequency required by the interval. The just perceptible difference increases generally in the order of unison, octave, fifth, fourth, major sixth, major third, minor third, major second, minor sixth, minor seventh, major seventh.[1] Individual differences appear in the intervals of the fourth, third and sixth.[2]

Related to the just perceptible difference is the accuracy in judging the exactness of an interval. It may be determined by using one fixed and one varied tone and requiring a judgment on each occasion concerning the correctness or incorrectness of the relation. This accuracy is nearly the same for all the usual musical intervals.[3] An increase in a consonant interval is accompanied by a feeling of tension, sharpness or irritation; a decrease by one of depression, shallowness or dullness.[4] A slightly increased major third ($4:5^+$) and a slightly decreased minor third ($5:6^-$) and also a slightly increased octave ($1:2^+$) and fifth ($2:3^+$) are preferred by the ear to the exact intervals.[5]

The presence of overtones diminishes the accuracy of judgment of intervals; this accuracy is the same for the third, the fifth and the octave; there is a general tendency to increase the major third, the fifth and especially the octave; the intervals of simultaneous tones are much less accurately judged than those of successive tones; with simultaneous tones there is a special tendency to increase the interval.[6]

Coinciding overtones in the consonant intervals probably have some effect on their character. Most musical in-

[1] SCHISCHMANOW, as before, 596.

[2] PREYER, as before, 38.

[3] STUMPF UND MEYER, as before; BUCH, *Ueber die Verschmelzung von Empfindungen, besonders bei Klangeindrücken*, Philos. Stud. (Wundt), 1900 XV 267; FAIST, *Versuche über Tonverschmelzung*, Zt. f. Psych. u. Phys. d. Sinn., 1897 XV 102; MEINONG UND WITASEK, *Zur experimentellen Bestimmung d. Tonverschmelzungsgrade*, same, 189.

[4] PLANCK, *Die natürliche Stimmung in der modernen Vocalmusik*, Viertelj. f. Musikwiss., 1893 IX 418; STUMPF UND MEYER, as before, 392.

[5] STUMPF UND MEYER, as before, 396.

[6] STUMPF UND MEYER, as before, 400.

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struments produce notes, or tone-complexes, consisting of partials with frequencies in the relations 1, 2, 3, 4, 5, 6, . . . Two notes with fundamentals in the relation 1 to 2 (octave) will have the partials $\left\{\begin{smallmatrix}1&&2&&3&&4&&5&&6&&7&&8&&9&&10\\&2&&&&4&&&&6&&&&8&&&&10\end{smallmatrix}\ldots\right\}$. Two notes with the relation 2 to 3 (fifth) will have the partials $\left\{\begin{smallmatrix}2&&4&&6&&8&&10&&12&&14&&16&&18&&20\\&3&&6&&9&&12&&15&&18&&\ldots\end{smallmatrix}\right\}$. The relation 3 to 4 (fourth) gives $\left\{\begin{smallmatrix}3&&6&&9&&12&&15&&18&&21&&24&&27&&30\\&4&&8&&12&&16&&20&&24&&28&\ldots\end{smallmatrix}\right\}$.

The other consonant intervals less than an octave have less and less coincidence of their partials, in the order mentioned on p. 104. The coincidence of the overtones was assumed by HELMHOLTZ[1] as the basis of the feeling of gratification that accompanies consonant intervals. The consonant intervals may appear 1. in a succession of tones, whereby the coinciding partials occur as repetitions, or 2. in simultaneous tones, whereby the coinciding partials become stronger.

When two tones differing in pitch up to about a major second are sounded together, the result appears as a tone of intermediate pitch[2] with beats. With a great difference in pitch, the result appears as a combination of two tones.[3]

The shortest time during which a tone must be produced depends on whether it is to be heard 1. as an indefinite sound, 2. as a tone, or 3. as a tone of a definite pitch. The three degrees of recognition involved in these problems require successively longer times; only the second problem has been investigated.

A sensation of tone can be produced by a small number of tuning fork vibrations,[4] under favorable circumstances by 1.6, for the higher tones, to 5, as the scale is descended;[5] or by

[1] HELMHOLTZ, Lehre v. d. Tonempfindungen, 5. Aufl., 310, Leipzig, 1896.

[2] STUMPF UND MEYER, as before, 321.

[3] KRÜGER, as before, 324.

[4] MACH, *Physikalische Notizen*, Lotos, 1873, 23; EXNER, *Zur Lehre v. d. Gehörsempfindungen*, Arch. f. d. ges. Physiol. (Pflüger), 1876 XIII 228; AUERBACH, *Ueber die absolute Anzahl von Schwingungen, welche zur Erzeugung eines Tones erforderlich sind*, Ann. d. Phys. u. Chem., 1879 VI 591; GELLÉ, *De la durée de l'excitation sonore nécessaire à la perception*, C. r. Soc. de Biologie, 1886 (8) III 38.

[5] SCHÜLZE in WUNDT, Grundzüge d. physiol. Psychol., 4. Aufl., 451, Leipzig, 1893.

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a small number of puffs of air,[1] the minimum being two according to most experimenters. An electric fork in front of a spherical resonator can be used to produce a simple tone, which can be carried to the ear in a distant room by a rubber tube. A stopcock in the tube can be made to turn on the sound for a definite time.[2] The shortest audible vowels have never been determined. The experiment might be made in a similar way or by closing the secondary circuit for definite intervals while a vowel is being transmitted by a telephone from a talking machine.

Sounds enter consciousness more or less gradually. The tone rises suddenly to near its maximum and then increases gradually for some time. A tone c increases in its intensity for about 48 vibrations, a tone c^{-1} for about 44 vibrations.[3] Weak sounds may require even 1^s to 2^s to reach the maximum.[4]

A sound persists in consciousness after the external vibration has ceased. If a tone is produced for a very short time at stated intervals, the tone actually heard will be a little longer in proportion to the silence than is the case physically. If the silences are now made successively smaller, the moment will come when the persistence of the tone will cover the physical silence and the sound will no longer be heard as interrupted but as continuous. A fork giving the desired tone is kept in vibration electrically before its corre-

[1] PFAUNDLER, *Ueber d. geringste Anzahl v. Schallimpulsen, welche zur Hervorbringung eines Tones nöthig ist*, Sitzber. d. k. Akad. d. Wiss. Wien, math.-naturw. Kl., 1879 LXXVI 2. Abth., 561; KOHLRAUSCH, *Ein Beitrag zur Kenntniss der Empfindlichkeit des Gehörsinnes*, Ann. d. Phys. u. Chem., 1879 VII 335; *Ueber Töne, die durch eine begrenzte Anzahl von Impulsen erzeugt werden*, Ann. d. Phys. u. Chem., 1880 X 1; CROSS AND MALTBY, *On the least number of vibrations necessary to determine pitch*, Proc. Amer. Acad. Arts and Sci, 1891-92, 222; HERROUN AND GERALD, *Note on the audibility of single sound waves, and the number of vibrations necessary to produce a tone*, Proc. Roy. Soc. Lond., 1802 L 318; ABRAHAM UND BRUHL, *Wahrnehmung kürzester Töne und Geräusche*, Zt. f. Psych. u. Phys. d. Sinn., 1898 XVIII 176.

[2] SCHÜLZE, as before.

[3] EXNER, *Zur Lehre v. d. Gehörsempfindungen*, Arch. f. d. ges. Physiol. (Pflüger), 1876 XIII 234.

[4] URBANTSCHITSCH, *Ueber d. An- und Abklingen akustischer Empfindungen*, Arch. f. d. ges. Physiol. (Pflüger), 1881 XXV 323.

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sponding resonator (p. 14); a disc with openings in it at regular intervals revolves between them. From the smaller end of the resonator a tube leads to the ear, the other ear being closed. The sound can reach the ear only when one of the openings is opposite the fork. The disc is revolved at a constantly increasing rate till, instead of a succession of sounds, the tone of the fork is heard as a continuous sound.[1] When this occurs, each sound must persist mentally in nearly full intensity long enough to fill the silent physical interval. The time can be calculated from the speed of the disc. These intervals as determined by MAYER were for c^{-1}, 0.0395"; c^0, 0.0222"; c^1, 0.0142"; g^1, 0.0098"; c^2, 0.0076"; e^2, 0.0065"; g^2, 0.0060"; c^3, 0.0055". Starting with an interval so short that the tone appeared unbroken and increasing it until it appeared of irregular intensity, URBANTSCHITSCH found this interval to vary from 0.012" for low tones to 0.006" for high ones.[2] This would indicate the minimum time necessary in order to produce a tremolo effect. High tones are relatively louder to the ear than low ones; for equally loud tones the time of persistence is probably constant.[3]

Measurements might profitably be made of the perceptibility of speech elements as judged by the minimum time they must last in order to be recognized. The methods would be analogous to those used for printed letters.[4]

When two tones are alternated as in a trill, they must each last at least about 0.03" in order to be heard with the trill effect; the figure remains nearly the same for all regions of

[1] MAYER, *Acoustical investigations: I. Determination of the law connecting the pitch of a sound with the duration of its residual sensation*, Amer. Jour. Sci., 1874 VIII 241; *A redetermination of the law connecting the pitch of a sound with the duration of its residual sensation*, Amer. Jour. Sci., 1875 IX 267.

[2] URBANTSCHITSCH, *Ueber das An- und Abklingen akustischer Empfindungen*, Arch. f. d. ges. Physiol. (Pflüger), 1881 XXV 323.

[3] ABRAHAM, *Ueber d. Abklingen v. Tonempfindungen*, Zt. f. Psych. u. Phys. d. Sinn., 1899 XX 417.

[4] CATTELL, *Ueber d. Trägheit d. Netzhaut u. d. Sehcentrums*, Philos. Stud. (Wundt), 1886 III 94; SANFORD, *The relative legibility of small letters*, Amer. Jour. Psychol., 1888 1 402; JAVAL, Rev. scientifique, 1881 XXVII 802; summary in SCRIPTURE, New Psychology, Ch. VI, London, 1897.

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the scale and for all differences of pitch between the tones.[1] A succession of notes can be heard when each tone lasts at least 0.03".

The energy, or the physical intensity, of a sound wave is defined as the work done by it in passing through a unit surface in a unit time. It is directly proportional to the square of the amplitude and inversely to the square of the period (or directly to the square of the frequency).[2]

The relation between the energy and the mental intensity is not a simple one. Under constant conditions a tone of a given frequency will increase and decrease in apparent loudness as its physical intensity increases and decreases. The relation is fairly well expressed by saying that the mental intensity varies as the logarithm of the physical intensity,[3] a relation that has been established for certain tones.[4] The exact expression of the relation is $I = C \lg E$, where I is the intensity of the sensation, E the physical intensity of a tone of a certain pitch, and C a personal constant, and where lg indicates the logarithm with the basis e (natural, not BRIGGS'S logarithm). It is not known if this relation holds true when tones of different pitches are compared.

The faintest audible degrees of tones, noises and speech sounds can be determined with considerable accuracy by the differential audiometer. This is a development from the induction balance.[5] A secondary coil S (Fig. 64) connected to a telephone T is placed between two oppositely wound primary coils PP in series with each other and a microphone M (transmitter). A current is sent from a battery (the figure shows a lamp battery DE in connection with the dynamo cir-

[1] ABRAHAM UND SCHÄFER, *Ueber d. maximale Geschwindigkeit v. Tonfolgen*, Zt. f. Psych. u. Phys. d. Sinn., 1899 XX 408.

[2] RAYLEIGH, Theory of Sound, II 17, § 245, London, 1899.

[3] FECHNER, Elemente der Psychophysik, 2 Aufl., Leipzig, 1889.

[4] WIEN, *Ueber die Messung der Tonstärke*, Diss., Berlin, 1888; also in Ann. d. Phys. u. Chem., 1889 XXXVI 834.

[5] HUGHES, *On an induction-currents balance, and experimental researches made therewith*, Proc. Royal Soc. Lond., 1879, May 15; reported in NATURE, 1879 XX 77.

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cuit) through the primary coils *PP*. Sounds entering the microphone *M* cause fluctuations and interruptions of the current in the primary coils *PP*, whenever the circuit is closed at *K*. If the secondary coil *S* is placed near one of them, the sound will be heard in the telephone *T*. As the secondary is moved away from the primary, the sound decreases, becoming zero at the middle where the effects of the primaries neutralize each other. A scale showing the distance of the secondary coil from the middle can be used to indicate degrees of intensity of the sound; the intensity is not pro-

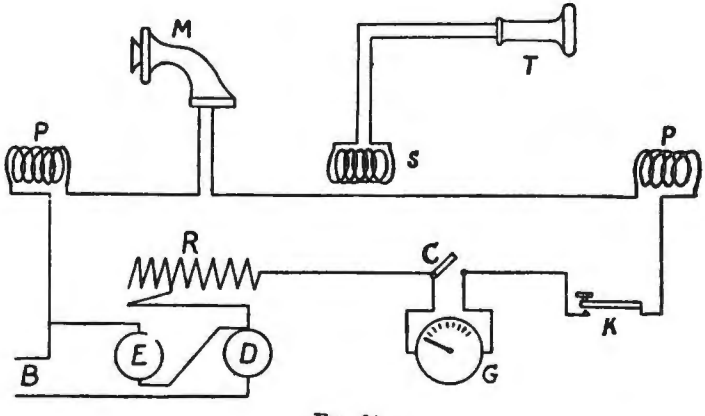

FIG. 64.

portional to the distance. Pressure on the key *K* closes the primary circuit and sets the audiometer in operation. With a constant source of current the measurements on different occasions may be made comparable. The figure shows an ammeter *G* for testing the current and a resistance *R* for regulating it; the microphone should be short-circuited when this is done. The ammeter can be short-circuited when the audiometer is being used. By means of a phonograph or gramophone record in fixed connection with the transmitter the initial sounds may be kept constant. The telephone of the audiometer may be placed in a distant room so that the person tested is in no way disturbed. This instrument has

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not yet been applied to the study of speech, although it would furnish accurate measurements of the audibility of speech sounds singly and connectedly under the most varied conditions of enunciation. For ordinary tests of hearing the microphone is omitted and clicks are produced in the telephone by closures at *K*.

A less accurate method of determining the faintest audible sound consists in removing the source of the sound to different distances. Accurate but rather complicated methods of measuring the intensities of tones have been devised by WIEN [1] and SHARPE.[2]

The faintest audible tone of the frequency 240 was determined by WIEN with his special apparatus. Its energy amounted to $0.068^{\mu\mu mg}$, which means that the energy of the air vibration striking the tympanum was equal to the energy represented in a weight of 1^{mg} falling through $0.068^{\mu\mu}$ ($\mu\mu$ = millionth part of a millimeter, mg = milligram).

The just perceptible difference in intensity varies proportionately with the loudness of the tone [3] or the noise.[4]

Among the other mental properties of sounds the objectivity and the emotional tinge may be mentioned. The objectivity of a tone is a property expressing the degree to which we consider the tone not to belong to ourselves. A tone produced in imagination, as in mentally singing a score, has

[1] WIEN, *Ueber d. Messung d. Tonstärke*, Diss., Berlin, 1888; also in Ann. d. Phys. u. Chem., 1889 n. F. XXXVI 834.

[2] SHARPE, *A double instrument and a double method for the measurement of sound*, Science, 1899 N. S. IX 808.

[3] WIEN, as before.

[4] VOLKMANN in FECHNER, Elemente d. Psychophysik, 2. Aufl., I 479, Leipzig, 1889; RENZ UND WOLF, *Versuche über d. Unterscheidung differenter Schallstärken*, Arch. f. physiol. Heilk., 1856 XV 185; TISCHER, *Ueber die Unterscheidung von Schallstärken*, Philos. Stud. (Wundt), 1883 I 495; MERKEL, *Das psychophysische Grundgesetz in Bezug auf Schallstärken*, Philos. Stud. (Wundt), 1888 IV 117, 251; *Die Abhängigkeit zw. Reiz u. Empfindung*, Philos. Stud. (Wundt), 1888 IV 541, 1889 V 245, 499; STARKE, *Die Messung von Schallstärken*, Philos. Stud. (Wundt), 1886 III 264; *Zum Mass der Schallstärke*, Philos. Stud. (Wundt), 1889 V 157; ANGELL, *Untersuchungen über d. Schätzung von Schallintensitäten*, Philos. Stud. (Wundt), 1892 VII 414; KÄMPFE, *Beitr. zur exper. Prüfung d. Methode d. richt. u. falschen Fälle*, Philos. Stud. (Wundt), 1893 VIII 511.

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almost no objectivity; it is attributed to our innermost self. Tones actually sung by ourselves are more objective; those sung by others are highly objective, though even here the degree of objectivity increases with the strangeness of the singer, the distance, etc. It is quite possible that the degree of objectivity depends closely on the action of the muscles connected with the voice and on the sounds heard by the ear. Even in internal song and speech the vocal organs execute minute movements, which can be registered.[1] Weak movements with no sounds heard would mean little objectivity. Stronger movements as in actual singing and speaking with sounds heard would have more objectivity. Sounds heard when no movements are made by ourselves would have more nearly complete objectivity.

The sound mass that we experience at any moment is generally resolved by us mentally into groups of sounds; thus, in the music of an opera we attribute certain portions to the singer, others to the violins, others to the horns, etc. Much of this analysis can be attributed to the results of past experiences; the analysis of tone complexes, however, seems to be a fundamental process. The nature and laws of the mental analysis are still experimentally uninvestigated and little can be said beyond the facts obtainable by unaided observation.

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For acoustical apparatus: Kœnig, Paris. For magnetic markers: Petzold, Leipzig; Zimmermann, Leipzig; Verdin, Paris. For the Galton whistle: Edelmann, München.

[1] Curtis, *Automatic movements of the larynx*, Amer. Jour. Psychol., 1900 XI 237.

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CHAPTER IX

PERCEPTION OF SPEECH ELEMENTS

EACH individual has a system of auditory habits in the sense that the various speech sounds are more or less familiar to his ear. These auditory habits are intimately connected with his habits of speech. Just as the latter have been termed the 'basis of articulation' (SIEVERS [1]), so the former may be called the 'basis of aural perception' (OERTEL [2]); the united system of habits may be expressed by the term 'basis of speech,' or 'phonetic basis.' Each individual has his own phonetic basis. The bases of the members of a community are closely alike, and we may speak of the phonetic basis of a community. In like manner the various languages may each be said to have its peculiar phonetic basis.

Just what vocal sound is perceived by the ear depends largely on the sensitiveness to differences (p. 100) and on the past sounds that are most familiar. A perfectly strange language appears to a great extent as a murmur of indefinite sounds; it is only by familiarity with definite sound-groups that the ear learns to recognize the separate sounds. Finer discrimination usually occurs only when the vocal organs are used to imitate the sounds, and the results of a person's own efforts are compared with the sounds imitated. The finest discrimination occurs when special training is directed to it.

The experiments of MÜLLER and PILZECKER [3] in learning, by seeing and speaking, various series of syllables, each with a

[1] SIEVERS, Grundz. d. Phonetik, 4. Aufl., 105, Leipzig, 1893.

[2] OERTEL, Lectures on the Study of Language, 241, New York, 1901.

[3] MÜLLER UND PILZECKER, *Experimentelle Beiträge zur Lehre vom Gedächtniss*, Zt. f. Psychol. u Physiol. d. Sinn., 1901, Ergänzungsband I, 247.

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vowel between two consonants, showed that the best remembered (or most impressive) sounds were the vowels, then the initial consonants, then the final consonants; that for persons who learned mainly by the ear the German vowels and diphthongs appeared in the following order of decreasing effectiveness, ɔi, œ, i, ai, e_2 (*äh*), y, au, o, ā, e_1 (*eh*), ă, u, depending evidently on their acoustic impressiveness and on their impressiveness through relative lack of frequency in speech; that for persons not inclined to ear-learning the order of decreasing effectiveness was ā, e_1, ai, au, y, ă, o, œ, ɔi, e_2, i, u; that for the former class the order for the final consonants was š, p, z, m, t, f, χ or ç, n, l, r, k, s; and for the latter class š, χ or ç, z, p, n, l, t, s, k, f, m, r; that no regular arrangement of impressiveness could be made for the initial consonants. These seem to be the only experiments yet made on what we may venture to call the 'acoustic impressiveness of vocal sounds;' the investigation should be extended on account of its important bearings on the methods of teaching language and on the study of speech changes; the methods of experimenting are described in Ch. XIV below.

Just as the intensity of a sound diminishes with the distance from its source, so does the amount of the just perceptible difference change also for some reason when weak speech sounds are heard at different distances. The relative distances at which the average ear can perceive and distinguish various German speech sounds under average conditions have been approximately determined by WOLF.[1] The vowel a is heard furthest; then at decreasing distances there follow o, ai, e, i, au, u, š, m, n, s, f, k, t, r, b and h.

When whispering sounds so that at 8^m none could be understood by a listener, ROUSSELOT[2] found by steadily decreasing the distance that at a little less than 8^m i was heard; at 7.2^m kə was heard; at 7^m gə was heard as kə but weaker;

[1] WOLF, *Neue Untersuchungen über Hörprüfung und Hörstörungen*, Arch. f. Augen- u. Ohrenheilk., 1873 III (2) 35.

[2] ROUSSELOT, *Les modifications phonétiques du langage*, 38, Rev. des pat. gallo-rom., 1891 IV, V; also separate.

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at 6^m u; at 6.55^m žə and šə as šə; at 6.10^m bə and pə as bə; at 5^m a; at 5.62^m tə; at 5.46^m də as weaker tə, bə and pə as pə; at 5.15^m sə and zə as sə; at 5^m žə distinct from šə; at 4.90^m fə; at 4.68^m və as weaker fə; after 3^m e as i or e; at 2^m mə as pə or bə; also at 2^m e distinct from i; also at 2^m o, œ, nə, lə, rə; at 1^m mə; also at 1^m pə always distinct; at 0.50^m u, və as fə or və; at 0.25^m bə and pə almost completely distinct, fə always distinct, və nearly always correctly, də distinct; at 0.10^m gə almost always correctly, bə, pə, fə, və, tə, də always distinct; at 0.05^m gə with perfect clearness; even with the lips at the ear sə and zə indistinct.

With an ordinary voice such that no sound was clear at 9.60^m ROUSSELOT found that the hearer understood a, e, i, o, y, at 9^m; pə, kə, tə at 8.55^m; bə, šə, sometimes sə, rarely fə at 7.10^m; sə and fə very distinctly at 7^m; də, mə, nə at 6^m; žə, gə at 5.70^m; zə at 5.50^m; və, u, œ at 5^m.

The property of speech sounds illustrated by the experiments of WOLF and ROUSSELOT I venture to term their 'acoustic penetration.' These two isolated sets of results for particular voices on particular occasions furnish suggestions for systematic investigations of the penetrative power of the various sounds of a given language, of a given speaker or singer, of given conditions of mind and body, and of given methods of speaking; and of various national habits of speech perception, of various habits of listening, etc. In future investigations it may be found advisable to use a phonograph or gramophone as a constant source of sound, and also to use the audiometer method of weakening it (p. 109).

The perception of a sound is greatly influenced by associative suggestions. Elements are unconsciously modified, suppressed or created. Even hallucinations of weak tones supposed to be physically present can be readily produced in nearly all normal individuals by appropriate suggestions from the surroundings.[1] The suggestive influence of phonetic habits

[1] SEASHORE, *Measurements of illusions and hallucinations in normal life*, Stud. Yale Psych. Lab., 1895 III 1.

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is marked in causing sounds to be heard differently. ROUSSELOT[1] relates that his sister heard **moⁿpovpjare** 'mon pauvre Pierret' quite correctly, but heard **popovpo** as **popofpo**, the **v** appearing as **f** before **p** when there was no suggestion from the meaning. A record of the sounds noted in an attempt by various Germans at recording some French words at dictation showed[2] effects of suggestion from the native language such as to produce **rəvəne, revni** and **rəvne** for **rvəni, par** for **pa**, etc. Innumerable examples have been reported in studies of the speech of children and of the attempts of persons, tribes and nations to acquire foreign words.[3]

Associative suggestion can be used to increase the accuracy of perception of sounds. ROUSSELOT,[4] after two months of careful phonetic observation, perceived for the first time the differences between the speech of his mother and that of himself, and noted that a regular progression in change of dialect could be heard in the speech of father, son, and grandson every time he was able to get together the members of a family; and also that steps of phonetic change occurred from village to village. A specimen of this latter form of change is found in the pronunciations of 'lapin' in various neighboring villages in France: **lapeⁿ** (Dinan), **japeⁿ** (St. Carné), **japeⁿ** (Meillac), **lapiⁿ** (Corseul), **lapeⁿ** (Quessoy), **lapaⁿ** (Moncontour), **lapeⁿ** (Plénée-Jugon), **lapeⁿ** (Cesson).

The faults of perception may be illustrated by a series of tests made on 530 pupils of presumably somewhat varied nationalities in a Boston public school.[5] The ages ranged from 8 to 14; only 5 were found to be somewhat deaf to the sound of a tuning fork. The records for a series of spoken monosyllables included the following specimen results:

'fan' was recorded as: fan (511 times), than (5), fair (4), thank (3), fell (2), — (2), clams (1), fang (1), sam (1);

[1] ROUSSELOT, *Les modifications phonétiques du langage*, 40, Rev. des. pat. gallo-rom., 1891 IV, V; also separate.

[2] ROUSSELOT, Principes de phonétique expérimentale, 37, Paris, 1897.

[3] OERTEL, Lectures on the Study of Language, 242, New York, 1901.

[4] ROUSSELOT, Principes de phonétique expérimentale, 43, Paris, 1897.

[5] WILTSE, *Experimental*, Amer. Jour. Psych., 1888 I 702.

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'log' was recorded as: log (434), love (65), — (10), flog (3), dog (3), cock (2), long (1), lo (1), lack (1), lawl (1), lord (1), lull (1), lock (1), lough (1), loud (1), lode (1), glove (1), bog (1), bare (1);

'long' was recorded as: long (497), — (11), lawn (4), log (3), loan (3), lamb (2), alarm (1), arm (1), kong (1), lung (1), lant (1), length (1), lul (1), love (1), lone (1), laugh (1);

'pen' was recorded as: pen (386), hen (48), pan (47), hand (13), ham (5), pain (4), pine (3), pail (3), head (2), paper (1), paint (1), pear (1), pland (1), can (1), han (1), land (1), ream (1), ten (1), then (1);

'dog' was recorded as: dog (519), dug (3), dove (3), dod (1), dollie (1), god (1), dull (1);

In order to furnish any useful information such results must be carefully analyzed. This analysis cannot be based upon the printed forms and the conventional orthography, but upon the actual pronunciations. It is sounds not letters which must be classified. The record of 'fan' would show the following apparent representation of the three sounds f, æ, n which make up the word:

f is reflected 518 times by f, 5 times by ð, 3 times by θ, once by s, once by kl; æ is reflected 522 times by æ, four times by ɛ̄, twice by e; n is reflected 516 times by n, 4 times by r or ə, 3 times by ŋk, twice by l, and once each by ŋ, m, and mz.

But a careful consideration of these results will show that the sounds which reflect f, æ and n, are by no means always due to a faulty perception of these sounds. Many times the child had evidently missed the sound altogether, and substituted for it some other sound which, together with the other sounds heard, would make a word. Such cases of sound-substitution are entirely different from those where a sound is misheard. In 'than' for 'fan' we have undoubtedly a *lapsus auris* (the reverse of that which transformed 'Theodor' in Russian into 'Fedor,' and vulgar English 'nothing' into 'nuffin'). In 'clams' for 'fan' f was not misheard as kl; the child un-

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doubtedly heard only the meaningless sound æn which called up the sound-memory of 'clams' and this was written down.

Carefully gathered results of this kind would indicate approximately the relative likenesses of the sounds used to the wrongly heard sounds. The errors in perception show some curious resemblances to the errors of child-speech and to historical phonetic changes. Further investigation of such phenomena is highly desirable.

The perception of a speech sound depends on the ability to produce it. Children and foreigners do not hear the inaccuracies of their own pronunciations. Stammering children often reach an advanced age without discovering their defect; some come to the laryngologist for cure because they find their speech unintelligible to others although they do not perceive any peculiarities in their own sounds. A case is known of a young man with a falsetto voice who had never perceived the peculiarity.

A speech sound produced by an individual is the result of a very large number of fine adjustments of the speaking apparatus influenced by an infinitude of past and present experiences in hearing, thinking and speaking. The sound varies from moment to moment and from one occasion to another. With sufficiently accurate methods of measurement no two sounds would be found alike; the variations are limited by the ability to perceive the differences.

Owing to the inaccuracies of sensation, sounds in close succession may differ without the difference being perceived. Owing to the inaccuracies of movement, sounds intended to be alike will differ from each other. Owing to the increase of variation in action and in the least perceptible difference in hearing when sounds are repeated at increasing intervals, they may on different occasions differ widely although considered to be the same. Records of different individuals show[1] that language elements supposed to be identical are often notably different within the same dialect

[1] JOSSELYN, *Étude sur la phonétique italienne*, 172, Thèse, Paris, 1900; also in La Parole, 1901 III 251.

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and that the same language element is often pronounced in very different ways by the same individual.

With the formation of habits the vocal organism (mental, nervous and muscular) acts within a steadily decreasing range of variation. With the repetition of an auditory stimulus the range of variations unnoticed by the sense of hearing becomes more limited. With a source of comparison, such as a phonograph record or the speech of a person or of a community, the individual keeps the more closely to an average in reproduction the more carefully and repeatedly he makes his comparisons. These factors tend to maintain a sound at a constant average, and, in case of a steadily progressing change, to keep like sounds changing likewise under the same or different conditions.

The following cases may serve to illustrate different phases of the interaction of sensory and motor variation.

The deficiencies in perceiving the details of words and in associating the proper movements show themselves in the use of wrong sounds among those that can be produced correctly. The records of my own child at 16 months showed: **šœk** for **sup** 'soup,' although p appeared in **bapa** and **pun** for **papə** 'papa' and **spun** 'spoon;' **bəkə** for **bətə** 'butter' and **wawa** for **wɔtə**, although **t** was frequently used. The failure to perceive initial sounds appeared in **æt** for **hæt** 'hat;' when **hæt** was spoken with an exaggerated h, the result was **gæt**. An exaggerated perception of the explosives appeared in **kætɪ** for **kæt** 'cat,' **hɔtɪ** for **hɔt** 'hot;' **dɔkə** and **dɔgə** for **dɔg** 'dog.' Mistaken perceptions of sonancy occurred in **žugə** for **šugə** 'sugar,' **gəm** for **kəm** 'come.' The use of the glottal catch instead of t occurred many times in **miˀ** for **mit** 'meat;' the sound of ˀ was distinct from that of t and the action of the glottal catch could be felt by the finger over the larynx. The child had never heard a glottal catch. At later dates some of these errors were perceived; thus **mit** for **mit** was used along with **miˀ**, and **wawa** often corrected spontaneously to **wɔtə**. At 18 months he used **ɔlobə** for **ɔlovə** 'all over' and **kuʎit** for **kulit** 'cool it' (spoken with the *l*-mouillé

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which he had never heard), although he could use **v** and **l** in **veigud** 'very good' and **ləbmamə** 'love mamma.'

When a group of fairly constant sounds is heard repeatedly, there is a tendency to hear any slightly different sound as one of the constant group. This is favored by the indefiniteness of any sound owing to the size of the just perceptible difference for each of its elements and the indefiniteness of remembered sounds. This phenomenon may be termed 'the identification of similar sounds.' The processes of assimilation of neighboring sounds that occur regularly in language are permitted by the lack of distinction of difference in the results. Thus in **twenti** 'twenty' the **w** has become partly devocalized on account of the greater ease in speaking it in this way; the change is permitted by the failure of the ear ordinarily to detect it. A similar example is **pædz** for **pædz** 'pads' before a pause or a voiceless sound.

JOSSELYN reports the case of a friend with a good musical ear who insists that his own **tlu tləks tlæn** does not differ from the **klu kləks klæn** which he hears and that both begin with **k**; in these words he makes **l** merely a lateral surd explosion of the **t** and fails to notice the lack of the proper **k**-explosion and the loss of sonancy in the **l**.

The ear may fail to notice a gradual lengthening of the rush of air at the end of an explosive, which arises from gradually increasing slowness in moving the tongue or lips. The occlusives thus become aspirated[1]; and the aspirate may develop into an independent sound. For example, **t→tʰ→th**, as seen in French **toⁿ** 'ton,' German **tʰōn** 'ton,' Danish **thuŋə** 'tunge.' If the channel is made farther forward in the cavity of the mouth, the rush of air produces a fricative consonant instead of an **h**. The character of the fricative varies according to the place of stricture. Danish **thuŋə** 'tunge' may thus become **tsuŋə**,[2] a development parallel to the second German sound-shifting. The affricatæ may further be simplified to simple spirants, **ts→s**. The whole development arises from

[1] STORM, Englische Philologie, 2. Aufl., 74, Leipzig, 1892.

[2] STORM, as before, 74.

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the tendency to an alteration in muscular action permitted by the failure of the ear to distinguish the successive stages of the change. In this way t→t^h→th→ts→ts→ss→s. Thus the original word that appears in English as tel 'tell' appears in Danish as thalə and with further development in German as tselən. Likewise to the English hit 'heat' corresponds German hitsə 'hitze' and to hɔt 'hot' the German hais 'heiss.'

The conscious, semi-conscious or unconscious distinction of differences is a form of mental work, the repetition of the same sound involving less perceptive stimulation than a series of different sounds. The 'harmony of the vowels' in some languages seems favored by auditory as well as by motor economy. In these languages the vowels in a word must belong to the same group or must be the same, except in so far as other influences are at work.[1] For example, in Hungarian the hard vowels form one group and the soft vowels another; the language establishes a principle of vowel-harmony, according to which in general only vowels of the same class may occur in a word.[2] This principle requires in many cases two kinds of suffix for the same meaning: 'háznál,' at the house; 'kertnél,' at the garden; 'írnak,' they write; 'kérnek,' they ask. Similar requirements of vowel-harmony appear in Finnish, Northern Turkish and other languages of the Ural-Altaic group. Sporadic examples occur in the Arian languages; Heraclean χάραδος corresponds to Homeric χέραδος, in Latin *nihil* stands for **nehil*. In *alimentum* and *monumentum* the vowels *i* and *u* respectively are determined by the color of the vowel in the preceding syllable, *a* and *o*.[3] In the French and Canadian dialectic forms klerte = 'clarté' and šerite = 'charité' the change appears to be due to harmonic assimilation of the first vowel

[1] References in Passy, *Changements phonétiques*, 186, Thèse, Paris, 1891.

[2] Balassa, *Phonetik d. hungarischen Sprache*, Inter. Zt. f. allg. Sprachw., 1889 IV 154.

[3] Brugmann, Grundriss der vergleichenden Grammatik der indogermanischen Sprachen, I 2. Hälfte, 2. Aufl., 835 § 962 f., Strasburg, 1897.

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to the last one. Consonant harmony is not unusual. It occurs in isolated cases in the colloquial forms of all languages,[1] as well as constantly in infant speech.

It has been shown by LACLOTTE[2] that the tongue movements used in producing a vowel affect not only the preceding consonant but also the vowel before that consonant. The tendency to assimilate the articulations for the former of two vowels to those for the latter may be an impulse toward unity of character, but such an impulse must, I believe, be favored and developed by the ear in order to be effective.

The unconscious desire to avoid the labor of perceiving a difference may be one reason why the two portions of a diphthong often show a tendency to assimilation. Sometimes the second portion approaches the former in character and is absorbed by it; thus ai→ā in Old English 'stan;' ei→ē in Swedish and Danish 'sten.' Sometimes the latter portion prevails; thus ei, oi, ēi and ui have all become i in Modern Greek pronunciation. Sometimes the two elements of a diphthong approach each other in character and form a vowel of intermediate character; thus au of Latin 'aurum' has become o in Spanish 'oro' and French 'or;' French *ai* is regularly pronounced e.

To lighten the work of distinguishing among sounds that resemble one another small differences may be exaggerated or like sounds may be made different. These phenomena may take part in the development of diphthongs out of long vowels. The diphthongization started by any cause permitted to act on account of the inability to perceive variation is exaggerated as soon as the vowel is felt — even dimly — to be a diphthong that must be pronounced in that way. This usually affects the first portion most; often it ultimately becomes a quite different vowel; thus hūs → hous → haus 'house;' rīm → reim → raim 'rime.' These changes are complicated by motor factors, but the motor adjustments are governed largely by the ear. Such phenom-

[1] PASSY, as before, 189.

[2] LACLOTTE, *L'harmonie vocalique*, La Parole, 1899 I 177.

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ena as the tendency of English long vowels to become open may be mainly or entirely due to auditory preferences and not to motor habits; observations on the deaf might be of value here.

The result of the neglect of some differences and the exaggeration of others has been stated by PASSY to be that 'language tends constantly to bring into prominence what is necessary.'[1] It sometimes favors, sometimes opposes another principle, that of ease of speaking. Both are principles of economy; from a psychological point of view the former might be called that of 'perceptive economy,' the other that of 'motor economy.' Perceptive economy requires not only the suppression of needless distinctions but also the emphasis of needful ones.

Closely connected with the variations in perception are the changes in memory. Variations of the same sound fuse to the same auditory-motor memory image; the memory images, with their indefiniteness and their progressive changes, are the important factors of many speech changes. Thus, the general change of initial t to ts in Old High German probably arose from the change of initial t to ts when followed by i or e; this brought with it the change of initial t in tu and to on account of the union of all t's in one memory-image.[2]

The gradual changes in the general speech of a community, a family or an individual are brought about by internal or external factors causing a shifting of the general average of the sounds within the limits of the just perceptible difference.

The unnoticed variations in pronunciation are factors of change in language. They are particularly effective in the language of children whose peculiarities of speech are largely due to deficient perception of sounds and their combinations, to incomplete and erroneous associations with sounds in memory, to imperfect control over the vocal organs and to incorrect associations between the sounds heard from others,

[1] PASSY, as before, 227.

[2] KARSTEN, *Sprecheinheiten u. deren Rolle in Lautwandel u. Lautgesetz*, Trans. Mod. Lang. Assoc. Amer., 1890 III 190; also in Phonet. Stud., 1890 III 5.

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the movements made by themselves and the sounds of their own speech. Such variations cannot, however, furnish an adequate explanation for the historical changes of speech sounds, for the variability in articulation cannot be regarded as the cause of a phonetic change. It must be regarded rather as the condition under which certain changes are permitted to take place. The ultimate causes for such changes must be sought elsewhere. Variability of articulation cannot work a change unless all deviations, or at least a large majority of them, are in one direction. The force or forces which turn them into the same direction are the real causes for the change.[1]

Some of the causes of phonetic changes are certainly purely auditory, others are purely motor, many are due to phenomena of association and memory; on nearly every point, however, experimental data are still lacking although it would not be difficult to devise methods of investigation. As a guide for future work we may assume the principle of the unified nature of the human constitution. In its application to an individual this principle would lead us to expect to find in speech and language the more or less modified processes that appear in other activities. Thus, as instinctive economy shows itself in every form of perception (visual, tactual), in every form of thought (scientific, literary), and in every activity (writing, manual labor), we can with confidence assume its action in speech and language. Again, the modification of effort as the speed is increased, which is a form of economy, must appear in speech because it appears in all mental activities. Numerous other laws of human activity are to be looked for in the study of speech for the same reason. In regard to various individuals and communities our fundamental principle entitles us to expect as much agreement in general with variation in particulars as we find in anatomical, physiological and psychological work.

The facts summarized in this chapter suggest various applications to the methods of learning foreign languages:

[1] OERTEL, Lectures on the Study of Language, 103, 246, 269, New York, 1901.

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1. the value of training of the sense of hearing to perceive (at first consciously and then sub-consciously) the finer distinctions among speech elements in spite of their associations with other sounds; this may be done by direct auditory training in distinguishing differences (p. 116), by aid from producing the sound (p. 118), by records of vocal movement (Part III), etc. : 2. the training of the sense of hearing to correctly perceive and distinguish complexes of sounds as wholes without noticing the elements; this may be done by using words, phrases, etc. in the ways just suggested.

References

For summary of the phenomena of sound change: Passy, Changements phonétiques, Ch. III, Paris, 1891; Paul, Principien der Sprachgeschichte, Ch. III, Halle, 1898; Sweet, History of English Sounds, Oxford, 1888; History of Language, Ch. III, New York, 1901; Oertel, Lectures on the Study of Language, Lect. III, New York, 1901.

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CHAPTER X

SPEECH IDEAS

THE current of thought in consciousness varies in its density from moment to moment. The regions of less density may be used to divide off parts of greater density; such portions of greater density are what we usually term 'ideas,' or 'thoughts.' Each denser portion of the speech current in consciousness is an 'auditory idea' or — as a matter of speech — a 'phonetic unit.' A word is sometimes said to be the expression of one idea; this is probably always true for disconnected words. In connected speech, however, an idea is usually expressed by several words. Thus, in the phrase 'I, said the fly, with my little eye' in a gramophone record of a recitation of *Cock Robin*[1] the idea 'I' is followed by the complex idea 'said the fly,' the subordinate idea 'with' and the single idea 'my little eye.' In the last case the thought in the mind of the speaker was evidently a particular eye; the fact of its being 'mine,' and of its being 'little' were only dimly present and really served only to make up the details of the picture. The words of this group can be heard to run together; in the tracing from the plate there was no break in the vibrations of the speech curve. The group 'my little eye' was evidently a phonetic unit. If by a 'word' we understand the group of sounds or letters usually considered as a linguistic unit, this phonetic unit consisted of several words. The fusion of words into phonetic units appears often in the mistakes of foreigners and

[1] SCRIPTURE, *Researches in experimental phonetics (first series)*, Stud. Yale Psych. Lab., 1889 VII 35.

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children. Its applications to the laws of phonetic change have been pointed out by JESPERSEN.[1]

It is to be noted that the term 'word' is ordinarily used in an inconsistent and arbitrary fashion. Thus 'another' is one word and 'a different' two, 'city hall' always two words, 'railway' one word, 'street car' two, 'Newhaven' in England one, 'New Haven' in America two, etc., although in each of these cases only one phonetic unit is present. The compounding of words that occurs in German makes them more closely represent phonetic units. 'Versicherungsgesellschaft' and 'insurance company' both indicate one idea; both are spoken with no pause; the English division into two words is merely a matter of typography. 'Versicherungsgesellschaftsgebäude' and 'building of the insurance company' are likewise psychologically identical though typographically different. German compounds are in no way longer than or different from English ones except in being written and printed without spaces. In both languages the accent is the unifying element, distinguishing in English, for instance, the compound 'blackbird' from the two independent words 'black bird.'

A 'phonetic unit' in the meaning in which I have used the term is to be distinguished from a 'phonetic element.' KARSTEN[2] considers that in each language we are to assume single sounds for such simplest sound-memories as we can prove to exist; thus the two Roumanian forms of t indicate that at a previous time two memory-groups of t must have arisen from the single Latin memory-group. Such single sounds may properly be called 'phonetic elements.' Both terms, 'phonetic unit' and 'phonetic element,' are psychological ones; the 'phonetic element' is the simplest possible 'phonetic unit' that can be proved to exist, while the 'phonetic unit' is a synthesis of elements that varies on each occasion. In like manner it may be possible to define words

[1] JESPERSEN, *Zur Lautgesetzfrage*, Int. Zt. f. allg. Sprachw., 1887 III 193.

[2] KARSTEN, *Sprecheinheiten u. deren Rolle in Lautwandel u. Lautgesetz*, Trans. Mod. Lang. Assoc. Amer., 1890 III 195; also in Phonet. Stud., 1900 III 9.

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as such combinations of phonetic elements as can be proven to have independent existence in memory.[1]

It may be considered as well established that printed words are perceived in wholes as ideograms and not as combinations of letters. In this respect English words are not to be distinguished from Chinese characters, and they are often not inferior to them in complexity and useless adornment. We may — I believe — even go further and say that groups of words ordinarily form single ideograms, the undistinguished elements acting to produce a combination of marks of sufficient peculiarity to arouse a certain idea. Finally, it is doubtless true that complexes of sounds in words or phrases act also as ideograms. This ideographic characteristic of a word is indicated by several facts. It takes no more time to recognize a short printed word than to recognize one of its letters.[2] Among the phenomena of aphasia it has sometimes been noticed that 'entire words are read more promptly than the letters composing them' and that 'words which were read correctly were spelled wrongly,' the patient often attempting from the sound of the perceived word to guess at the spelling although he had the letters before him. Experiments by GOLDSCHEIDER and MÜLLER[3] showed that the perception of certain determining letters was sufficient for the recognition of the word. ERDMANN and DODGE[4] have shown that words may be perceived under conditions that exclude any perception of the single elements.

In experiments to determine the amount of change in a printed word, used as an ideogram, that might be made without a change in the perceived word, PILLSBURY[5] exposed words containing various misprints. An omitted letter was

[1] KARSTEN, as before.

[2] CATTELL, *Ueber d. Trägheit d. Netzhaut und d. Sehcentrums*, Philos. Stud. (Wundt), 1886 III 97.

[3] GOLDSCHEIDER UND MÜLLER, *Zur Psychologie u. Pathologie des Lesens*, Zt. f. klin. Med., 1894 XXIII 130.

[4] ERDMANN UND DODGE, Psychologische Untersuchungen über das Lesen auf exper. Grundlage, Halle, 1898.

[5] PILLSBURY, *The reading of words*, Amer. Jour. Psychol., 1897 VIII 333.

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most often noticed, a wrong letter less and a blurred letter least. The characterless blur of a mutilated letter furnished more suggestive material for the mind to make into the correct one than a wrong letter did; an omitted letter altered the picture of the syllable. Thus, 'shabbilw' briefly exposed was read as 'shabbily' and associated with the word 'genteelly,' the subject declaring that he saw the word spelled 'shabbily.' 'Eaxth' was read as 'earth,' 'fashxon' as 'fashion,' 'cotton' as 'custard,' 'ordnary' as 'ordinary,' etc.

The same phenomenon occurs even when the word is left exposed indefinitely. I have found the following cases in some experiments on the association of ideas. The word shown (indicated by SMALL CAPITALS) aroused generally a visual association (likewise indicated) or a motor word (indicated by small letters). The records included:[1] BERUF — brief [before the word was fully recognized] — berufstand — berufstüchtigkeit; KARAVANE — [at first read as] KRAVATE — karavane — afrika, ABSICHT — ARBEIT [because only beginning and end noticed]. Closely related to this is the involuntary completion of a word as in the case: THE — THEE — [a feeling that this is incorrect] — the door. Similar cases have been observed by CORDES.[2] The word SCHOLK appeared at once to the subject as SCHALK with the consciousness that something else was present; the word IMPERATIVE appeared as IMPERATOR before the word was read to the end.

The effect of preceding suggestions on the perception of words has been noticed by MÜNSTERBERG[3] and PILLSBURY.[4] For example, the word 'lid' was called out just before the letters 'xover' were shown for an instant too brief for reading them; the subject supposed that he saw the word 'stove.'

[1] SCRIPTURE, *Ueber d. associativen Verlauf d. Vorstellungen*, Philos. Stud. (Wundt), 1891 VII 51.

[2] CORDES, *Exper. Untersuchungen über Associationen*, Philos. Stud. (Wundt), 1901 XVII 66.

[3] MÜNSTERBERG, *Studien zur Associationslehre*, Beiträge zur experimentellen Psychologie, 1892 IV 20.

[4] PILLSBURY, as before.

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The word 'small' called out beforehand caused 'greal' to be read as 'small,' the letters supposed to be seen being 'mal.' The most striking characteristics of the whole word (or ideogram) are perceived and begin to bring up some internal word with the rest of the idea of which it is a component. This internal word contains many visual elements that often suffice to complete a defective visual word, or even to modify it. 'If *h* is seen as the second letter in a word, it is associable with *s* or *t*, among others, for the first letter. If the form of the word and some other letter suggest that the word, as a whole, is *should* rather than *though*, the *sh* connection will be effective.'[1] The condition of mind largely determines how the perceived outline is completed.

That the perception of printed words does not occur by letters or always even by single words is a fact clearly shown by visual lapses, or misreadings. The phenomena are familiar to every one; a careful collection of cases has been made by MERINGER and MAYER.[2] The following typical forms have been noted: 1. exchanges of neighboring words ('zu viel' for 'viel zu') or of near sounds (**žoka** for **koža**); 2. anticipations of words ('des Brutus Cäsar Liebe zum Cäsar' for 'des Brutus Liebe . . .') or of sounds ('verspäteter' for 'verpesteter,' 'tänzen sähe' for 'tanzen sähe'); 3. postpositions of words and syllables (seldom or never except in disease) or of sounds ('er würschet euch zu sehn' for 'er wünschet . . .'); 4. rearrangements ('weiberfrucht' for 'weiberfurcht'); 5. omissions of words [common] and syllables ('abhängen' for 'abzuhängen') or of sounds ('stet' for 'stets)'. Many of the other misreadings observed by MERINGER and MAYER were due to other causes than union in visual perception.

Observations on the misunderstandings of auditory words show that the vowel of the root syllable and the vowels in general are most often heard correctly while the consonants (especially the initial ones) are often heard wrongly.[3] 'Feld

[1] PILLSBURY, as before.

[2] MERINGER UND MAYER, Versprechen und Verlesen, 100, Stuttgart, 1895.

[3] MERINGER UND MAYER, as before, 157.

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im Meere' was understood for 'Feld in Mähren,' 'Vetter aus Kroke' for 'Vetter aus Chikago,' 'Hühner isst' for 'jünger ist,' 'Bahnen' for 'Vulkane.'

BAGLEY[1] made phonograph records of mutilated words (*a*) used without context, (*b*) used with one or two related words, (*c*) used at the beginning of a complete sentence, (*d*) used in the middle of a complete sentence, (*e*) used at the end of a complete sentence. The mutilations consisted in omission of an initial, medial or final consonant; for example, 'the book was put a-ide,' 'the siege was interrupted by a tru—.' The observer was instructed to listen to the sentence as reproduced and to repeat it to the operator, who recorded it as given by the observer, noting the errors. BAGLEY draws the following conclusions concerning the perception of auditory words:

1. In monosyllabic words the elision of the initial consonant affects perception more than the elision of the final consonant.

2. When a word is given with one or two related words, the chances for its correct perception (that is, perception of the word in spite of the mutilation) are increased by 82% as compared with the chances without context.

3. When the mutilated words are placed in a sentence instead of being isolated, the chances for correct perception are remarkably increased.

4. In the middle of a complete sentence there is a significant increase in the chances of correct perception as compared with the chances at the beginning.

5. The position most favorable for correct perception is at the end of the sentence.

6. Elision of p, t, k, b, d, g works the greatest injury to the perception of a mutilated word; elision of w, r, l, j the least (vowels not considered).

7. The mutilated word with context is not, as a rule, filled out at once by aid of the sounds contained in it but by the

[1] BAGLEY, *Apperception of the spoken sentence*, Amer. Jour. Psychol., 1900 XII 80.

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idea of the correct word aroused by associations derived from the context. Thus, with 'the matter is a function of ti— and space' one observer perceived 'ti—' as 'tide' but substituted 'time' by association with 'space;' with 'wri-ing in pain, he called for help' one observer supplied 'writhing' after perceiving 'pain.'

It may be suggested that auditory words and phrases form 'ideophones' just as printed ones form 'ideograms.' The further distinctions may be made of ideograms and ideophones into sensory (visual words and auditory words) and motor ones (written words and spoken words).

In all probability the most prominent features of a phonetic unit are first perceived and the details are gradually filled in. In the case of finger reading by the blind this double process occurs through separate organs; the right hand precedes in traveling across the line of raised letters and furnishes a vague idea of the words which is filled in by the left hand following it.[1]

An idea is a more or less complicated union of elements. These elements are derived from past and present experiences. The idea 'milk' as it occurs to me at the present moment is the result of past and present experiences of sight, taste, touch, etc., of the object itself and of associated experiences such as visual, auditory and motor words. It is generally stated that the idea of the object occurs first and the word follows; there seems to be no justification for this separation in time; experiences of every kind may arise at the same time.

The sum of the speech-elements in an idea is called the 'internal word;' visual, auditory, arm-motor, and voice-motor groups, or factors, are distinguished. Some persons see the printed word in memory most prominently, others hear it, others speak it. When the motor factors are strong, they can be detected in the action of the muscles. Unconscious larynx movements in connection with internal words have been observed in experiments by HANSEN and

[1] HELLER, *Studien zur Blindenpsychologie*, Philos. Stud. (Wundt), 1895 XI 460.

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LEHMANN[1] and have been registered by CURTIS.[2] The arm movements have been observed by CUMBERLAND.[3]

The most prominent elements of internal words are the motor sensations of the vocal organs and the auditory sensations. The idea is generally most closely connected with these and to a less degree with the printed letters and the arm sensations. The closer the connection between the various factors and the greater the accurate familiarity with each, the more complete the internal word.

The advantage of fusing the word with the object into one idea appeared in an experiment by BELL[4] in teaching a deaf child. The method has been extended to the instruction of normal children.[5] Printed words like BED, DOOR, WINDOW are placed on the objects that the child sees and the words are repeated as frequently as possible while the objects are seen or handled. The result is a very intimate fusion of the language elements with the other ones in the various ideas of the child's experience.

In regard to acquiring a foreign language the facts mentioned in this chapter seem to indicate: 1. the desirability of correctly associating groups of words to single ideas without the necessity of thinking out the details (p. 126); 2. the advantage of learning words and phrases as ideograms and ideophones (p. 128); 3. the desirability of learning the details of such ideo-units in the earlier lessons in order to form the correct associations between them and their meanings (p. 130); 4. the naturalness of first noting the most prominent characteristics of ideograms and ideophones and gradually distinguishing their details (p. 132); 5. the profitableness of

[1] HANSEN UND LEHMANN, *Ueber unwillkürliches Flüstern*, Philos. Stud. (Wundt), 1895 XI 471; SCRIPTURE, New Psychology, 63, 259, London, 1897.

[2] CURTIS, *Automatic movements of the larynx*, Amer. Jour. Psych., 1900 XI 237.

[3] CUMBERLAND, *A thought reader's experiences*, Nineteenth Century, 1886 XX 867; SCRIPTURE, New Psychology, 255, London, 1897.

[4] BELL, *Upon a method of teaching language to a very young congenitally deaf child*, Amer. Annals of the Deaf and Dumb, 1883 XXVIII 124.

[5] SCRIPTURE, *In the Japanese way*, Outlook, 1897 LV 557.

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closely uniting the internal word to the idea of the object itself (p. 132); the advantage of emphasizing the auditory and motor elements in building up the internal word (p. 133).

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CHAPTER XI

ASSOCIATION OF IDEAS

AN idea is generally followed by another whose content stands to that of the former in the relation of previous contiguity in space or time, of similarity, or of contrast.[1] These relations have been termed 'laws of association;' they have proved useful in arranging objects for memorizing. It has been pointed out[2] that these so-called 'laws' are simply classes in which pairs of associated ideas may be placed. It is also true[3] that the various classifications of associations are merely classifications of objects as usually associated, or of the relations of the meanings of words associated together. It has been said that they have been made on logical and not on psychological principles.[4]

HERBART[5] treated ideas as definitely bounded groups of sensations capable of indefinite existence outside of consciousness; they favored or opposed each other according to certain formulas and thereby rose or fell in consciousness. Owing to the lack of experimental data such a mechanics of ideas was necessarily fanciful.

[1] ARISTOTELES, De memoria, Ch. II, 451 b 16 f.

[2] WUNDT, Grundzüge d. physiol. Psychol., 4. Aufl., II 453, Leipzig, 1893.

[3] THUMB UND MARBE, Exper. Untersuchungen über d. psycholog. Grundlagen d. sprachlichen Analogiebildung, 14, Leipzig, 1901.

[4] ORTH, in a review contained in Zt. f. päd. Psychol. u. Path., 1901 III 222.

[5] HERBART, Psychologie als Wissenschaft, Königsberg, 1824; Lehrbuch zur Psychologie, 2. Aufl., Königsberg, 1834; Sämmtliche Werke, herausg. von Hartenstein, V, VI, VII; DROBISCH, Empirische Psychologie, Leipzig, 1842; Erste Gründlinien d. math. Psychol., Leipzig, 1850; VOLKMANN, Lehrbuch d. Psychologie, Cöthen, 1884; ZIEHEN, *Das Verhältniss d. Herbart'schen Psychol. zur physiol.-exper. Psychol.*, Samm. v. Abhandl. aus d. Gebiete d. päd. Psychol. u. Physiol., 1900 III Heft 5.

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One attempt to treat the results of an experimental investigation showed that ideas could not be considered as definite objects in any way, and resulted in the attempt to develop a new theory.[1] The technique of the experiment consisted essentially in placing the subject in a dark compartment with a ground-glass or tissue-paper screen on which the image of a printed word or a picture was projected by a lens provided with a photographic shutter. The subject observed and stated the train of thought aroused by each image. This arrangement in various modifications has proved useful in further investigations.[2] In stating the results of experiments in the following pages visual images are indicated by small capitals, motor images by lower case roman letters and auditory images by italics.

The general characteristics of an association may be stated in the following way. At any given instant t_0 the mind consists of an immense complexity of elements of various intensities. One group of elements is of maximum intensity; others are in all degrees down to a faintness of intensity such that their presence can be proved only by indirect means.[3] For example, the mental condition at the present moment may be that of looking at a book; the book may be considered as the idea present in mind at the moment, but all the other things seen, heard, felt and thought at the same moment — no matter how dimly — and all the unperceived elements of mind form part of it.

The main group in consciousness undergoes more or less rapid change in its elements; some remain fairly constant; some disappear; some new ones appear. At a moment t_1 the most intense group may be partly or wholly different from

[1] SCRIPTURE, *Ueber d. assoc. Verlauf d. Vorstellungen*, Diss., Leipzig, 1891; also in Philos. Stud. (Wundt), 1891 VII 1; New Psychology, Ch. XIII, London, 1897.

[2] MÜNSTERBERG, *Studien zur Associationslehre*, Beitr. z. exper. Psychol., 1892 IV 20; PILLSBURY, *A study in apperception*, Amer. Jour. Psychol., 1897 VIII 313; CORDES, *Experimentelle Untersuchungen über Associationen*, Philos. Stud. (Wundt), 1901 XVII 30.

[3] SCRIPTURE, as before, 136; New Psychology, 205, 391.

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that of the moment t_0. Thus, the thought of the book at the moment t_0 was followed by the memory of a certain classroom on a certain occasion at the moment t_1. This did not occur through the substitution of one group by another, but through gradual changes (at different rates) of the elements of the first group and the gradual formation of the new group. The total content of the mind at the moment t_0 and the changes during the time from t_0 to t_1 determine the content at the moment t_1. An 'idea' is not an object of unchangeable form that appears and disappears but is a group of activities extended in time. For example, the term 'boat' is given to an object of fairly stable existence; although the boat may not be present to the senses, yet it is assumed to exist and to be somewhere. Our idea of a boat is not of this nature; when we are not thinking of the boat, no idea of it exists; when we think of it, the idea forms, acts and passes again out of existence.

An 'idea' is a sum of conscious elements sufficiently distinct from other elements to be more or less definitely marked off as a group. An idea may be considered as a region of greater density in the course of thought.

The persistence and disappearance of an element in an idea depend on its intensity and on its connections with other elements of mental life. Memory elements have been shown [1] to fade away at first rapidly and then more and more slowly, always approaching to but never quite reaching complete loss — the curve of memory being an asymptotic one. Repetition of an element adds to its intensity; with sufficient repetition its strength even at a much later time will keep it ready for prominence in consciousness by slight new additions. The definiteness of an element, measured by its least perceptible change (p. 101) or by the frequency of confusion with a slightly different element (p. 103), has been shown to decrease with time; this renders it more and more likely to appear the same as elements that originally differed somewhat from it.

[1] EBBINGHAUS, Ueber d. Gedächtniss, Leipzig, 1885; WOLFE, *Untersuchungen über das Tongedächtniss*, Philos. Stud. (Wundt), 1886 III 534.

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The new elements entering consciousness by the senses find at hand in all degrees of intensity innumerable elements from past experiences, and the resulting union of coinciding elements with omission of disparate ones brings a new idea into prominence and at the same time modifies it. The union of certain elements of a new idea with familiar ones of previous experience may be seen in the case where the printed word ABTEI was at first almost read as ARBEIT and in the numerous cases of mistaken perception of misspelled and misspoken words (above). A word may be perceived as a word and then followed by a thought of its meaning, but usually the perception of the word and the thought of its meaning occur as one act.[1] In either case the very first member in an association is an assimilation of a group of sensations into a complex of present and revived sensations; in the former the sensory elements are prominent, in the latter they are less so.

Each element in an idea undergoes changes in intensity and in definiteness owing to the influences of other elements; these steadily modify the idea until in a short time it seems a different one. Such changes are evident in the case where a picture of a scorpion was followed 1. by a memory of a picture of a scorpion, 2. in a class-room, 3. by a memory of a teacher discoursing concerning it. The taste of tea on one occasion suggested 1. a taste memory of the almost tasteless solution of a homeopathic medicine, 2. a visual memory of such a solution in a glass, 3. a memory of the sensations of a throat sickness. The steady development of the mental picture is apparent in each case. The gradual grouping of mental elements is likewise seen in examples like that in which the printed word SEWING was followed by a visual picture of a person sewing, which 'gradually became that of a definite person in the act of sewing.' The manner in which many elements are strengthened so that a series of different groups appears as a succession of ideas is seen in a case where a picture of a deer was followed 1. by a visual picture of the land where deer are

[1] CORDES, *Exper. Untersuchungen über Associationen.* Philos. Stud. (Wundt), 1901 XVII 30.

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used as draught animals, 2. by a memory of a deer seen in a forest, and 3. by a memory of a picture of a deer seen long before.

The processes that change one idea to another may be said to result in the loss of some of the elements of the first and the addition of new elements.[1] Thus, the printed word FLUCH suggested to an Englishman the printed word FLUSH; the four letters FLU H had been more often connected in a certain order with S than with C; consequently the C was suppressed and the S added. Similar associations by the same person (English) were RAHM — RAUM (the word 'Rahm' was unknown to him), SED — SAID — SEED, LEFO — LEAF, KOT — COD, GACOLUSIM — COLOSSAL — COLOSSEUM; some of these indicate that the visual and motor words were acting together. In many cases the association consisted in simply adding new elements: HOHL — HOHLEN, MON — MONTAG. Similar associations by an American were: MÜHE — MÜHSAM, KOT — COTTON, LEFO — LEPER, MASS — MASSACHUSETTS (with this subject English words were followed almost without exception by visual memories of objects and scenes, not by words). Another American associated: THIS — THAT, GOODNESS — goodness — badness, FROM — from here — from this, SAT — saturday, IS — is not — be, OF — of — of him, VERY — very — very true, HOW — how — do you do, THE — THEE — (feeling of dissatisfaction) — THE DOOR, SPURS — SUPURS. Some of the results recorded for a German were: KLUG — und weise, FLUCH — der bösen tat, MASS — mass für mass, A — B, RAUB — thier, MUHE — los, etc., nearly all word associations being simply additions. The records of a Japanese gave: HOHL — HOHE, KLUG — heit, A — aal — B, BERUF — brief — berufsstand — berufstüchtigkeit, etc.

It still remains to explain why some elements persist and some disappear and why certain new elements arise. The statement that 'elements that have been present together tend to recall each other' gives the principle on which objects are to be used in order to form associations but does not indicate

[1] SCRIPTURE, *Verlauf d. Vorstell.*, as before, 18.

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the mental processes. The whole course of thought may be, I believe, explained on the assumption of three principles: 1. every element of thought fades more or less rapidly in intensity in an asymptotic course (p. 137); 2. every element loses its definiteness more or less rapidly also in an asymptotic way (p. 137); 3. elements of the same kind are added. The first two principles are familiar phenomena of memory. The definiteness of an idea is measured by its confusibility with another idea (p. 103). Ideas that are confusible with each other are to be considered as the same. The addition of the same elements is a familiar phenomenon in sensation; stimuli, as of the skin, too weak to be perceived finally become noticed and even painful if frequently repeated; similar summations of weak stimuli have been noticed in experiments on muscles, nerves, and the brain.

The whole course of thought at any time may, I believe, be treated as consisting of *all* previous experiences, which are fading in intensity and definiteness without ever being entirely lost, which are being fused with each other whenever the definiteness is so far diminished that they are practically the same, and which rise into prominence according as the fusion produces sufficient intensity. The entrance of a new sensation adds new elements; the resulting perception depends upon the degrees of intensity and definiteness of the elements already on hand at the moment of entrance; the course of thought then follows on the usual principles with the result that at the next moment a new combination reaches prominence.

The theory advocated was promised on a previous occasion.[1] It differs from that of HERBART in denying definite boundaries to ideas and the principles of attraction and repulsion between them, but resembles it in considering that elements of ideas have an existence in the mind although not perceived.

This view is contrary to that of many contemporary psychologists. Their view is that when an idea fades away, it ceases to exist, that it leaves brain adjustments behind it, and that,

[1] SCRIPTURE, as before, 101.

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when these adjustments again affect brain action, the idea reappears. Such a presentation of the case seems inadequate. Brain action is an uninterrupted sequence of physiological activities. Mind action must, I believe, be analogously treated as a continuity of mental processes. The two sets of phenomena are, of course, closely related; for convenience we may perhaps mix them in a discussion. But the supposition that mental facts are accidental attachments to members of the brain sequence is only a little less futile than the one that they form a sequence of brain-mind-brain-mind, etc. The former contradicts the fundamental hypothesis of physiology; the latter that — according to my opinion — of psychology, namely, that the whole of mental life must be explained by reference to elementary *mental* processes. The habit among some writers of 'explaining' any psychological difficulty by inserting 'sequences of neural processes' — generally inconsistent with the later discoveries of neurology and often absurd — between mental ones has been a great hindrance to the development of psychology; its appearance in linguistics would be deplorable.

WUNDT'S view[1] is a development of the principles of similarity and contiguity formerly adduced as explanations of association; it may be summarized as follows. The associative processes cannot occur between ideas but only between the elements that compose them. A 'reproduced' element generally belongs to many previous ideas. Only two processes are present in the association of ideas, namely, connection of like elements, and connection of those that have entered into a functional relation by occurrence together. These may be called 'connection by likeness' and 'connection by contact.' Every association of ideas involves association of elements by both connections. At the first moment an idea reawakens the same elements of earlier impressions in a simultaneous association with the result of greater prominence of familiar elements and neglect of unfamiliar ones. As I have already pointed out, the principles of likeness and contact are classifications;

[1] WUNDT, Grundzüge d. physiol. Psychol., 4. Aufl., II 467, Leipzig, 1893.

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the reawakening of the same elements involves a sleeping existence of elements in the mind similar to that for HERBART'S complete ideas; the neglect of unfamiliar elements also resembles HERBART'S conflict of ideas.

According to CORDES,[1] a single element or a complex of elements in an idea becomes specially prominent on account of favoring internal or external conditions; the other elements fade away while the more prominent elements persist; new elements assimilate themselves to the persisting ones and form a new idea. This is a common form of association. In other cases the new elements attract so much attention to themselves that the persisting ones are neglected and rapidly fade away; in such a case the induced idea appears to contain little or nothing of the preceding one. By special attention certain elements of an idea can be made to persist through a series of associations; this principle is of great importance in learning languages.

An idea may bring two or more ideas by association independently of one another. The following cases occurred in my records: A — aal — B; GACOLUSIM — galicia — gladstone, is — is not — be, both the associated ideas being plainly connected with the inducing idea and not with each other. In like manner the word FILZ aroused[2] the associations 1. of brown felt, used in sound-boxes, 2. the economic term 'verfilzen;' the two associated ideas have no connection with each other; we may suppose that they were both aroused by FILZ and that one of them developed more rapidly than the other.

The united effect of two ideas in producing a succession can be seen in a case by CORDES[3] in which the simultaneous presentation of a tone from a musical instrument and of the word KLEIN was followed by the memory of a very small tuning fork; in another case a tone and the picture of Emperor William II. was followed by the thought of the Hymn to Ægir. In general we may say that two simultaneous ideas have an effect that depends on their relative masses; if

[1] CORDES, as before, 58.
[2] CORDES, as before, 48.
[3] CORDES, as before, 61.

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one of the ideas is overpoweringly weighty, the next idea will be chiefly influenced by it; but if two are nearly balanced the next idea will be the result of the two. It has been noted by MAYER and ORTH[1] that when a person responds by an associated word to the word he hears, the association may be more than a simple one. Thus, the word 'stift' was followed by the visual memory of a student friend of that name and the person responded by the word 'student;' the word 'lead' was followed by a distinct visual image of a flat piece of grayish-white lead, after which the response 'heavy' was made; 'soul' was followed by the internal word 'body' after which the response 'mind' was made.

In many cases the course of thought seems to have no very definite region of density. Such cases as those reported in some association experiments by CORDES[2] are common; upon seeing the word MEDICI the observer gave no definite association but said, 'I thought of the whole epoch in art that is represented by the name;' to the word DONCHÉRY he 'associated the whole complex from Zola's *Débâcle*, the word MACMAHON came late and only because he wished something definite.' In other cases there may be a sufficiently definite idea with a whole region of semi-definite elements, as in the record by CORDES where SULLA was followed by an idea of Catiline 'together with a picture of the map of Italy and dimmer thoughts of the wars that have occurred there.' On another occasion the word STAHL aroused[3] 'a lot of reproductions, apparently simultaneous: an image of a fine piece of steel, blue; memory of a touch impression, that reminded of the steel works of native place; Stahl as the name of a medical man and of a philosopher; the ideas seemed to be simultaneous; they came one after another into the focus of consciousness, but with each it was clear that it was already present; very quick; very fine phenomenon.'

[1] MAYER UND ORTH, *Zur qual. Untersuchung d. Association*, Zt. f. Psychol. u. Physiol. d. Sinn., 1901 XXVI 1.

[2] CORDES, as before, 51.

[3] CORDES, as before, 52.

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This generally overlooked existence of regions of not very definite density has been specially emphasized by MAYER and ORTH.[1] The persons experimented upon often said that they experienced certain mental conditions which they could not call definite ideas or acts of will. Sometimes these vague conditions acquired some definiteness; for example, the word 'mustard' was followed by a peculiar mental phenomenon that seemed describable as a memory of a common proverb [without the proverb actually being thought of] and the response 'seed' was made.

On some occasions a word is followed by another apparently entirely different; it is generally found, however, that there is some common mental characteristic in the two words. This common mental characteristic may be either their connection on some previous occasion, or their connection with other words or objects that nevertheless do not present themselves. The former characteristic seems to have no psychological meaning except as a paraphrase of the latter. A connection on some previous occasion is a statement of a fact of the past; adduced as an explanation of the association it implies some present fact. In many cases of association the fact present is the persistence of some elements from the inducing idea into the induced ideas; in cases where no such persistence can be detected it may well be assumed that elements have persisted without any notice of them. In my experiments there were some associations of different words that could be readily traced to a previous connection: ZAUM — zügel (zaum und zügel), SED — but, THIS — that, etc. They were not common; a word was most frequently followed by words to complete a phrase or by memory pictures. Even with foreign words the associations consisted generally in adding elements of the same language or in bringing up memory pictures, and not often in translating. Although the similarity associations are among the most common visual ones, they do not occur frequently between words. The few examples found in the investigation mentioned were: TRUPPE

[1] MAYER UND ORTH, as before, 5.

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— manöver [probably through memory images of scenes or words], TRUPPE — menge [likewise], ZAUM [confused with ZAUN] — hecke. All these cases of 'previous connection' are to be interpreted by the following principles.

An association where the word *A* is followed by a word *C* on account of relations of both *A* and *C* to an idea (or group of ideas) *B* which does not fully or at all enter consciousness has been called a 'mediate association.' In order to investigate mediate association experimentally, the following method was devised.[1] On one card there was a German word and some Japanese characters. On another card there was a strange word (Japanese, in Roman letters), with the same characters. A series of cards, with the same number of each kind, was shown in irregular order. For example, in one experiment the following series (the Japanese characters being represented here by Greek letters) was shown in the order here given: — (1) HANA $a\beta$, (2) HITO $\gamma\delta$, (3) IUKU $\epsilon\varsigma$, (4) KURU $\eta\theta$, (5) MENSCH $\gamma\delta$, (6) GEHEN $\epsilon\varsigma$, (7) KOMMEN $\eta\theta$, (8) BLUME $a\beta$. The subject was asked to state if he had noticed any associations between the first four words and the second four; he said he had not. Thereupon the words alone without the characters were shown him, with the request to state the first thing that entered his mind after each. The results were as follows: — (1) HITO — MENSCH, (2) KURU — KOMMEN, (3) HANA — ? (4) IUKU — GEGEN, (5) KOMMEN — IUKU, (6) GEHEN — ? (7) MENSCH — HITO, (8) BLUME — HANA. At the end the subject declared that all the associations were involuntary, that he could give no reason for them and that the Japanese characters had not occurred to him at all. Several of these associations were, however, correct; it seems probable that they were brought about by the influence of the Japanese characters which, nevertheless, had not entered into consciousness. This probability is increased by other experiments in which the word-association was correctly made, and was *followed* by the occurrence of the characters. In still other cases the association was correctly formed with-

[1] SCRIPTURE, as before, 81; New Psychology, 202, London, 1897.

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out thought of the characters, whereas the subject could reproduce them when asked. Finally, the characters themselves were found to be in all stages of indefiniteness and forgottenness, even in correct associations. In experiments made by ASCHAFFENBURG[1] a number of cases occurred in which the connection between the two ideas was intelligible only on the supposition of an intermediate idea. In the greatest number of cases this intermediate idea appeared to have been a sound-association with the inducing idea, while the relation of the induced idea to the intermediate one was of any kind.

Several excellent examples of mediate association were observed by CORDES.[2] In one case the word BALDE was followed by a memory of 'Göthe's garden house at Weimar — white, two-storied house on the side of a hill, clear — then (that it was later, I can say with perfect certainty) the words: "warte nur, balde ruhest du auch" — then the thought: "ah, that explains it."'

In my experiments I pointed out that the mediate idea *B* was found in all degrees of consciousness, from full consciousness where the succession of ideas appeared as $A - B - C$, to complete lack of consciousness where *B* was unnoticed and the succession appeared as $A - C$ with possible or even impossible introspective recovery of *B*. The view of CORDES[3] is an amplification of mine: mediate association is often to be considered as a special case of the usual immediate association where the second idea is a complex idea out of which certain elements become specially prominent and form an idea whose relation [through identical elements] to the first one can readily be found; and in other cases as an immediate association where the usual formation of a definite idea out of the complex of the second idea [through identical elements] was hindered in some way, with the result that an unusual group was formed.

[1] ASCHAFFENBURG, *Experimentelle Studien über Associationen, I. Theil*, Psychol. Arbeiten (Kräpelin), 1895 I 40; THOMAS, *Ein weiteres Beispiel von Association durch eine Geruchempfindung*, Zt. f. Psychol. u. Physiol. d. Sinn., 1895 XII 60.

[2] CORDES, before, 74.

[3] CORDES as, as before, 73.

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Related to mediate association is association through unnoticed sensations or unconscious memories. In addition to observations of such occurrences[1] they have been produced in careful experiments.[2] A series of four or five cards, each containing a picture in the middle and a small letter or character in one corner, were shown in succession for so short a time that, at the most, the subject was able to recognize only the picture without the small letter. Thereafter the small characters were exhibited alone, and the subject had to state which of the pictures first occurred to him. The following is a specimen series, the pictures being indicated by words.

Peacock.	Shield.	Cat.	Flag.	Negro.
F	A	I	: :	C

The results on one occasion were: I—cat, : : —flag, A—shield, C—negro, F—?. Upon being questioned, the observer stated that he had not recognized any of the small characters in the original series. Many similar results were obtained. In some cases the subject would feel that a certain picture belonged to a certain letter, although he had not seen the letter before during the experiment, as far as his knowledge went.

Forgotten associations may also have their effects. On seventeen successive days KRÄPELIN[3] used the same series of inducing ideas, and measured the quickness of association. This increased during the first few days, and then remained at a constant level of about one half the original time. After an interval of one and three-quarter years the same ideas were used among others in measurements of quickness; for these ideas the time was much shorter than for the others, although

[1] JERUSALEM, *Ein Beispiel von Association durch unbewusste Mittelglieder*, Philos. Stud. (Wundt), 1894 X 323; WUNDT, *Sind die Mittelglieder einer mittelbaren Association bewusst oder unbewusst?* Philos. Stud., 1894 X 326.

[2] SCRIPTURE, as before, 136.

[3] KRÄPELIN, *Ueber den Einfluss der Uebung auf die Dauer von Associationen*, St. Petersburg. med. Wochenschrift, 1889, No. 1 (cited from Aschaffenburg).

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the earlier associations had been forgotten. The greater ease and rapidity of familiar associations as compared with unfamiliar ones is shown in the greater facility in learning oriental languages by the use of Roman letters rather than strange ones.[1]

Cases frequently occurred in my experiments in which the train of thought had started before the word or object was clearly perceived. Similar observations have been made by MÜNSTERBERG, CORDES and others.

Mediate association is probably the source of many associations said to occur by similarity and contrast, both the inducing and induced ideas being connected with a group of ideas more or less dimly in consciousness. Other similarity and contrast associations contain identical elements that are fully conscious. These phenomena of mediate association have been used to explain the so-called 'free rise' of ideas in consciousness, that is, the appearance of ideas quite unconnected with the preceding ideas. It does in fact account for many of them. I do not believe, however, that such a 'free rise' is impossible; it may occur spontaneously whenever enough elements have become so indefinite (p. 140) as to unite with others to form a sum of sufficient intensity. The influence of mediate association appears clearly in the memory experiments of EBBINGHAUS,[2] of MÜLLER and SCHUMANN[3] and of MÜLLER and PILZECKER.[4] In a series of syllables successively read in trochaic rhythm associations are formed not only between neighboring syllables but also between distant ones, especially between the emphasized ones.

Associations may be formed between percepts of the same sense (visual with visual, auditory with auditory, motor with motor) or between those of different senses (visual with motor,

[1] SWEET, Practical Study of Language, 36, London, 1900.

[2] EBBINGHAUS, Ueber d. Gedächtniss, 139, Leipzig. 1885.

[3] MÜLLER UND SCHUMANN, *Exper. Beiträge zur Untersuch. d. Gedächtnisses*, Zt. f. Psychol. u. Physiol. d. Sinn., 1893 VI 307.

[4] MÜLLER UND PILZECKER, *Exper. Beiträge zur Lehre vom Gedächtniss*, Zt. f. Psychol. u. Physiol. d. Sinn., 1900, Ergänzungsband, I 216.

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etc.). This is true not only of different forms of the same word but also of different words.[1] Thus, the two syllables 'bas' and 'dut' may be so connected that the sight of 'bas' at once produces the motor response 'dut' without intermediate association of motor 'bas' or visual 'dut.'

In the preceding account of the association of ideas no use has been made of the term 'association by function.' The meaning of this term may be illustrated by the following quotation from PAUL: 'We hear from time to time a number of sentences which are built up in the same way and which therefore unite to a group. The memory of the special content of the individual sentences may fade more and more; the common element becomes strengthened by the constant repetition; and thus the rule [for the construction of a sentence] is unconsciously abstracted from the examples.'[2] It is not necessary to assume a special form of mental activity for such associations by function; the cases can, I believe, all be treated just as other associations. In speaking of 'me' a person has in mind a picture including not only the word but a multitude of sensations and thoughts, past and present, concerning himself among which are numerous elements of past experiences in which he and others have been the object of some action. To such past cases he has been taught to associate the words 'me' and 'him,' not 'I' and 'he.' A new experience suggested by 'me' may bring 'him' on account of the apparently identical elements in the general picture; the fading away of the definiteness of the two objects in the original pictures brings an unconscious fusion in memory of the previous objects of an action, and when a distinction of persons is called for at a later time the objectivity will still remain. The use of 'knowed' as the past of 'know' is due to the habit of using d when referring to the past just as a word 'yesterday' or 'then' might be used. The other functional associations and the formation of sentence-habits may be reduced to the same principles. In going over

[1] MÜLLER UND PILZECKER, as before, 12.

[2] PAUL, Principien der Sprachgeschichte, 3. Aufl., 100, Halle, 1898.

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PAUL'S examples[1] of speech changes due to association by function I find that every one can be explained as I have indicated. The mental process in using the Attic Greek πολίτου by association of the masculine genitive of the first declension with the genitive *ου* of the second,[2] or 'Berthas' for the German genitive of 'Bertha,' is exactly as described for the case of 'me' above. The associations may be considered as 'associations by function' if this term is taken to refer only to the use of the words associated; the assumption of a mental process of association by function is, I believe, a needless one. We must undoubtedly admit an association by function[3] just as we do an association of part to whole, an association by contrast, etc., but as pointed out above (p. 135), these terms are no more than convenient classifications of the relations of the things associated. In this chapter an attempt has been made to explain how the associations actually do take place in the mind; what is philologically a functional association is psychologically a process not essentially different from the other associations. The cases of 'agrammatism'[4] are explainable as due to weakening of the fundamental processes of memory and association.

For instruction in language the following conclusions are suggested by the facts of this chapter: 1. a word-idea should be learned as parts of various courses of thought in order to form the necessary language associations in addition to being learned separately in the earlier lessons; 2. the learner should make an effort to *actively* produce the complete idea with its object-memories and internal word and not rely on the so-called 'spontaneous' rise of the idea from memory; 3. constant repetition is neces-

[1] PAUL, as before, 106.

[2] BRUGMANN, Griechische Grammatik, 3. Aufl., 224, München, 1900.

[3] PAUL, as before; THUMB UND MARBE, Experimentelle Untersuchungen ü. d. psychol. Grundlagen d. sprachl. Analogiebildung, 61, Leipzig, 1901; OERTEL, Lectures on the Study of Language, 156, New York, 1901.

[4] KRÄPELIN, Psychiatrie, 6. Aufl., II, 312, Leipzig, 1899; HELLER, *Ueber Aphasie bei Idioten u. Imbecillen*, Zt. f. Psychol. u. Physiol. d. Sinn., 1897 XIII 181.

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sary; 4. both ear and eye should be carefully trained to quick and accurate perception; 5. the learner should be trained to associate the ideas and words that actually occur in the language studied and to avoid other associations, that is, as far as possible to learn exclusively in the language studied with avoidance of translating into or thinking in the native language; 6. the language instruction should be associated as far as practicable with surroundings that tend to arouse and confine the thoughts peculiar to the language, as occurs by residence in the region to which the language belongs, by appropriate furnishings of the room, etc.; 7. words and phrases should be associated as much as possible with objects or pictures; 8. the most frequently needed words of a language should be learned in as many different connections as may be practicable; 9. the associations of language elements should be made so firm that they occur even before the ideas reach full consciousness; 10. owing to the inability of speech to keep up with the rapidity of thought, the formation of ideophones should be encouraged.

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CHAPTER XII

HABITS OF ASSOCIATION

THE forms of association represent habits of thought and speech. Some of these forms are easier than others for each individual, community, language, etc.

The firmness with which ideas are associated may vary. Two measures of firmness have been proposed: the reciprocal of the time required, and the relative frequency.

The time required for an association may be roughly measured by starting a stop watch as the inducing word or picture is presented, and stopping it when the reply comes. Finer measurements may be made by means of chronoscopes with appropriate connections. Various chronoscopes have been devised by HIPP, EWALD, D'ARSONVAL, and others; the pendulum chronoscope with its attachments has been specially constructed for work on association and similar problems.

The pendulum chronoscope (Fig. 65) contains in the first place an accurately adjusted double-bob pendulum. This is held by a catch at the right-hand side. In making an experiment this catch is pressed noiselessly and the pendulum starts on its swing. It carries on its lower bob a piece of magnet iron that holds to itself a light indicator in an accurately but automatically adjusted position. This indicator has two branches, a point passing in front of the scale and a flat piece passing behind it. This indicator replaces the older hanging pointer shown in the figure. At a definite instant the pendulum in its swing releases a catch and thereby drops a shutter that covered an opening in a screen at the back of the chronoscope. Behind this screen there may be a word which

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is exposed by the fall of the shutter. The person experimented upon responds to this word by repeating it or by calling out some association. A telegraph key held in a clamp (fastened to the back of a chair) is adjusted so that its knob



FIG. 65.

is pressed lightly against the chin of the subject. The moment this knob is pressed a current is sent through a magnet under the chronoscope; this releases a horizontal bar moving behind the scale. Since the flat part of the pointer swings between the scale and this bar, it is picked off the pendulum when the bar snaps. In making the instrument a zero-mark is placed on the scale plate at the instant the shutter

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starts to fall; the other divisions of the scale in hundredths are so carefully registered on the scale plate that a well-made instrument gives readings accurate to less than half a thousandth of a second. The finer divisions into thousandths may be marked on the scale or, preferably, left for the eye.

Behind the shutter there is a wheel carrying catches for small cards with words or pictures on them. The subject is seated so that he can see the shutter-opening comfortably. When the subject is to be placed in a distant room, a break contact attached to the shutter is used to operate a distant magnetic shutter; otherwise the manipulation is the same. For response to a spoken word a magnetic release of the pendulum is substituted for the catch that usually holds it, the pendulum being now at zero; this release is operated by a key under the chin of the speaker. When the subject is in a distant room, the inducing word is spoken into a telephone or a speaking tube.

A lip key or a voice key may be used in any of these experiments in place of the chin key. The lip key[1] is so arranged that the movement of the lips interrupts an electric circuit and sends the current through the chronoscope magnet. The voice key is essentially a tube shaped at one end so as to fit closely over the mouth, and closed at the other by a diaphragm of leather,[2] metal,[3] or membrane,[4] which is agitated by the vibrations from the mouth. A contact in the middle of the diaphragm serves to interrupt an electric circuit with

[1] CATTELL, *Psychometrische Untersuchungen*, Philos. Stud. (Wundt), 1886 III 312; KRÄPELIN, Ueber d. Beeinflussung psychischer Vorgänge durch einige Arzneimittel, Jena, 1892; MÜLLER UND PILZECKER, as before, 7.

[2] CATTELL, as before, 313.

[3] BOUDET DE PARIS, Des applications du téléphone et du microphone à la physiologie et à la clinique, Paris, 1880; BOUDET DE PARIS, Étude de voix articulée, Paris, 1880; SCRIPTURE, *Some new apparatus*, Stud. Yale Psych. Lab., 1895 III 107; Thinking, Feeling, Doing, 53, New York, 1901.

[4] ROUSSELOT, *Les modifications phonétiques du langage étudiées dans le patois d'une famille de Cellefrouin*, Revue des patois gallo-romans, 1891 IV, V; also separate; ROUSSELOT, La méthode graphique appliquée à la recherche des transformations inconscientes du langage, Paris, 1891.

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each vibration. The voice key shown in Fig. 66 has a metal diaphragm *D* which touches the platinum point of the adjustable screw *S* at the slightest agitation; the electric circuit *B* with poles at *D* and *S* is thus closed.

In using the chronoscope in this way the latent time of a magnet should always be known. A simple change of wires from the chin-key to the contact on the shutter causes the chronoscope to pick off its own pointer; the time registered is that of the action of the magnet, the lost time of the other mechanism having been included in the scale-graduation; this time is very constant at 0.007^s to 0.009^s according to the strength of the current in relation to the adjustment of the sensitiveness of the release. This adjustment of the release

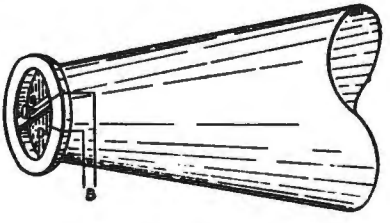

FIG. 66.

is accomplished by a special screw at one side of the apparatus.

To find the time required to read a word aloud a card with that word is inserted behind the shutter; the pendulum is released; the shutter drops at zero; the subject responds when he sees the word; the indicator is caught off at the moment of response; and the time elapsed is read from the scale. This may be called the time of a visual-motor word-association. To find the time of an association of ideas the person is to call out not the word he sees but the first other word that occurs to him; the increase is called the association-time.

For each set of experiments the average and the immediate probable error are computed. This latter quantity —of great value as an indication of stability in the mental operation — is calculated by finding the differences v_1, v_2,

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..., v_n between each separate result $x_1, x_2, \ldots, x_n$ and the average a (that is, $v_1 = x_1 - a$, $v_2 = x_2 - a, \ldots, v_n = x_n - a$), squaring the differences and adding the squares (obtaining $v_1^2 + v_2^2 + \cdots + v_3^2$), dividing the sum by one less than the number of experiments $(n - 1)$, and taking two thirds of the square root of the quotient. The complete process of finding the average and the probable error from the individual results $x_1, x_2, \ldots, x_n$ is indicated by the equations

$$a = \frac{x_1 + x_2 + \ldots + x_n}{n},$$

$$v_1 = x_1 - a,\ v_2 = x_2 - a,\ \ldots,\ v_n = x_n - a,$$

$$R = \tfrac{2}{3}\sqrt{\frac{v_1^2 + v_2^2 + \ldots + v_n^2}{n - 1}}.$$

Among the measurements of association time that find their application in speech those of TRAUTSCHOLDT, CATTELL and ASCHAFFENBURG may be mentioned. The experiments were not undertaken with any thought of such an application and the data for our purposes are not numerous. Investigations on the firmness of language associations, on the influence of alliteration and rime, on language habits, and similar topics are still to be made. The experiments by TRAUTSCHOLDT[1] showed that the quickest associations were those between words used in common connections (gold — silver, light — dark). CATTELL[2] has determined the time required by two persons for associations of various kinds; some of the averages are given in the table opposite for B, a German, and C, an American.

The influence of language habits is marked. The shortest associations are those between words of two languages. The other short associations such as 'city — its country,' 'month — its season,' 'month — following month' 'prominent man — his profession' owe their facility to the numerous repe-

[1] TRAUTSCHOLDT, *Exper. Untersuchungen über d. Assoc. d. Vorstellungen*, Philos. Stud. (Wundt), 1883 I 241.

[2] CATTELL, *Psychometrische Untersuchungen*, Philos. Stud. (Wundt), 1886 III 452, 1888 IV 241.

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titions that have been heard, seen and made by the person. Less past familiarity explains also the longer time for 'month — preceding month' and for translations of the longer words. Other longer times as for 'language — author,' 'author — one of his works,' 'class of objects — some example,' seem to be explainable only on the supposition that the first idea induces more than one association, and that extra time is required for one of these to become more prominent than the other.

		B	C
letter	its name	0.43^s	0.46^s
group of letters	the word	40	40
picture	its name	47	54
picture	its name in a foreign language	64	69
short English word	German word	22	25
long English word	German word	32	38
short German word	English word	27	15
long German word	English word	58	40
city	its country	34	43
month	its season	41	31
month	following months	34	38
month	preceding month	71	82
author	his language	41	34
prominent man	his profession	45	35
country	one of its cities	38	34
season	one of its months	55	42
language	an author	68	52
author	one of his works	108	68
class of objects	some example	69	50
picture	a part of it	38	43
adjective	substantive	85	33
verb	subject	81	51
verb	object	61	35

Experiments of somewhat different kind by BINET and HENRI[1] showed that the time necessary to repeat the heard word œ^n 'un' was 0.22^s when the word was known beforehand, 0.54^s when it was not, 0.78^s when the word was to be repeated not in the same accentuation; that the time required to cease producing a continued sound at a signal was 0.27^s; and to stop counting a series of figures was 0.34^s.

According to ASCHAFFENBURG[2] the external associations —

[1] BINET ET HENRI, *Les actions d'arrêt dans les phénomènes de la parole*, Rev. phil., 1894, XXXVII 608.

[2] ASCHAFFENBURG, *Exper. Studien über Associationen*, Psychol. Arbeiten (Kräpelin), 1896 I 209.

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that is, of objects connected in space and time, or by speech usages or by similarities of sound — are more common and take less time than internal or logical associations. When a spoken word is associated to an auditory word, the connection may occur directly or with one or more ideas between them.[1] The latter is the most common case; it requires somewhat more time.

According to experiments made by BERGSTRÖM[2] the time required for sorting a series of cards into piles was lengthened if they had previously been sorted into piles differently arranged, or if the different arrangement had been learned by the eye or the ear alone. This showed the interference of a previous habit with a present activity; the effect decreased with the time that had elapsed. It presumably increased with the firmness of the previous habit. This interference of an association by a shortly preceding one is seen in the difficulty of alternating š and s in similar associations as in 'Shall he sell sea shells? Shall she sell sea shells?' and in similar confusions for other sounds where a group of associated articulatory movements is to be sometimes varied by a small change. This phenomenon may be called 'associative stammering;' like stammering it is due to improper coordination of muscular movements, but the trouble arises from associative interferences in thought and not from defects of muscular control. The term 'stuttering' (Lautstottern) is hardly justifiable, as the mental and physiological processes utterly lack the excessive innervations and muscular cramps that characterize stuttering.

The interference of associations is assigned by WHEELER[3] as the compelling force that may carry a sound-change from one word to another. For example, the later habit of pronouncing *u* as ju in words like 'new' and 'Tuesday' ac-

[1] MAYER UND ORTH, *Zur qual. Untersuchung d. Association*, Zt. f. Psych. u. Phys. d. Sinn., 1901 XXVI 1.

[2] BERGSTRÖM, *Exper. on physiol. memory by means of the interference of associations*, Am. Jour. Psychol., 1893 V 356.

[3] WHEELER, *The causes of uniformity in phonetic change*, Trans. Amer. Philol. Assoc., 1901 XXXII 6.

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quired in opposition to the earlier one of using u may lead a person to extend the use of ju to most cases of u, as in 'tune, due,' etc., and even in 'do' and 'two.' The laws governing such interfering associations might be investigated by time-measurements according to the methods of this chapter or by studies of the speech curves.

The firmness of an association may be judged by its frequency. No investigations have been conducted on the frequencies of specific associations. Data concerning some such associations have been obtained by statistics of favorite words, and of phrases and rimes in written works.

The most frequent forms of associations that occurred with six participants in my own investigations (p. 136) are shown in the following table in which the figures give the number of times each form occurred; the ? in the table indicates the inability to classify the association; the —— indicates 'no association.'

	Subjects:						
Kind of association.	S.	N.	D.	H.	R.	K.	Total
Picture — picture	13	61	17	50	70	0	211
" — sound	0	0	1	0	0	0	1
" — visual word	0	1	5	0	2	3	11
" — motor word	37	0	10	5	0	18	70
" — ——	0	4	15	1	4	0	24
" — ?	23	6	26	2	2	0	59
Visual word — picture	6	6	9	1	5	0	27
" " — sound	0	0	0	0	0	0	0
" " — visual word	5	9	7	9	3	0	33
" " — motor word	18	33	6	0	5	10	72
" " — ——	2	0	3	0	1	0	6
" " — ?	7	3	15	0	0	0	25

The table shows that pictures were followed most frequently by memory pictures, less frequently by internal words described as 'words as though spoken' (motor words, or, perhaps, motor-auditory words) and still less frequently by visual words. Visual words were followed most frequently by motor words, less frequently by visual words (imagined or remembered), and still less frequently by memory pictures.

In experiments in which the subject was required to associate

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a word to one that was called out, KRÄPELIN[1] found that substantives produced associations of substantives in 90% of the cases. MÜNSTERBERG[2] found that substantives were answered by 68% substantives, 14% adjectives and 18% verbs, and that adjectives were answered mainly by adjectives, infinitives by infinitives. ASCHAFFENBURG[3] found that substantives were followed by 81% substantives, 6% adjectives, and 10% verbs.

According to BOURDON[4] words form associations through their meanings rather than through resemblance in sound.

Experiments made by GUICCIARDI and FERRARI,[5] in which a paper with the five combinations *ile, eno, ago, ondo, olle* was placed before each subject with the instruction to write as many rime-words as possible in ten minutes, showed for 54 persons 1347 rimes by spontaneous sound-association, 292 by running over artificial combinations till a word was found, 163 by memory associations of past events, 30 presumably by a mixture of sound- and writing-associations, 15 by visual associations, — the kind of association being stated by each subject himself.

In the experiments of THUMB and MARBE[6] a word was called out and a stop-watch, marking fifths of a second, was set going; upon the reply from the subject the watch was stopped. Names of personal relations (father, brother, etc.) were answered 80% of the time by names of relations (mother, sister, etc.). Certain pairs of associations were favored in frequency and quickness: father — mother, mother — father, son — father, daughter — mother, brother — sister, sister —

[1] KRÄPELIN, Ber. über d. 56. Versamml. deutscher Naturforscher und Aerzte, Freib. i/B, 1884 258.

[2] MÜNSTERBERG, *Studien zur Associationslehre*, Beiträge zur exp. Psychol., 1892 IV 32.

[3] ASCHAFFENBURG, as before, 206.

[4] BOURDON, *Succession des phénomènes psychologiques*, Rev. philos., 1893 XXXV 238.

[5] GUICCIARDI E FERRARI, *Di alcune associazioni verbale*, Rivista Sperimentale di Freniatria, 1897 XXIII No. 3.

[6] THUMB UND MARBE, Experimentelle Untersuchungen über d. psychol. Grundlagen d. sprachl. Analogiebildung, Leipzig, 1901.

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brother, etc., some of these (father — mother) being more regular than others (mother — father). Adjectives were answered mainly by adjectives of an opposed meaning: large — small, old — young, etc. These pairs were favored also in quickness. Pronouns were answered mainly by pronouns in certain favored pairs: he — she, this — that, etc. Adverbs of place and time were answered mainly by adverbs of the same class: where — there, here — there, when — then, to-morrow — to-day, etc., but with less tendency to favored pairs. A numeral was generally answered by the next higher numeral: one — two, nine — ten, etc. Verbs — interspersed with other words — were answered by 52% substantives, 42% verbs, 2% adjectives and 4% scattering. Some favored pairs appeared: give — take, take — give, etc. When the subject was limited to a verb as his response to a finite form of a verb, it was found that two persons associated most frequently the analogous number-person-tense form of another verb, while two others associated other forms of the same verb. In the latter case the favored associations were the next following person, the same form of another tense, and the participle or infinitive.

In some experiments by OERTEL[1] no such associations of numerals were found.

On the pedagogical side it seems safe to conclude that for the practical use of a language an effort should be made to have the word-associations occur quickly; that even for purposes of thought and general instruction the associations between things should be accompanied by associations between words; that one aim of instruction should be to form permanent habits of association; etc.

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[1] OERTEL, *Note on the association of numerals*, Amer. Jour. Philol. XXII 261.

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MÜLLER UND PILZECKER, *Exper. Beiträge zur Lehre vom Gedächtniss*, Zt. f. Psychol. u. Physiol. d. Sinn., 1900, Ergänzungsb. I 289. For manipulation of EWALD chronoscope: GILBERT, *Mental and physical development of school-children*, Stud. Yale Psych. Lab., 189 4II 47. For description and manipulation of D'ARSONVAL chronoscope: PHILIPPE, Technique du chronomètre de D'Arsonval, Paris, 1899. For description and manipulation of the pendulum chronoscope: SCRIPTURE, *Some new apparatus*, Stud. Yale Psych. Lab., 1895 III 98; *Elem. course in psychol. measurements*, same, 1896 IV 133; New Psychology, 155, London, 1897; The Pendulum Chronoscope (in preparation).

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CHAPTER XIII

SPECIAL ASSOCIATIONS IN SPEECH

AMONG the phenomena of speech that depend on the association of ideas no more easily investigated or more important problems could be selected than those of syntax. Although the methods readily suggest themselves, experimental work can hardly be said to have been begun and the subject can find no treatment on the present occasion. A short time ago the same statements might have been made in regard to most phonetic and linguistic phenomena involving associations of ideas; some beginnings have, however, been recently made by statistical and experimental methods.

The effect of more than one center of density (p. 137) at the same moment may be seen in 'lapses' of speech.[1]

According to MERINGER and MAYER the most frequent lapses consist in exchanges between parts of a sentence, a word or a sound appearing too soon (anticipation) or too late (postponement); in general two parts are interchanged that have similar or identical functions. Among the examples are: 'wertlaut' for 'lautwert;' 'malarium plasmodiae' for 'plasmodium malariae;' 'du leichst dir merk seinen namen' for 'du merkst dir leicht seinen namen.' Words in antithesis [or other favored associations, p. 142] are specially liable to exchange: 'da steht der einsatz nicht für den gewinn.' In most exchanges of words an adjective is exchanged for an adjective, a substantive for a substantive, etc. [that is,

[1] AVENARIUS, Kritik d. reinen Erfahrung, II 472, Leipzig, 1890; MERINGER UND MAYER, Versprechen und Verlesen, Stuttgart, 1895; BAWDEN, *A study of lapses*, Psychol. Rev., Mon. Suppl. III No. 4.

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according to the principle of favored associations]. The exchanges of syllables are not so common: 'gebrecherverhirne' for 'verbrechergehirne,' 'musikatorisch-deklamatalisch.' Vowels of nearly the same emphasis are specially subject to exchange: 'alabister-bachse' for 'alabaster-büchse,' 'reidflinsch' for 'rindfleisch.' Further frequent changes are found in those of initial consonants of syllables of approximately the same emphasis: 'denile semenz,' for 'senile demenz' ['Kelen Heller' for 'Helen Keller' is a case of my own]; and in final sounds of differently or similarly emphasized syllables: 'steinbeiss' for 'steissbein,' 'ich verganz gass' for 'ich vergass ganz.' Such exchanges do not seem to occur at all frequently between the vowels of differently emphasized syllables, as 'hendla' for 'handle,' or between initial and final sounds, as 'tug' for 'gut.' It is furthermore notable that the result of such transposition is usually a well known and habitual sound-sequence.[1]

The general rule seems to be that exchanges occur only between sounds equally important in the particular case of speech. 'The sounds of internal speech are not all of the same importance. With a sound that is just being spoken there fuse traces of all those of equal importance that are intended to be spoken and also traces of all past ones.'[2] This principle is proposed as the explanation of verbal lapses, of the action of a speech sound on those distant from it, of the similar phenomena of assimilation and dissimilation in non-contiguous sounds, of vowel harmony, of exchange, etc. In associative effectiveness the various sounds could be arranged in the descending order: 1. initial sound of the root syllable, initial sound of the word; 2. vowel of the root syllable, vowel of a syllable with secondary emphasis; 3. initial sound of an unemphatic syllable; 4. all other vowels, all other consonants.[3]

Other associations than those in the particular spoken phrase are often active; 'eine päpstliche enklitika' for 'eine

[1] OERTEL, Lectures on the Study of Language, 231, New York, 1901.
[2] MERINGER UND MAYER, as before, 164.
[3] MERINGER UND MAYER, as before, 137.

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päpstliche encyklika,' by a speaker who had written an essay on the 'encliticae.'

The scheme of possible transpositions is indicated in an example (Fig. 67) where + denotes the initial sound of an emphatic syllable, × the initial sound of an unemphatic syllable, ♁ the vowel of an emphatic syllable, — the final sound of an emphatic syllable, ⊖ the final sound of an unemphatic syllable. At the time when the *f* of *faul* has become the center of attention, the remainder of the sentence is also present in mind. The most prominent sounds *st*, *D* and *m* become closely associated and may be interchanged. The sounds of the second rank of importance are *au*, *aa*, *ä* and *ar*; these also become associated and may be interchanged. Like associations may occur in the third rank *t*, *n*, and also in the fourth rank *l*, *te*, *ne*.[1]

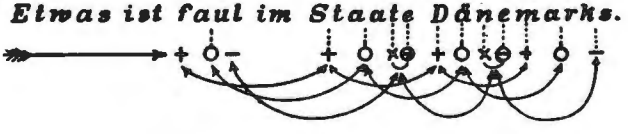

FIG. 67.

Instead of a transposition a portion of speech may replace, add itself to or unite with another without losing its own place. This may occur by anticipation or postponement. Such association occurs only between portions that are complementary to each other and not between portions of similar nature, for example, between a root syllable and an ending but not between two root syllables. Cases of anticipation occur in the various forms, 'ungehallt verhallen' for 'ungehört verhallen,' 'funktion der geschnelligkeit . . .' for 'funktion der schnelligkeit des gefühls,' 'schlēcht überlēgt' for 'schlĕcht überlēgt,' 'wie ich um die ecke gekommen bist, weist du?' for '. . . gekommen bin. . . .' The various types of postponement are to be seen in the following examples: 'er wünscht zu wünschen' for '. . . zu wissen,' 'warenheilkunde' for

[1] MERINGER UND MAYER, as before, 28.

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'warenkunde' in a conversation concerning 'heilkunde,' 'stoss eines erdbobens' for '. . . erdbebens,' 'sozialistische zekten' for '. . . sekten,' 'wie ein botāniker blūmen sā . . .' for 'wie ein botāniker blūmen sämmelt,' 'bessere leute als er sind' for '. . . er ist.' Anticipations are more frequent with the young; postponements occur mainly with the old and because of fatigue, rarely in energetic speaking.[1] MERINGER and MAYER are hardly correct in placing here the cases like 'ein rechter dummer mensch' for 'ein recht dummer mensch.' They are due rather to a lax grammatical coordination which is often found in colloquial speech for the more logical subordinating structure. A parallel case in English is 'now you are nice and dirty' for '. . . nicely dirty.'[2]

Contamination[3] is an alteration through simultaneous association. In the former case there are two nearly equal centers of density in the stream of thought which produce a combined effect. Typical examples were found in: 'hängt in zusammenhang' from the familiar phrases 'hängt zusammen' and 'ist in zusammenhang;' 'ich war bis 7 uhr zu haus habe ich geschrieben' from 'ich war bis 7 uhr zu haus' and 'bis 7 uhr habe ich geschrieben;' 'ich habe eine empfohlung an sie' for '. . . empfehlung . . .' just after hearing the words 'sie sind mir empfohlen;' 'linsengericht' for 'linsensystem.' Such contaminations of two lines of association appear in 'mixed metaphors.'

The mental processes that show themselves in lapses may be assumed to be constantly active in speech and to have contributed to the changes in language. It is possible that some actual lapses frequently repeated may have been imitated by the community and so passed into the language (PAUL). It is more probable that the lapses confused the memory images of certain words so that the speakers became uncertain as to the proper form and finally adopted the new one.

As examples of word forms that have arisen by contamina-

[1] MERINGER UND MAYER, as before, 52.

[2] STORM, Englische Philologie, 2. Aufl., I 690, Leipzig, 1896.

[3] MERINGER UND MAYER, as before, 53; OERTEL, as before, 170.

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tion we may select[1] German 'gewohnt' from the Middle High German adjective 'gewon' and the participle 'gewent' from 'wenen,' gewöhnen; 'zu guter letzt' from 'zu guter letz (Middle High German 'letze,' departure) and 'zu letzt;' 'Fritzens' for 'Fritzen,' under influence of the common genitive ending 's;' 'gegessen' from 'gezzen' from the feeling for the usual extra prefix 'ge' in the participle. These cases indicate, I believe, the close connection between functional association (p. 149) and the fusion of past associations. Examples of phrase forms arising by contamination are:[2] 'das gehört mein' from 'das gehört mir' and 'das ist mein;' 'I am friends with him' from 'I am friendly with him' and 'we are friends;' 'der selbe wie' from 'der selbe der' and 'der gleiche wie.'

The phenomenon of assimilatory condensation, as in 'ein kleinernes' for 'ein kleines schweinernes,' has been called 'contamination by successive association.' The whole phrase is in mind while it is being uttered; the riming of two of the prominent sounds causes an immediate transfer of the center of density from one syllable to the other; in the utterance the intervening sounds are slurred or omitted. I have observed a related phenomenon in the case of a child two years old who usually said **dēētĕkŏ** for **dēdŏtĕkŏ**, **māzkōt** for **māmŏzkōt**, **ĭnbēzrūm** for **ĭnbēbĭzrūm** although the longer forms were often used also. Careful observation led me to believe that the omitted syllables were not simply dropped out but were represented in utterance by some very brief sounds at the ends of the preceding syllables; thus the glide from **z** to **r** in **ĭnbēzrūm** seemed to differ from the usual one although I could not hear any very distinct sound or detect any special b-movement of the lips. From the general laws of mental life and from some experimental records of speech sounds we would expect that even with such a condensation of thought the vocal organs will perform the usual movements in a highly abbreviated way and produce what might be called rudimentary sounds. The question can be

[1] PAUL, Principien der Sprachgeschichte, 3. Aufl., 145. Halle, 1898.
[2] PAUL, as before, 149.

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decided only by experiments. The phenomena seem related to those of haplology found in the history of words, as in 'nutrix' for 'nutritrix.'

It is to be noted that among the thousands of lapses in German noted by MERINGER and MAYER certain forms were rare: exchanges within a group of consonants (only one case, 'skenien' for 'xenien'); omission of letters except in final syllables; omission of syllables that cannot be explained by the principles of association ('erste katorie' for 'erste kategorie'). Omissions of letters and syllables occur, however, constantly in ordinary speech; such phenomena of syncope in the history of language have been explained as the results of increased speed (BRUGMANN) but most of them are rather to be considered as economy effected by condensation.

Such effects of visual and written lapses on a large scale may have occurred[1] at the time of the great adoption of French words into English; thus the use of *n* for *u* in foreign words may have produced two forms of which the incorrect one finally prevailed. Thus the Old French has 'enhaucer.' In Anglo-Norman the forms 'enhancer' and 'enhauncer' are found which → 'enhaunce' → 'enhance,' the Anglo-Norman forms probably (KÖPPEL) arising from erroneous writing of *n* for *u* in the Old French form.

In the history of language there has been at all times a tendency to make commonly associated words alike in form. MERINGER and MAYER would explain such historical assimilations in the same way as assimilations that occur in lapses (above); it may be suggested that the principle of economy by similarity may be applied here as well as to the explanation of vowel harmony (p. 121).

A good illustration of the mental action in assimilation by analogy is to be found in BROWNING'S word 'gadge' in the lines

> 'The dead back-weight of the beheading axe!
> The glowing trip-hook, thumb-screws and the gadge!'
> (*A Soul's Tragedy*, Act I.)

[1] KÖPPEL, *Spelling-Pronunciations*, Quellen u. Forschungen zur Sprach- u. Culturgeschichte, 1901 LXXXIX 1.

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Upon being told that he had probably meant to write 'gag' he replied: 'Gadge is a real name, in JOHNSON, too, for a torturing iron.' The word is not given by JOHNSON. BROWNING probably[1] had in mind the form 'gagge' and had changed it to 'gadge' after analogy with 'egge,' 'wegge,' 'brigge' which have become in Modern English 'edge,' 'wedge,' 'bridge.'

The assimilation of a somewhat different word to the form of a group with which it is associated is seen in the change of 'october' to 'octomber' or 'octember' to resemble 'september,' 'november,' etc. in Vulgar Latin, Old French, Modern Greek and Slavic. A like assimilation occurs in forming new words as 'electrocute' in America. The common ending is felt by the popular mind as a suffix (e. g. 'mber,' 'cute') to be added to a class of words.

The process of assimilation as a principle of economy of thought appears in the following remarks by WHITNEY.[2] 'When phonetic corruption has disguised too much, or has swept away, the characteristics of a form, so that it becomes an exceptional or anomalous case, there is an inclination to remodel it on a prevailing norm. The greater mass of cases exerts an assimilative influence upon the smaller. Or, we may say, it is a case of mental economy: an avoidance of the effort of memory involved in remembering exceptions and observing them accurately in practice. The formal distinction of plural for singular was one which our language was never minded to give up. Of all the plural signs, the one which had the most distinctive character was *s*. The attention of the language-users became centered upon this as an affix by which the plural modification of sense was made, and then proceeded to apply it in words where it had not before been used; and the movement, once started, gathered force in its progress until it swept in nearly all the nouns of the language. So with the verb. By the numerical predominance of forms like *loved* from *love*, the addition of a *d* got itself more

[1] KÖPPEL, as before, 39.

[2] WHITNEY, Life and Growth of Language, 75, New York, 1875.

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conspicuously associated with the designation of past time; and men began to overlook the cases which by right of former usage ought to be made exceptions.' This reaction against unusual forms and purposeless differences is seen constantly in the history of language.[1]

These phenomena of assimilation, which seem closely related to those of functional assimilation, are to be explained in much the same way.

The principle of favored associations appears clearly in various familiar examples of assimilation collected by THUMB and MARBE.[2] Vulgar Latin has 'grevis' from 'gravis' by association with 'levis.' The influence of the word for one numeral on that for the following one is seen in Greek 'δυσί' for 'δυοῖν' influenced by 'τρισί,' Gothic 'fidwôr' for '*hwidwôr' by 'fimf,' Lithuanian 'septynì' for '*septimì' by 'asztunì,' Latin 'novem' for '*noven' by 'decem,' Lithuanian 'devynì' for '*navynì' by 'deszimts,' Slavic 'devętĭ' for 'novętĭ' by 'desętĭ.' The influence of adverb-associations is seen in the resemblances of forms in Gothic 'hwar, thar, hêr;' Old High German 'wâr, thâr, hiar;' Anglo-Saxon 'thider' for '*thæder' by 'hider;' Middle High German, 'wannân, dannân, hinnân;' Modern Greek τώρι (for τώρα 'now'), ἀπόψι for ἀπόψε, 'to-day,' etc. The influence of associated pairs of pronouns is seen in Greek ἡμεῖς for *ἠμεῖς by ὑμεῖς, Modern Greek ἐσουνοῦ for ἐσοῦ by 'αὐτουνοῦ,' etc. Favored associations in verbs result in assimilative changes as in Ital. 'rendere' for 'reddere' influenced by 'prendere,' Port. 'bebesto' from Lat. 'bibitus' by 'comesto.' Assimilations that correspond to such associations are found in 'ich frug' for 'ich fragte' after 'ich trug.'

Assimilation by analogy may be made to include the cases of change in pronunciation due to spelling. In recent times, when the use of printed words has become as

[1] PAUL, Principien d. Sprachgeschichte, Ch. X. *Isolierung und reaction dagegen*, 3. Aufl., 170, Halle, 1898.

[2] THUMB UND MARBE, Exper. Untersuchungen über d. psychol. Grundlagen d. sprachl. Analogiebildung, 49, Leipzig, 1901.

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frequent and as important as that of spoken words — for some people even more frequent and important — there is a tendency to assimilate spoken words to forms suggested by the usual associations of sounds to spelling. It is to this influence that we may ascribe some of the variations of American pronunciation in different parts of the country. A similar tendency appears in Northern British English. '[The North] is much less tolerant of pronunciations which go against the normal force of the spelling, such as the *z* in . . . discern, dishonour, sacrifice, abscission, transition.'[1] In England the pronunciation of many words has been influenced by the spelling; a summary of the cases has been given by KÖPPEL;[2] an illustrative case is that of h. 'Initial h, which was preserved through First and Second Modern English, began to be dropped at the end of the last century, but has now been restored in Standard English by the combined influence of the spelling and of the speakers of Scotch and Irish English.'[3] The restoration in Southern English has occurred completely in a series of words[4] such as 'hereditary, hospital, hostile, humility, habit, hebrew, hermit, homage, horizon, hosanna, host, hostage.' In some words like 'hostler, herb, humble, humor,' the h is sometimes omitted, although this practice is decreasing. In 'heir, honest, honor, hour,' the h is completely dropped. In America the restoration is complete and the initial h of stressed words is never dropped except in 'heir, honest, honor, hour' and some derivatives. Even in unstressed syllables the American seldom drops the initial h although he may weaken it. Such pronunciations as ənotel for 'a hotel,' ənistɔrikl for 'a historical' are not used in ordinary speech; the spellings 'an hotel' and 'an historical' which are sometimes used in American books to conform to British spellings, do not represent — as they do in England — the actual pronunciation; an American would read 'an

[1] LLOYD, Primer of Northern English, 31, Marburg, 1899.

[2] KÖPPEL, *Spelling-Pronunciations*, Quellen u. Forsch. zur Sprach- u. Culturges., 1901 LXXXIX 1.

[3] SWEET, New Engl. Grammar, 280, Oxford, 1892.

[4] KÖPPEL, as before, 4.

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hotel' as **ən hotel** or, rather, **æn hotel** and would feel it as a foreign oddity. It is to be noted that the rough American **h** is quite a different sound from the faint Southern English **h** and that it cannot be dropped without making a much greater change in the impression on the ear.[1]

When a sound or a group of sounds is perceptibly like another, this other may be brought by association more or less into mind, with possible interruption of the course of thought. This effect is produced by alliteration and rime in verse for just that purpose. It is offensive in prose when noticed because it interrupts the succession of ideas. This is probably the reason why the English language does not like the immediate repetition of any emphatic word. It is possibly also the cause of such harmonic dissimilation of sounds as in Latin 'solaris' for 'solalis,' 'sepulcrum' for 'sepulculum,' 'meridies' for 'medidies;' Greek *ἐτέθην* for *ἐθέθην*, *τίθημι* for *θίθημι*; Spanish 'árbol' from 'arborem;' French 'rossignol' from 'lusciniolam.' The loss of consonants or of syllables may occur also for the same reason. The peculiarities of the cases in which these phenomena occur perhaps depend on the degree with which the similarity attracts attention.

In many of the lapses the tendency to dissimilation is clear; it is to be noted that in the conversational speech of to-day blunders are sometimes found when the conditions are the same as those that in the history of language produced dissimilations of sounds or syllables.[2] It may be possible, however, to explain some dissimilations on the principle of mental economy (p. 122). Just what relation this principle bears to lapses is not clear. Many of the phenomena of dissimilation are still obscure.[3]

The explanations of MERINGER and MAYER seem to apply clearly to one form of metathesis, namely, that where two

[1] SHAW, Three Plays for Puritans, 314; quoted in OERTEL, Lectures on the Study of Language, 239, New York, 1901.

[2] MERINGER UND MAYER, as before, v.

[3] OERTEL, Lectures on the Study of Language, 208, 232, New York, 1901.

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more or less distant sounds change their places, as Latin 'crocodilus' → Middle High German 'kokodrille,' Italian 'glorioso' → dialectic 'grolioso,' Latin 'periclum' → Spanish 'peligro.' Metathesis of neighboring sounds[1] as Anglo-Saxon 'fix' = Old High German 'fisc,' 'first' = 'frist,' seems to find little analogy in lapses; MERINGER and MAYER[2] found only one case in their records. I find one ('wist' for 'wits') in BAWDEN'S list[3] in which two neighboring sounds are exchanged. MICHELS'S[4] explanation of Indger. '*pōtmen' → 'ptōmen' as having arisen by widely spread lapses seems difficult to accept. Under the influence of a printed word where the elements are perceived *simultaneously* it might well occur that two neighboring elements should exchange places in the spoken word, as in the actual case of 'frith' for 'firth'; but the change of order in a *succession* of auditory and motor elements, as 'fiks' for 'fisk,' is a speech phenomenon whose fundamental psychological principles have not yet been investigated. A suggestion may be found in the fact that an idea includes a group of elements extending over a region of time; considered in this way the cases do not differ fundamentally from those of metathesis of distant sounds.

The subject of associative interference in speech should be attacked by experimental methods. Phenomena that show themselves strikingly to cursory observation will be found — according to a well-established psychological principle — to occur regularly in minor degrees in all persons. By measurements of the increase of time in speaking a phrase when the subject hears or has just heard an interfering association the nature of the fundamental process might be investigated. The experimental conditions are not hard to arrange. In this way the incipient stages of verbal lapses might be traced by the differences in time.

Measurements of association-time may perhaps be used to

[1] PAUL, Principien der Sprachgeschichte, 59.

[2] MERINGER UND MAYER, as before, vii.

[3] BAWDEN, *A study of lapses*, 111, Psychol. Rev., Mon. Suppl., III, No. 4.

[4] MICHELS, *Metathesis im Indogermanischen*, Indogerm. Forschungen, 1894 IV 62.

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study the effect of the emotional tinge on the use and fate of words, the stages of expansion and contraction in the meaning of a word, the disturbance of the meaning of one word by a change in that of another, and various other special associations in speech.

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CHAPTER XIV

FORMATION OF SPEECH ASSOCIATIONS

LEARNING a language consists to a large extent in forming associations among ideas and words. The determination of the best methods of doing this should be one of the chief objects of experimental phonetics.

When experiments are made to determine the influence of one factor in a method, all other factors must be kept constant. The skill of the experimenter is mainly involved in attempting this, and the accuracy of the results depends on the degree of approximation to this condition. The disagreements of the results of various investigators are generally due to lack of accuracy in this respect; the results of the less accurate experiments are to be rejected in favor of those of more accurate ones. With the progress of the science and the development of its technique the accuracy steadily increases.

When it is desired to determine the facts of association depending on the forms of speech and not on the meaning, experiments may be made with symbols, such as meaningless syllables, figures, or signs. Syllables come most closely to the actual conditions of language; their preparation requires considerable care in order to make the conditions alike in different experiments. The various series of syllables should be built as equally as possible. The 'normal' series of MÜLLER and SCHUMANN[1] consisted each of 12 syllables made in the following way. The letters *b*, *d*, *f*, *g*, *h*, *j*, *k*, *l*, *m*, *n*, *p*, *r*, *s*, *t*, *w*, *z*, *sch* representing 17 initial consonant sounds in German were written on small pieces of cardboard. The

[1] MÜLLER UND SCHUMANN, *Exper. Beiträge zur Untersuchung d. Gedächtnisses*, Zt. f. Psychol. u. Physiol. d. Sinn., 1893 VI 19.

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pieces were mixed in a box. Likewise a similar collection *aa*, *a*, *e*, *i*, *o*, *u*, *ä*, *ö*, *ü*, *au*, *ei*, *eu* for the vowels and diphthongs and a third collection *f*, *k*, *l*, *m*, *n*, *p*, *r*, *s*, *t*, *z*, *ch*, *sch* for the final consonants were arranged. To form a syllable one card was drawn by chance from each box; the cards were not replaced in the box. In this way 12 totally different syllables were obtained; for example, *baup*, *teir*, *schös*, *mal*, etc. In case two successive syllables had similar contiguous consonants or formed a word, the order of the syllables was changed; certain objectionable combinations were avoided. The method may be readily applied to any language.

The symbols, syllables, words or pictures to be learned may be presented to the eye by holding up or turning over cards successively at regular intervals,[1] or by placing each behind a shutter which opens for a definite time at definite intervals[2] (p. 136), or by placing them on the surface of a revolving cylinder which shows each for a given time as it passes before an opening in a screen.[3] The first of these methods is very convenient. Special care is required in keeping the conditions constant. The cards must be shown evenly at a definite rate. The use of a revolving cylinder renders it possible to obtain a constant rate of exposure; the movement of the syllable while it is seen is somewhat disturbing. The ideal method would be a strip of syllables jerked forward and exposed by a mechanism similar to that of a kinetoscope, or a drum with syllables moved by an intermittent gear connected with a shutter over the exposure opening.

As tests for the formation of associations among series of syllables, the following ones have been employed.

The test of first complete formation consists in going over the syllables until the set can be repeated at a definite rate

[1] EBBINGHAUS, Ueber das Gedächtniss, Leipzig, 1885.

[2] SCRIPTURE, *Ueber d. qual. Verlauf d. Vorstellungen*, Philos. Stud. (Wundt), 1891 VII 50.

[3] MÜLLER UND SCHUMANN, *Exper. Beiträge zur Untersuchung d. Gedächtnisses*, Zt. f. Psychol. u. Physiol. d. Sinn., 1900 VI 81; MÜLLER UND PILZECKER, *Exper. Beiträge zur Lehre vom Gedächtniss*, Zt. f. Psychol. u. Physiol. d. Sinn., 1900 Ergänzungsb. I 99.

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correctly from a given one for the first time without hesitation and with a consciousness of correctness.[1] They should be read each time from beginning to end and not learned in portions; the learner attempts as soon as possible to announce the next syllable before it is seen and in case of success to continue the announcement from memory without looking at the syllables; upon any hesitation the remainder of the series is read through as usual; when the whole series is first repeated correctly from memory, it is considered as having been learned; the number of repetitions (also the length of time) required is taken as the measure of the work involved.

Another test consists in recording the number of syllables that can be reproduced. The subject may be left free during a given time to recall in any way he can as many syllables as possible, or a syllable may be shown him and the next one required, or his method of recollection may be regulated in some other way.

A third test may be made by measuring the time required for a person to recall the syllable following one shown him, that is, the time of association (p. 155). He may be instructed to give the following syllable as quickly as possible, whether he is perfectly sure or not, and to use the word 'no' in case he feels that he has forgotten the right one.[2]

The maintenance of constant internal conditions is important. Maximum attention may be approximately obtained by requiring the syllables to be learned as rapidly as possible; rest is attained by pauses between series; the same hour of the day is employed for experiments that are to be compared; the manner of living is changed as little as possible; the involuntary tendency to rhythmic emphasis is regulated by adoption of some one form.[3] Learning in trochaic rhythm has been adopted in several investigations.[4]

[1] EBBINGHAUS, as before, 31.

[2] MÜLLER UND PILZECKER, as before, 8.

[3] EBBINGHAUS, as before, 34.

[4] MÜLLER UND SCHUMANN, as before; MÜLLER UND PILZECKER, as before.

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In conducting experiments where the number of successes is compared with the total number of the trials, it is necessary to follow the established methods of statistics; there must be exact definition and treatment of the countable unit; there must be careful investigation of the laws of probability involved; and accurate determination of the degrees of trustworthiness to be attached to the results.[1] Many of the mathematical methods that have led to discoveries in biology will prove of value in the problems of memory.

EBBINGHAUS'S experiments have shown that the number of repetitions required for learning different series of meaningless syllables increases at first slowly, then rapidly, and finally less rapidly, as the series are longer; that each repetition of a series saves the same amount of labor in relearning it at a later time; that the memory effect, as judged by the saving in relearning a series at a later time, decreases as the logarithm of the elapsed time; that when many repetitions are necessary it is more advantageous to scatter them over a considerable time than to do them at once; that members of a series of syllables become associated not only with the adjacent ones but also with the others.[2]

JOST[3] has shown that the repetition of an association adds the more to its firmness the longer the time it occurs after the association is first formed; the result is seen in the greater effectiveness of spreading the repetitions of an association over long intervals as compared with bunching them. This seems to indicate that in learning a language, if the number of possible repetitions is limited, as by the number of lessons, the repetitions should occur at the longest possible intervals.

The experiments of MÜLLER and PILZECKER[4] showed

[1] SCRIPTURE, New Psychology, Ch. II, *Statistics*, London, 1897; EBBINGHAUS, Ueber d. Gedächtniss, Leipzig, 1885.

[2] Some of EBBINGHAUS'S tables and curves are reproduced in SCRIPTURE, New Psychology, Ch. XII, London, 1897.

[3] JOST, *Die Associationsfestigkeit in ihrer Abhängigkeit v. d. Verteilung d. Wiederholungen*, Zt. f. Psychol. u. Physiol. d. Sinn., 1897 XIV 436.

[4] MÜLLER UND PILZECKER, as before, 194.

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that the number of correctly reproduced syllables increased with the number of repetitions; that the time T_r for associating the correct syllable decreased slightly; that the time T_f for associating the wrong syllable (when that occurred) increased; that the time T_v of saying 'no' on not being able to remember the syllable also increased; that in all cases $T_r < T_f < T_v$; that under equal circumstances the time of response increased with the time that had elapsed since the formation of an association.

The associations in a series of syllables are weaker if the learning of the series is immediately followed by active attention to some other work. Syllables that have already been associated with certain others are more difficult to bring into new associations, but their use in forming the new associations strengthens the older ones.[1]

The number of words that can be remembered in the form of connected phrases is very many times that of disconnected words; the most important words in phrases are best remembered; in short phrases the number of replacements of the original word by a synonym is greater than the number of words forgotten; in long phrases it is less; for phrases of more than 20 words there was, among more than half the pupils tested, a slight alteration of the sense of the phrase when reproduced.[2]

Arrangement of the material in rhythmic groups aids in fixing associations. For meaningless syllables the trochaic rhythm seems most favorable for Germans;[3] individual preferences are found.[4]

According to observations made by SMITH,[5] in which persons were required to learn a series of figures in 20 seconds, the slower the readings the better the memory, the percentage of mistakes being 3.3% for one reading lasting over the

[1] MÜLLER UND SCHUMANN, as before, 177, 318.
[2] BINET ET HENRI, *Mémoire des phrases*, Année psychologique, 1895 I 24.
[3] MÜLLER UND SCHUMANN, as before, 18, 257.
[4] SMITH, *Rhythmus und Arbeit*, Philos. Stud. (Wundt), 1900 XVI 197.
[5] SMITH, *On muscular memory*, Amer. Jour. Psychol., 1896 VI 453.

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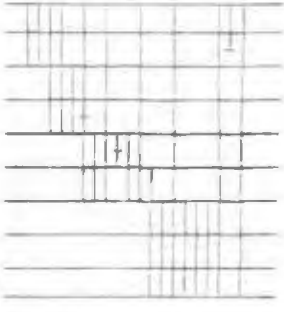
given time, 4.2% for two in the same time, 5.5% for three, and 6.5% for four. Memorization was said to be aided by speaking in a loud tone.

The methods of learning quantities of language have been investigated by STEFFENS.[1] The usual method of learning a stanza of poetry consists in repeating the lines in various groups. The variations in the repetitions followed by different persons in learning a strophe of Byron's *Don Juan* were indicated by STEFFENS in the following manner.

1. To horse! to horse! he quits forever quits
2. *A scene of peace*, though soothing to his soul;
3. Again he rouses from his moping fits,
4. But seeks not now the harlot *and the bowl*.
5. Onward he flies, *nor fix'd as yet the goal*
6. Where he shall rest him on his pilgrimage;
7. And o'er him many changing scenes must roll
8. Ere toil his thirst for travel can assuage,
9. Or he shall calm his breast, or learn experience sage.



This indicates that the person read the first two lines in succession, then repeated them, then read the first four lines, then repeated them, then read the third and fourth, then read the first six, but repeated the words 'and the bowl' an extra time, etc. The division of such a strophe into portions differed with each individual, but the general principle of learning by portions was always followed. STEFFENS then had strophes of verse, series of syllables, etc., learned by the same persons in two different ways: 1. as the person chose, that is, by portions; 2. by repeating the whole material each time from beginning to end; the results without exception showed a great economy in the second method. This advantage of the totality method over the sectional method was clearly and definitively established for material of practically constant character, the common prejudice in favor of the sec-

[1] STEFFENS, *Exper. Beiträge zur Lehre vom ökonomischen Lernen*, Zt. f. Psychol. u. Physiol. d. Sinn., 1900 XXII 321.

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tional method being shown to be unfounded. In view of the possible extensive application of this principle to the most varied subjects of teaching, the experiments should be extended to such problems as the learning of a vocabulary, the learning of phrases, etc. The principle seems to indicate, for example, that, if 25 pages of a foreign language are to be committed to memory, the work should not be done in sections, but that the whole should be gone over completely each time until learned. If the principle holds good, the statement[1] cannot be accepted that 'Economy teaches us to begin with as small a vocabulary as possible, and to master that vocabulary thoroughly before proceeding to learn new words.'

Experiments have shown[2] that under equal conditions a firmer association is made between a picture and a printed word than between two printed words, and that the learning of foreign words is aided by placing pictures rather than translations beside them. This principle has been used as an aid in various methods of instruction (COMENIUS) and has been adopted into most books for early lessons in the native language. Its application to the teaching of modern foreign languages, though comparatively recent, has been found to be highly successful. No systematic attempt appears to have yet been made to introduce it into the teaching of the ancient languages.

Experiments by MÜNSTERBERG and BIGHAM[3] seem to indicate that for figures the visual memory is superior to the auditory, and that both combined give still better results.

In experiments by KIRKPATRICK,[4] ten short words were pronounced to 379 school and college pupils, ten other words on a blackboard were exposed, and finally ten objects were shown, all at the same rate of one in two seconds. Immediately after each set was finished the pupils wrote as many as they could remember; three days later they again wrote all

[1] SWEET, The Practical Study of Languages, 110, New York, 1900.
[2] SCRIPTURE, *Education as a science*, Pedagog. Sem., 1892 II 111.
[3] MÜNSTERBERG AND BIGHAM, *Memory*, Psychol. Rev., 1894 I 34.
[4] KIRKPATRICK, *An experimental study of memory*, Psychol. Rev., 1894 I 602.

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that they could remember. The average numbers of items remembered immediately were 6.9, 6.9, 8.3 respectively, indicating the more efficient action of objects; the average numbers of words correctly remembered after three days were 0.9, 1.9, 6.3, showing a surprisingly great superiority of the memory for objects. The value of objects for forming firm associations probably depends on the much greater impression they make. In another set of experiments on other pupils the figures were 7.3, 7.8, 8.0 for immediate memory and 1.8, 0.5, 3.5 after an interval of three days. In order to determine to what extent the power to recognize completely or partially might remain when the limit of recalling had been reached, the words for the thirty original items were, at the end of the experiment on the third day, mixed with fifteen other words, the pupil being required to pick out the correct ones. The average results were 3.8, 2.7, 6.0 placed in the correct lists, the ability to recognize being greater than the ability to recall.

Series of meaningless syllables are generally more quickly learned when presented to the eye than to the ear, but are apparently *not* more firmly fixed in memory.[1]

Experiments on the methods of forming associations among the elements of words have been made by LAY.[2] According to LAY every didactic theory or hypothesis has its importance, but a feeling of insecurity is attached to it because it presents deductions from deductions and is far removed from the certainty of direct scientific experience; principles that are to be valid for the practical arrangement of a subject for teaching must have as high a degree of certainty as possible; the various methods proposed must be tested by accurate scientific experiments. LAY'S experiments in teaching the spelling of meaningless words showed that the thoroughness of learning a certain number of words depended on the method

[1] WHITEHEAD, *A study of visual and aural memory processes*, Psychol. Rev., 1896 III 258.

[2] LAY, Führer durch den Rechtschreibunterricht, 2. Aufl., Wiesbaden, 1899; *Didaktisch-psychologisches Experiment, Rechtschreiben und Rechtschreibunterricht*, Zt. f. päd. Psychol. u. Pathol., 1900 II 95.

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employed; simple hearing (dictation by the teacher) resulted in an average of 3.04 errors per pupil; hearing with soft verbal repetition by the pupil, 2.69; hearing with loud repetition, 2.25; simple seeing, 1.22; seeing with soft verbal repetition, 1.02; seeing with loud repetition, 0.95; loud spelling by the pupil, 1.02; copying with the hand, 0.54. The most efficient method was thus that of copying; the least efficient that of dictation. It may be suggested that copying involves unusual concentration of attention to the word shown and to the details of the word executed. The words in these experiments were repeated the same number of times; the dictation method thus required less time than the copying method. It was necessary, then, to determine which method gives the best results for the same time required in learning. LAY showed that, for the same time spent in learning, the copying method was the best, the visual reading with vocal repetition less good, the spelling and dictation methods still less efficient. He showed by experiment that the same order of efficiency prevailed in forming the permanent spelling associations. His results also showed that the vocal organs have far more influence in learning to spell than did the ear (that speaking was better than hearing); that the visual image was two to three times as effective as the auditory image; that copying was superior to seeing alone; that an understanding of the meaning of a word [greater attention aroused by interest] was an enormous aid.

SCHILLER[1] reports two sets of experiments on learning the spellings of words.

The first set consisted in learning to spell German words by various combinations of the senses and the volitions. The results showed the following relations in ascending order among the errors in spelling made by the pupils in one class: 1. copying the written word while softly pronouncing it; 2. copying while loudly pronouncing it; 3. looking at it and making movements of the hand in the air as if writing

[1] SCHILLER, *Studien und Versuche über die Erlernung d. Orthographie*, Samml. v. Abh. aus d. Gebiete d. päd. Psychol. u. Physiol., 1898 II 4. Heft.

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it; 4. spelling it aloud; 5. looking at it while pronouncing it loudly; 6. looking at it while pronouncing it softly; 7. looking at it with mouth closed; 8. hearing the word and making movements in air as if writing; 9. hearing it and pronouncing it loudly; 10. hearing it and pronouncing it softly; 11. hearing it only. The most accurate method was thus that of copying a written (or printed) word, the least accurate was that of hearing it. In general loud pronunciation at the same time helped.

The second series of experiments was on the learning of Latin words; the results were similar except in the fact that simultaneous loud pronunciation was disadvantageous in all cases.

In investigations by KEMSIES[1] ten dissyllabic Latin words with their dissyllabic German translations were presented five times in succession to groups of school-children, who were then required at once to write down all they had learned. In one form of experiment the words were read off, in another they were shown in print and in a third they were both read and shown. The experiments in which the words were heard showed great advantages over the others, both in the amount learned and in its exactness. The visual method was least successful. The combined learning by hearing and seeing showed on an average no advantage over that by hearing only; the gain by using two senses seemed often overbalanced by the distraction of attention thereby. This latter difficulty might — I suggest — be due to the particular method employed. When the words were learned first by one method and then by another, the result was not so good as when the same method was employed throughout. In learning the spelling of words KEMSIES found that visual learning was not so good as the auditory or auditory-visual learning.

In later experiments KEMSIES[2] used meaningless dissyl-

[1] KEMSIES, *Gedächtnissuntersuchungen an Schülern*, Zt. f. päd. Psychol. u. Pathol., 1900 II 21, 84.

[2] KEMSIES, *Gedächtnissuntersuchungen an Schülern, III.*, Zt. f. päd. Psychol. u. Pathol., 1901 III 171.

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labic words (to represent foreign words) with a dissyllabic German word (native word) for each to represent its translation. The following is a specimen set:

lómsi	achtbar	vágul	neulich
sípaf	Kutscher	kógri	scheinen
eúbor	lieblich	fédok	Nächte
émok	blasen	ráfus	Schmiede
túgan	Flasche	geíkul	sonnig

These sets were spoken by the experimenter, or were shown in large letters, or were both spoken and shown. For the auditory presentation the pupils sat with closed eyes in a quiet room; for the visual presentation the words appeared as transparencies to the pupils in a dark room; for the combined presentation the experimenter spoke the words in connection with the visual presentation. In one form of experiment the words were presented at the rate of half a second for each syllable, making 1^s for each word, 20^s for a set and 100 for five repetitions of a set. The test of learning consisted in writing the words as soon as possible after the end of the presentation. In another form of experiment the words were repeated at the same rate until the entire set was sufficiently learned so that the words were all recognizable although not necessarily completely reproducible. The final results by these methods have not yet been published.

The firmness of an association depends on the vividness of the impressions. Various methods of producing vivid impressions are used in forming language associations; they are based on the pedagogical methods used to fix attention.[1]

Motor (spoken) words are more firmly associated with each other than with auditory words. Only rarely — as with the deaf — are they directly associated with visual words. In learning to speak a foreign language the words should be constantly spoken in connection in order to establish direct associations among the words in their motor forms. The

[1] Summary of these in the chapters on attention and memory in SCRIPTURE, Thinking, Feeling, Doing, 2. ed., New York (in press).

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attempt to form associations mainly with auditory words is wasteful. With visual words it is quite impracticable to form associations readily available in conversation. All these sets of associations should be united so that the person 'thinks' a foreign language just as he does his own. The formation of associations between the native and the foreign language is liable to hinder the associations within the foreign language. The fundamental method to be followed in learning a language may be said to be that of forming, as firmly as possible, such associations among the language elements as actually occur in the language itself. 'The whole process of learning a language is one of forming associations.'[1]

In closing this chapter I feel compelled to emphasize the obligations of the science of experimental phonetics in respect to the methods of teaching languages, native and foreign, modern and classical. The present diversity of methods and conflict of opinions can have no possible justification except the lack of scientific data. The human mind acts according to just as definite laws as the expansion of steam and the transmission of motion. That more work can be gotten out of a pound of coal by the proper scientific and technical knowledge of applying it under the proper circumstances is no more true than it is that a thorough understanding of the mental processes involved in learning a language will render the economy and progress far greater than at present. These processes are still scientifically uninvestigated, and will probably remain so except in so far as experimental phonetics carries on the work. The results reported in this chapter are no more than indications of what is to be done; each practical problem — the value of pictures in elementary instruction, the value of translations from the native to the foreign language, etc., — must be solved by measurements of such accuracy as to be conclusive.

[1] SWEET, The Practical Study of Languages, 103, New York, 1900.

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PART III

PRODUCTION OF SPEECH

CHAPTER XV

VOLUNTARY ACTION AND THE GRAPHIC METHOD

THE production of vocal sounds results from the action of muscles. A muscle is a contractile body of slight but very complete elasticity; it is stretched to a great extent by a small pull but returns to its original length when released. The voluntary muscles are composed of fine fibers that extend the whole length of the muscle. The contraction of a muscle consists of the contraction of its fibers; this produces a decrease in length and an increase in thickness.

The laws of muscular contraction are best illustrated by experiments with the gastrocnemius muscle removed from the leg of a frog. To prepare the muscle, the top of a frog's head is cut off by inserting one blade of the scissors across the mouth, and placing the other behind the skull; the skin is stripped from the leg, the heel-tendon is cut, the muscle of the calf of the leg is separated from the rest, and cut from the bone. The muscle is kept moist by a brush dipped in a solution of $\frac{7}{10}$ of 1% of salt in water. The muscle is supported by a hook; another hook passing through the heel-tendon is attached to a simple recording lever writing on a moving surface. The scheme of the arrangement for recording a curve of contraction is shown in Fig. 68. The muscle *m*, stretched by a weight *g*, is attached to the lever *h* whose point *r* writes on a smoked plate *o*. This plate carries a projection *d* which, as it is moved, strikes the key *k* and breaks

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the circuit containing the battery *c* and the primary coil *p* of an inductorium *sp*. The breaking of the primary circuit *cpk* produces a momentary impulse in the secondary coil *s* which stimulates the muscle *m* through the wires carried to the hooks. The plate is covered with soot in the usual way (p. 7). It is first moved slowly and stopped when it just breaks the circuit; the muscle contracts and draws the vertical line seen at *r* in Fig. 69; this indicates the point on the plate at which the shock occurs. The plate is now returned to its position and moved rapidly along. The muscle draws its curve of contraction *k* on the plate. The record shows that the contraction begins at some time after the shock, rises to a maximum and then falls.

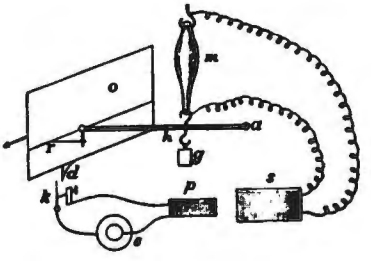

FIG. 68.

The 'myograph' plate can be replaced by a recording surface of any kind (Figs. 6, 7, 8, 71); a mechanism for breaking the primary circuit is readily attached to the axle (p. 93).



FIG. 69.

By placing a common telegraph key or a contact wheel (p. 91) or an electric fork (p. 15) in the primary circuit of the inductorium (Fig. 68), a series of shocks may be sent to the muscle. Each shock produces an effect; if the shocks follow so rapidly that the relaxation is not complete, the effects are added; when the shocks are sufficiently frequent, the muscle is strongly contracted without visible relaxation, the condition being called 'tetanus.' The tetanic contraction, however, consists of contractile movements whose frequency

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is the same as that of the shocks; when the muscles of the cheek are tetanized by the inductorium, a person with closed ears can hear a tone of the same frequency as that of the interruption of the primary circuit. Shocks so weak that no visible effect is produced when they are used singly may produce contraction if they are repeated with sufficient frequency; thus an irritation leaves an increased irritability.

To demonstrate the action of the nerve on a muscle the frog's gastrocnemius may be used with the sciatic nerve attached. The preparation is made as before (p. 188), but the sciatic nerve is carefully separated from the muscles along the thigh and cut as near the spinal column as possible; moreover, the muscle is left attached to the bone at the knee and the bones are cut just below the knee and half-way up the thigh. The muscle suspended from the thigh-bone is clamped in a standard and connected to the recording lever as before. The wires from the secondary coil are brought close together in a small handle and the nerve is laid across the ends by means of a small brush dipped in the salt solution. A shock to the nerve is followed by a contraction of the muscle. More time elapses between the moment of the shock and that of contraction than when the muscle is stimulated directly. This time increases with the length of the portion of the nerve between the muscle and the electrode. The irritation is conducted along the nerve at the rate of about 27^m a second; for the motor nerve of the human arm the rate is from 34^m to 43^m. Repeated shocks are followed by repeated contractions, and by tetanus.

The voluntary contraction of a muscle is tetanic. When the cheek muscles are contracted voluntarily, they can be heard to give a tone that is always of the same low pitch. The voluntary stimulation of a muscle requires the uninjured continuity of the nerve from the muscle to the central nerve system. The irritation from the central system proceeds along each nerve fiber separately; there is never any transmission from one fiber to another. The character of the irritation that proceeds along the nerve is unknown; it stimulates the end-plate at the end of the nerve and this plate irritates the muscle.

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The curve of tetanic contraction, that is, its variation of degree at each moment of time, depends on the strength of the motor nerve-impulse at each moment. Thus, the lip contraction and closure may be sudden or gradual, weak or strong, short or long, according to the degrees of irritation received at each moment by the muscles. The variations among speech sounds of the same type often depend not so much on variations in the positions of the organs as on variations in the course of the movement through these positions.

The motor nerves come from groups of cells in the brain and spinal cord. Sensory nerves from the tendons, joints, skin, mucous membrane and the muscle substance carry to the central nervous system irritations depending on the degree of contraction of the muscle. Thus, the position of the tongue is indicated at each moment by irritations from its surface and its muscles. When a movement is repeated so often that definite associations are established between the motor irritations of the various muscles at each moment and the sensory irritations present at that moment, the sensory irritations serve to regulate the motor ones and to govern the movement. This regulation takes place in the reflex centers; when it is once established, an impulse to the center is followed by the complete movement properly coordinated. These sensory impulses are of different degrees of fineness. Upon them depends to a large degree the accuracy of intended movements; their fineness can be increased by the proper practice. In cases of great dullness special methods and apparatus must be employed.[1] The motor cells receive irritations 1. from sensory fibers of the same or of another level in the cord (direct reflex); 2. from intermediate nerve cells that are irritated by sensory fibers (indirect reflex); 3. from cerebral fibers, especially from the cortex of the brain (voluntary movement).

The general scheme of reflex activity may be stated as

[1] ROUSSELOT, *Applications pratiques de la phonétique expérimentale*, La Parole, 1899 I 401; ZÜND-BURGUET, *Applications pratiques de la phonétique expérimentale*, La Parole, 1899 I 11, 138, 281; see also below, Ch. XXVII.

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follows. An immediate center, apparently without connection with higher sense nerves, controls the simplest reflexes in which mainly the organs of the stimulated portion are involved. The sensory nerves, however, send communications to many centers of other levels and to the highest centers. The higher the center the greater its expanse of irritation and control; it controls not only the muscles of its own level but also those of lower levels and thus brings about complicated activities. The highest centers act only by stimulating lower centers; they are, however, in direct connection with the higher sense-centers, so that single irritations from these may be followed by highly complicated activities.

The relations and connections of various portions of the brain are shown in the schematic Fig. 70 after AUZOUX's model.

The *spinal cord S* at its upper end becomes the *bulb B*. In the dorsal portion (to the left in Fig. 70) of the bulb, there are groups of cells — 'centers' — that control various complex muscular activities. The bulb contains the centers of coordination and reflex action for chewing, swallowing, action of the vocal cords, coughing, etc. It also contains the automatic center for breathing. The ventral portion of the bulb is occupied by nerve fibers.

Just above the bulb lies the *pons* (Fig. 70, *P*) and behind it the *cerebellum* (*Cl*). Overlapping the whole is the *cerebrum* (*Cr*), which consists of two hemispheres, a section through one of them being shown in the figure. The various portions known as the frontal, parietal, occipital and temporal lobes are indicated by the letters *FL*, *PL*, *OL*, *TL* (see also Fig. 57).

Among other functions the pons has that of transmitting the speech impulses from the voluntary centers to the lower ones; some diseases of the pons alter the length of syllables, producing what is known as 'scanning speech.' The cerebellum has no known speech function. The higher portions of the brain (*stalk*, *thalamus*, *corpus striatum*, *inner capsule*, etc.) are all to some degree involved in the muscular movements of speech.

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The various portions of the surface of the cerebrum — the *cortex* — are connected with the lower portions of the nervous system by 'longitudinal fibers' (in Fig. 70 marked by → as at *L*); with other portions of the same hemisphere by 'associa-

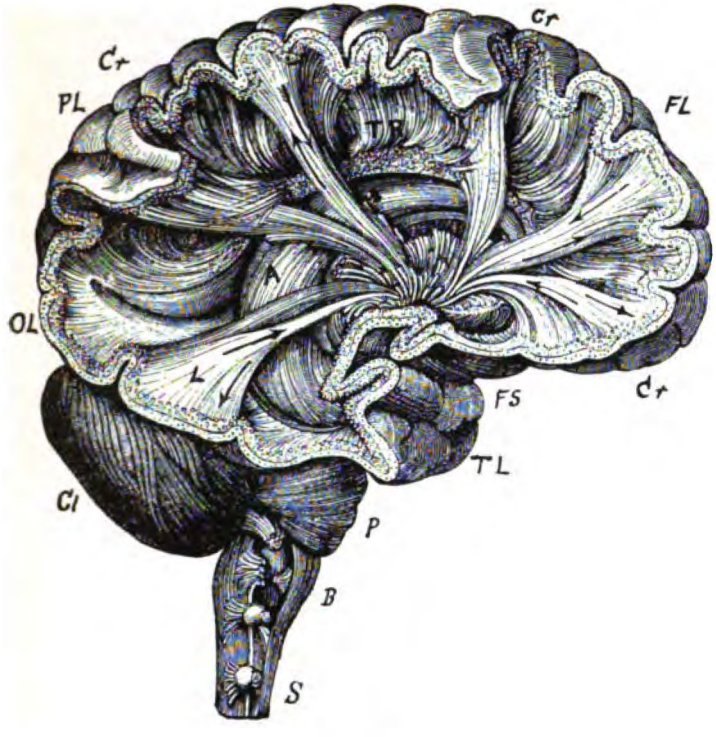

FIG. 70.

tion fibers' (as at *A*) and with portions of the other hemisphere by 'transverse fibers' (as at *TR*).

The cortex consists of immense numbers of nerve cells and fibers that seem capable of entering into endless combinations. Mental life is affected more directly and extensively by removal of portions of the cortex or injury of it than by injury of any other region of the body. The central portions of

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the cortex on each side are closely connected with the voluntary control of the muscles (see Fig. 57, p. 83). Injury of definite portions of these regions is followed by very definite disturbance in the power to voluntarily perform certain movements. This does not mean that the volitions are located in these portions of the brain, but that the two are closely connected in function.

A volition may be followed by a muscular act; thus the *decision* to press the tongue against the teeth may be followed by the actual performance of the act. The series of irritations may be traced back from the muscles through the end-plates, nerves and nerve centers in the central gray masses of the cerebrum to cells in the cortex. The connection between the volition, a mental fact, and the activity of the cortical cells, a physical fact, has found no satisfactory explanation.

Some of the peripheral nerves arise directly from the brain. Among these is the *hypoglossus*, which controls all the tongue muscles and most of those connected with the hyoid bone. The *vagus* contains motor fibers to the larynx and the bronchial muscles; sensory fibers from the larynx, trachea, bronchi and lungs; motor and inhibitory fibers to the velum; sensory fibers from the pharynx. The *glossopharyngeus* contains motor fibers to the velum (elevator of the velum), uvula, pharynx (middle constrictor of the pharynx) and the stylopharyngeal muscle; sensory fibers from the tongue and velum. The *acusticus* is the nerve of hearing. The *facialis* contains motor fibers to the face muscles, the stylohyoid and the stapedius muscles. The *trigeminus* contains motor fibers to the jaw muscles, the tensor tympani and the tensor of the velum.

Voluntary impulses do not act on separate muscles, but on the same complexes of cells as are involved in reflex actions.

Owing to the lack of data concerning the action of the nervous system and to the lack of methods for its investigation in regard to the production of speech sounds, the work of experimental phonetics lies at present almost entirely in studying the muscular movements and the volitions that

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give rise to them with little consideration of the nervous mechanism involved.

The methods used for registering muscular movement include, among others, that of air transmission by MAREY tambours.[1]

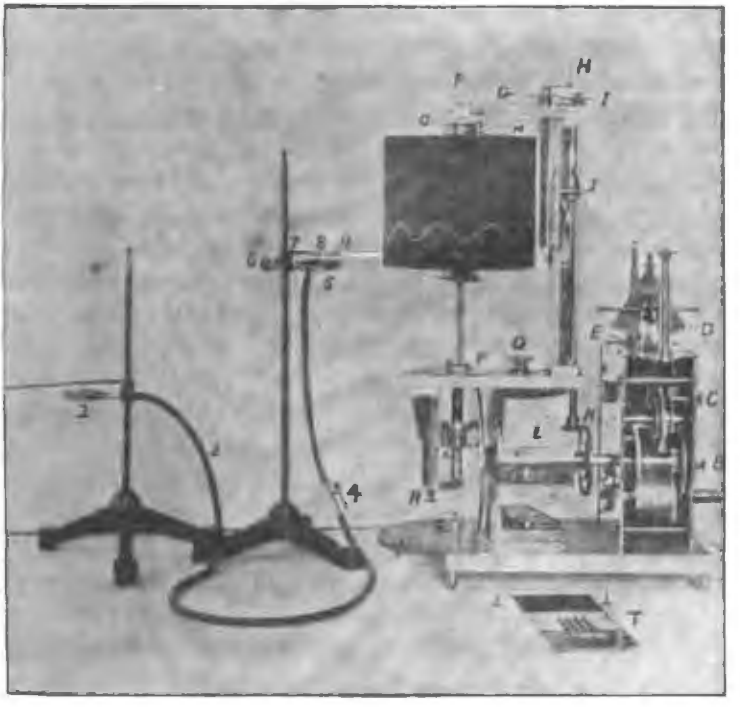

FIG. 71.

The tambour is a metallic box with a rubber top and a side tube. There are two tambours, the receiver and the recorder.

Any desired movement may be imparted to the straight lever of the receiver (*2*, Fig. 71). This lever communicates the movement to the air inside by varying the pressure on the rubber top. The movement of the air is transmitted along

[1] MAREY, La méthode graphique dans les sciences expérimentales. Paris, 1878; 2me tirage avec supplément, Paris, 1885.

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the rubber tube (*3*) to the recorder (*5*). The rubber top of the recorder moves in response to the movements of the air, and the light lever (*9*) resting on it repeats the movement. The valve (*4*) is used to equalize the air pressure.

The details of the recording tambour of the most common form are shown in Fig. 72. The tube *N*, to which the rubber connecting tube (*3* in Fig. 71) is attached, opens into the metal box *M*. The aluminum plate *K*, attached to the rubber cover *L*, communicates its movement by means of the link *J* and the clamp *H* to the lever *I*. A very light recording arm *T* (only a portion is shown) is placed on *I*. As the block *F* carrying the fulcrum *G* is movable by a hinge on the fixed block *E*, the lever can be inclined and the recording point raised or lowered by tipping *F*. The degree of amplification can be adjusted by sliding *H* along *I*, the link *J* being kept perpendicular to *I* by moving *M* by means of the screw *A*. The screw *C* fastens the tambour to a rod through *R*. A later form of the tambour is shown in Fig. 73; it is smaller and more sensitive. The construction is in general on the same pattern as the tambour in Fig. 72; the screw *A*, however, moves the whole tambour forward — a factor of great importance in adjusting two tambours so that their recording points are in proper alignment; the screw *B* turns the tambour sidewise and adjusts the degree of pressure of the point against the drum. The perpendicularity of *J* is maintained by fastening the metal box at the proper point by means of a screw shown near *M*; the lever *D* moves the block *F* on its hinge.

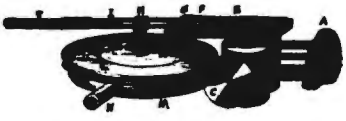

FIG. 72.



FIG. 73.

The receiving tambour resembles the recording one, but is often modified to suit special requirements.

The care and repair of tambours require some technical knowledge. The rubber membrane (heavier for the receiver,

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lighter for the recorder) must be evenly stretched. The box is made air-tight by inclosing in it a few bits of paraffine and warming the edge so that this runs along the contact between the rubber and the edge; the truthfulness of the record depends upon the prevention of any escape of air. The disc that holds the connecting link from the lever to the rubber is fastened to the latter by melted wax or paraffine.

The tambour ordinates are curved and not straight. The degree of curvature depends on the radius of the movement of the recording point. Before a set of experiments the tambour should be made to record a large excursion while the drum is at rest. The curved ordinates may be drawn on the drum before the record is varnished by turning it to each desired point and recording an excursion while it is at rest. When this is not done, all comparisons must be made by a curved line obtained from the original excursion of the tambour on the motionless drum. In such cases all comparisons by straight lines are false; valuable and laborious researches have been ruined by the neglect of this self-evident fact. When comparisons are to be made by perpendicular lines, a large excursion *oabx* (Fig. 74) of the recording point is made while the drum is at rest, representing the perpendicular *oo*. The line *oabx* would be 'rectified' by moving its points to the left by the distances between each one and the line *oo*. A tambour tracing is rectified likewise; the tracing *a'b'x'b''a''* would thus be moved to the left as indicated by the dotted line. The dotted line need not be actually drawn. The most convenient method is to draw a set of lines parallel to the horizontal axis as shown in Fig. 74 and subtract from all horizontal measurements the distances from the line *oo* to *a*, *b*, *x*, etc.

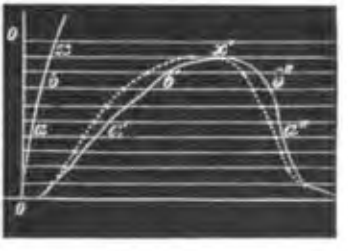

FIG. 74.

When the tambour is used to record on a drum, the lever

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h (Fig. 75) in its horizontal position should be parallel to the plane *tt* of a tangent to the surface of the cylinder *cy* at the point *p* touched by the flexible recording point *s*. As the lever rises or falls, the point *s* would leave the surface of the cylinder if it kept in the plane of the tangent, owing to its circular movement which brings it to one side of the vertical line on the cylinder; considerable spring and flexibility are thus required in the recording point in order to have it remain on the cylinder.

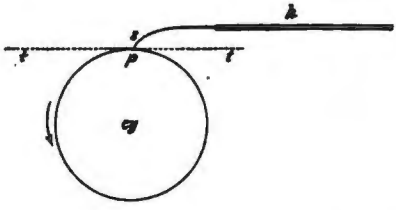

FIG. 75.

Tambour records may be made on any suitable recording surface. Drums for use with any motor power have already been described (p. 7). The smoked drum may be replaced by a glass wheel when the records are to be used in demonstration with a projecting lantern. The apparatus with a tambour is shown above in Fig. 8. For travelling purposes a clockwork drum may be made of aluminum.[1] The special clockwork drum shown in Fig. 71 is of a widely used type; it is frequently called a 'kymograph.' Its speed is so carefully regulated that, when its rate of revolution is once determined, it can be depended upon to maintain that rate with a high degree of accuracy, provided the spring is kept wound up to about the same tension and the whole apparatus is in perfect order.

The following instructions may be found of use. To remove the cylindrical drum grasp it at *O* and lift the arm *F*. Place the drum on a separate horizontal support and smoke it as usual (p. 7).

Lift the drum from the support, grasping it around the ring *O* at the end. Raise the spring *G* of the kymograph by the arm *F* till it catches. Let the end of the drum-axle drop into the socket *P*. Bring the groove of the ring *O* up till it

[1] JOSSELYN, *Étude sur la phonetique italienne*, 3, Thèse, Paris, 1900.

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catches on the wheel at the end of the arm *N*. Bring the top of the axle just below the socket held by *G*, and let *F* snap. The drum is now in position; it should be turned till the projecting point at the bottom of the axle catches in a notch of the spring *P*. If the kymograph is not firm upon the table, adjust the leg *M*.

Wind up the clock-spring by the handle. Move the brake *E* in order to release the governor *D*. When the screw *B* is tight the drum will turn with the clockwork; when *it is* loose, the drum is disconnected. The connection of the clockwork with the drum axle is established by the large friction disc which presses against the small friction roll *X*. When handling the drum, always disconnect it by turning *B*; this keeps the friction disc from being ground by accidental movements of the roll *X*.

The speed of the friction disc is changed by different combinations of the gears in the clockwork. The case of the clockwork can be readily opened by unscrewing the movable side *T*. There are two gears that move sidewise on their axles, a lower one and an upper one. When the upper wheel is in the middle position the screw *C* should be turned so as to bring the little wheel at the end of the arm into position between the largest and smallest cog-wheels. There are three sets of springs for the governor; that set should be chosen which allows the wings of the governor to take a medium position when in motion. The following table gives the speeds approximately obtainable by the different combinations.

SPEED NAME.	POSITION OF LOWER WHEEL.	POSITION OF UPPER WHEEL.	FRICTION ROLL AT LOWEST POINT.	FRICTION ROLL AT HIGHEST POINT.
I	Left.	Right (weak spring).	1ʰ 30ᵐ	12ᵐ
II	Left.	Left (medium spring).	6ᵐ	45ˢ
III	Left.	Middle (strong spring).	2ᵐ	15ˢ
IV	Right.	Right (weak spring).	12ᵐ	1½ᵐ
V	Right.	Left (medium spring).	40ˢ	5ˢ
VI	Right.	Middle (strong spring).	16ˢ	2ˢ

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The intermediate speeds between the figures in the table are obtained by moving the roll *X* by means of the screw *R*. An index connected with *X* moves over a scale so that a speed once found can be reproduced by direct adjustment of the index to the same point; to avoid back-lash the adjustment should be made in the direction from zero upward. For respiration records adjust the kymograph to about 20° for one revolution.

To determine the speed of the drum a time-line may be drawn on it by a vibrating fork (p. 15), a time-marker (p. 91) connected to some regular interrupter such as a clock, or directly by the graphic chronometer.[1]

The following experiments on finger movements are designed to illustrate some of the fundamental phenomena of voluntary action. They are described as being performed by the finger; they can be readily modified for application to the lip or the jaw by placing the receiving tambour in the proper position. The phenomena illustrated find their application to speech in many ways.

To make the finger perform some work analogous to that which occurs in stretching the vocal cords, a loop of tape over the middle finger is attached to a string ending in a rubber band. The arm may be laid on the table. The movement is registered by attaching to the string the lever of the receiving tambour and having the recording tambour write on the smoked drum.

The strength of the muscular contraction depends, within limits of variation, on the strength of the effort intended. The stronger the pull intended the greater is the actual pull. A series of efforts, however, with intensities in the relations 1 : 2 : 3 : 4 results in muscular acts that generally bear quite different and often changing relations[2] (Fig. 76).

Separate pulls will vary although intended to be alike. If the finger is first contracted with any desired force and after relaxation is again contracted to what is supposed to be

[1] JACQUET, *Studien über graphische Zeitregistrirung*, Zt. f. Biol., 1891 XXVIII 1.

[2] SCRIPTURE, New Psychology, 216–218, London, 1897.

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the same degree of force, a comparison of the two records will indicate the amount of the error of execution.

To obtain the error of execution we first find

$$a = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

where $x_1, x_2, \ldots, x_n$ are the measurements of the separate pulls, n the number of pulls and a the average pull; and then, calculating $v_1 = x_1 - a$, $v_2 = x_2 - a, \ldots, v_n = x_n - a$, we have

$$p = \tfrac{2}{3}\sqrt{\frac{v_1^2 + v_2^2 + \ldots + v_n^2}{n-1}}$$

as the probable error of execution. The size of this probable error is used as the measure of the uncertainty of the mus-

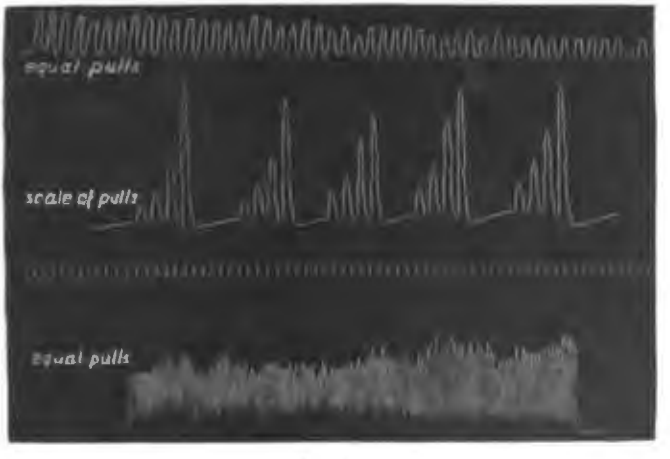

FIG. 76.

cular movement. This error is never zero; all movements vary around an average. The notion that the positions for a speech sound are something fixed for an individual is quite erroneous; there is an average for a certain intended position, but every particular position varies from the average. Some individuals have large ranges of variation, some have small ones. If no variations are detected, it is because the methods of measurement are not accurate enough.

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The error of execution is due partly to an error of perception and partly to an error of movement;[1] and partly also to an error in the intention.[2] Such an analysis, though probably a highly valuable undertaking, has not yet been made for any speech movements. The regulation of muscular movement occurs through adjustment of the impulses sent to the muscles in response to the sensations arising from them. The error of perception can be indicated by having the person state immediately after each contraction whether the pull appeared to him to be greater than, equal to, or less than the intended one.

The strength of a muscular contraction fluctuates although it is intended to be constant; the stronger or longer the effort, the greater the fluctuation. Let the finger be kept contracted to any desired degree; the record on the drum will show continual fluctuations (Fig. 77). The fluctuations will be found



FIG. 77.

to be greater for a strong contraction; they will become very great when the effort is maintained for a long time.

The irregularities in the pitch of the voice in striking or maintaining a note are due to defects in regulation of the tension of the vocal muscles. In taking the pitch of a note from an instrument the note is first perceived through the ear, then the vocal muscles are adjusted to produce it, thereupon the produced note is heard as coinciding with or differing from the desired one, and the vocal adjustment is corrected. The maintenance of any given pitch depends also on the regulation of the muscular tension by the sensations from the

[1] FULLERTON AND CATTELL, On the perception of small differences, 65, Philadelphia, 1892 (account in SCRIPTURE, New Psychology, 224, London, 1897).

[2] WOODWORTH, *Accuracy of voluntary movement*, Psychol. Rev., Monogr. Suppl. III, No. 2, 71.

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muscles. The error of execution in singing a note thus depends directly on the size of the just perceptible difference and on the size of the average error of movement. A large range of unperceived difference in the organ of hearing permits the voice to vary greatly but unconsciously. A large error of movement causes the voice to vary greatly. With a small range of unperceived auditory difference but a large error of movement the variations in pitch are detected by the singer but cannot be corrected.

A highly instructive experiment can be arranged by using two sets of tambours with springs and cords connected to two fingers. Records are to be made of the two when making contractions and relaxations at the same instants, of one contracting only with every second contraction of the other, of one contracting only when the other pulls with a certain strength, etc. By letting one finger (1) represent the action of the larynx in producing a tone and the other (2) the action of the other speech organs, we can produce greatly simplified representations of speech movements; thus, **aka** would be the succession of movements $\frac{1}{2}$-$_2$-$\frac{1}{2}$; **papa** would be $_2$-$\frac{1}{2}$-$_2$-$\frac{1}{2}$; etc. The records will show that the movements of the two fingers are not made accurately together, and that in such combinations as $\frac{1}{2}$-$_2$-$\frac{1}{2}$ the action of (1) tends to overlap its proper place, even producing $\frac{1}{2}$-$\frac{1}{2}$-$\frac{1}{2}$, etc. Exactly analogous results will be found to such phonetic phenomena as the change of **aka** to **aga**, of **papa** to **baba**, or as, in some cases, the partial desonation of **z** in **givzs** 'gives,' and the desonation of final vowels as in Fr. **veky**$_o$ 'vécu,' etc. OERTEL suggests that such experiments may clear up the obscurity of dissimilatory loss and substitution of certain sounds such as l, n, r.[1]

Closer imitations of the action of the speech organs may be made by using several tambours attached to different fingers or parts of the body. On the principle that all activities follow the same laws and differ only in complexity, these experiments can be used not only to demonstrate the laws of sound modification but also to suggest modifications that

[1] OERTEL, Lectures on the Study of Language, 234, New York, 1901.

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might otherwise be overlooked. Letting one finger represent the tongue and the other the velum, the tendency of the latter to relax its contraction before the tongue movement changes illustrates such a phenomenon as the nasalization of a vowel followed by a nasal consonant.

When several fingers are required to perform movements in succession, it will be found that certain associations are favored. Letting the separate fingers perform different movements we find that certain successions are easier than others. It is easier to repeat the movement of a finger than to change to another, to move the fingers in the order 1, 2, 3, 4, 5 than 1, 3, 5, 2, 4, etc. A close analogy to this is found in the vowel harmony that appears in isolated cases in nearly all

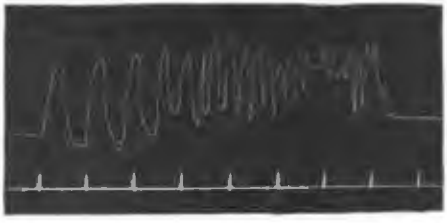

FIG. 78.

languages and is well developed in Hungarian and Finnish (p. 121).

A movement of a definite kind requires a definite time for its execution. When a voluntary movement is repeated with great rapidity, there is a limit beyond which the movement loses in definiteness. This may be illustrated by repeating the contraction of the finger with increasing rapidity; Fig. 78 shows a typical record. The hurriedness abbreviates the extent both of the contraction and of the relaxation; at some points the finger is almost immovably cramped. The slurring of sounds in rapid talking is an analogous example in speech. Under each set of circumstances there is a rate of repetition of a muscular movement which each person takes naturally; this natural rate is the least fatiguing and the most accurate

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one.[1] This natural rate varies with the individual, with the nature of the act, with fatigue, etc.

Reflex movements are more precise than voluntary ones, movements unattended to more so than those that receive attention.[2] These principles are of application in learning new speech movements.

A voluntary movement involves a more or less conscious volition, that is, a phenomenon of decision known to the person performing the movement. The greater the consciousness of the decision, the greater is the amount of mental energy consumed. The first lessons in learning new speech movements are liable to be very fatiguing. Through interest or excitement the fatigue may not be noticed by the learner till afterward, yet its effect in increasing the error of execution (p. 201) often becomes apparent to the teacher. As impressions made on a fatigued person are not so accurate or lasting, it is generally more economical to have frequent short lessons than less frequent long ones, if the latter produce fatigue. The acquirement of ability to perform a new activity does not increase in proportion to the number of times it is practised. The gain is at first slow, then more rapid, then very rapid, then slower, etc., until finally it becomes very small when the person has about reached the limit of his improvement.[3] After this point the practice is required in order to avoid loss.[4] The dependence of the energy and precision of a movement on the degree of fatigue, though

[1] SCRIPTURE, *Observations on rhythmic action*, Science, 1899 n. s. X 807.

[2] BLISS, *Investigations in reaction-time and attention*, Stud. Yale Psych. Lab., 1893 I 45; SCRIPTURE, New Psychology, 127, London, 1897.

[3] FECHNER, *Ueber d. Gang. d. Muskelübung*, Ber. d. k.-sachs. Ges. d. Wiss., math.-phys. Kl., 1857 IX 113; HENRY, *Recherches expér. sur l'entraînement musculaire*, C. r. Acad. Sci. Paris, 1891 CXII 1473; LOMBARD, *Some of the influences which affect the power of voluntary muscular contraction*, Jour. Physiol., 1892 XIII 14; BRYAN AND HARTER, *Studies in the physiology and psychology of the telegraphic language*, Psychol. Rev., 1897 IV 27; JOHNSON, *Researches in practice and habit*, Stud. Yale Psych. Lab., 1898 VI 51; MANCA, *Studi sull' allenamento*, Atti della R. Accad. d. Sci. Torino, 1892 XXVII 564.

[4] ASCHAFFENBURG, *Experimentelle Studien ü. Associationen*, Psychol. Arbeiten (Kräpelin), 1896 I 6, 11.

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repeatedly investigated for finger and arm movements,[1] has not yet been considered in the case of the vocal organs.

The degree of conscious intention may be so small as to be unnoticed. Such movements may be called 'unintentional' ones. They are being constantly made all over the body. They are of special interest from the fact that speech ideas have a tendency to express themselves in such movements. It is hardly too much to say that the vocal muscles are continually making unintentional speech movements in connection with our thoughts. These movements have been

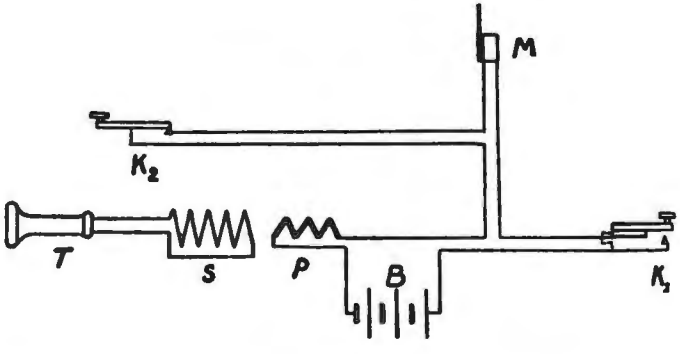

FIG. 79.

recorded by experimental means.[2] Under proper circumstances the faint speech sounds from them can be heard and understood.[3]

To respond to a stimulus by an act requires time. This time, the 'reaction time,' is longer the greater the nervous or mental action included in the process.

The time required to respond to a sound by a vocal move-

[1] Literature given by JOTEYKO, *Revue générale sur la fatigue musculaire*, Année psychologique, 1899 IV 1; HIRSCHLAFF, *Zur Methodik u. Kritik d. Ergographen-Messungen*, Zt. f. päd. Psychol. u. Pathol., 1901 III 185.

[2] CURTIS, *Automatic movements of the larynx*, Amer. Jour. Psychol., 1900 XI 237.

[3] HANSEN UND LEHMANN, *Ueber unwillkürliches Flüstern*, Philos. Stud. (Wundt), 1895 IX 471; summary in SCRIPTURE, New Psychology, 65, 259, London, 1897.

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ment may be registered on a recording drum (p. 7). The following arrangement will do. A current from the battery B (Fig. 79) is sent through the primary coil P of an inductorium, then through a magnetic marker M (p. 91), an open circuit key K_1 and a closed circuit key K_2. A telephone T is connected to the secondary coil S of the inductorium. Pressure on K_1 closes the circuit, makes a click in the telephone and deflects the point of the marker. While K_1 is held down and the marker deflected to one side, pressure on K_2 will break the circuit and remove the deflection. The marker is arranged to write on a drum beside the time line from an electric fork (Fig. 17); the time of the deflection of the point can thus be determined. The person experimented upon is to respond to a click in the telephone by actuating the key K_2, the time of the deflection is his 'reaction time.' For measurements in thousandths of a second the records must be corrected by adding the excess of latent time of the marker at the make over that at the break (p. 92). This correction can be avoided through using K_1 as a break-make key by the additional contact at the back; the sound occurs at the break; since it is registered by a break deflection the reaction time is measured between two break deflections and no correction is needed for latent time. Many variations may be made in the apparatus. It is often convenient to connect the reaction key K_2 to a separate marker; to use a spark coil (p. 12) instead of the marker; to use a chronoscope (p. 152) instead of the fork and the smoked drum. The key K_2 may be a chin key consisting of a telegraph key so placed under the chin as to break the circuit when the jaw begins to move (p. 154), a voice key that breaks the circuit by the action of the air against a metal plate (Fig. 66), or a lip key that breaks the circuit when the lips are compressed.

When the subject responds by a simple movement such as lowering the jaw, blowing, or pressing the lips, the action is closely like that of a response with the finger; all these forms are termed 'simple reactions.'

Of this reaction time very little is consumed by the trans-

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mission of the sound from the telephone to the brain and of the impulse from the brain to the vocal organs; nearly the whole of it represents the time required by the processes in the brain. These processes are known to us in consciousness as perception and volition; the 'simple reaction time' thus indicates very closely the time of these two. An average simple reaction time to sound will lie in the neighborhood of 0.20^s, varying with the individual, with the character of the sound, with the character of the movement, with fatigue, etc.

In a simple reaction the only mental processes involved are perception and volition. Two others may be added by requiring the subject to react to one stimulus and not to another. In the arrangement already described, the sound in the telephone may be weakened by moving the secondary coil *S* further away from the primary *P*. The subject, not knowing which will be heard, is to react when he hears the weak sound and not when he hears the loud one. He is thus obliged to discriminate between two sensations and choose between action and non-action. The time is greatly lengthened.

When the subject responds to the telephone click by a speech movement such as that of a vowel or a consonant, the action may be distinguished as a 'semi-vocal reaction.' A 'complete vocal reaction' may be measured with two voice keys, each in series with a battery and a marker. It may also be done with one key having either a double mouthpiece or a large trumpet. The repetition of a spoken word by the subject is a vocal reaction with discrimination and choice. A more complicated form of reaction occurs when the response is to be another word than the one heard but related to it in some way. Thus, it might be required to respond to an adjective by giving some noun; this would give an 'association time.' The methods of measuring association time with a chronoscope have already been described (p. 152).

The following further technical details concerning apparatus will be found useful not only in connection with the experiments of this chapter but also throughout laboratory work.

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The success of experimental work often depends on the electrical facilities of the laboratory. Batteries of different kinds are adapted to different forms of work. Nitric acid batteries (GROVE) give strong currents for a few hours but are troublesome to handle; chromic acid (dip) batteries give very strong currents for a brief time; ammonium chloride batteries (LECLANCHÉ), giving momentary currents and requiring renewal only at long intervals, are suitable for open circuit work, as for signals, bells, etc.; copper sulphate batteries (DANIELL) give very steady but weak currents for a long time; potash (LALANDE) and soda (EDISON) batteries give very constant currents of any strength for a long time with little trouble of renewal; storage batteries, which must

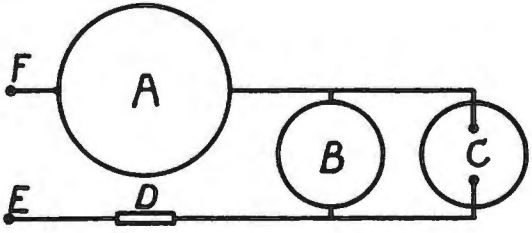

FIG. 80.

be charged from a dynamo, are universally available; low voltage direct currents may be obtained directly from a suitable dynamo or by a dynamotor from a high voltage direct or from an alternating current; low voltage currents can be obtained directly from a high voltage circuit by means of lamp batteries.

The lamp batteries are so convenient in a laboratory supplied with the usual direct current that a description of them seems advisable. In the three-socket battery (Fig. 80) the current from the main line is brought to the posts *E F*; the socket *A* contains a lamp that allows the desired amount of current to pass; the socket *B* contains a small lamp of such resistance that the fall of potential between its poles gives the voltage desired for the experimental work; the socket *C*

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contains a plug with wires to the apparatus; *D* is a switch. On a 110-volt circuit a large lamp *A* called a 110-volt 32 c. p. lamp (about 110 ohms) allows 1 ampere of current to pass through it; a small lamp *B* of 10 ohms reduces the current to a little less than 1 ampere; the tension at the two poles of the socket *B* as indicated by the volt meter is about 8 volts. When connection is made through the apparatus, the current will be divided between the small lamp and the apparatus in inverse proportion to the resistance; for an apparatus with small resistance, e. g. a key and low

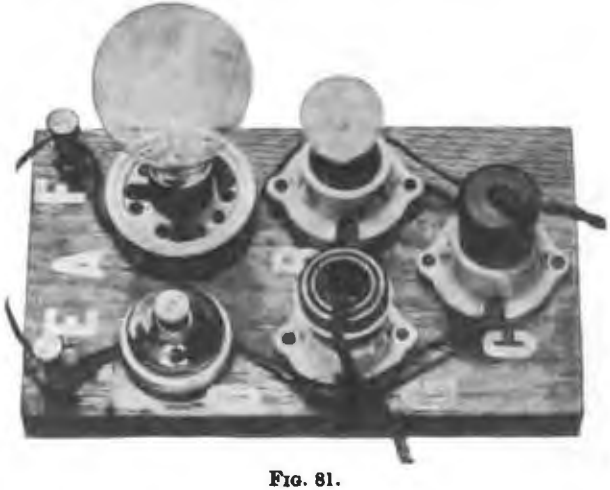

FIG. 81.

resistance telegraph sounder, almost the entire current of 1 ampere will pass through it; the tension, however, is that at the poles of the small lamp, namely, 8 volts. For apparatus of greater resistance small lamps of higher resistance are used; for currents of greater intensity larger lamps are used in *A*. Experience has shown that a 4-ampere and a 1-ampere pair of lamps suffice for most experimental work.

The four-socket battery is of great convenience. The socket *G* (Fig. 81) is placed in series with that of the small lamp *B*; a plug with wires runs from it to one piece of apparatus while wires run from *C* to another piece. To run a high

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resistance telegraph sounder it is connected to the wires of *G* while the key is connected to those of *C*. As long as the key is closed, the current passes almost entirely through *C*; when it is opened, it is forced at the tension of the main line (consequently with greater effect) through the sounder. To run a high resistance marker (Fig. 61) with an electric fork (Fig. 17) having a magnet of low resistance, the fork is connected to *C* while the marker is connected to *G*; in this way a strong current is obtained through each. Closure of the circuit at *G* changes the battery into a three-socket one.

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For recording drums: Petzold, Leipzig; Zimmermann, Leipzig; Albrecht, Tübingen; Verdin, Paris. For tambours: Verdin, Paris; Albrecht, Tübingen. For clamps, standards, scalpels, etc.: Petzold, Leipzig; Zimmermann, Leipzig; Müncke, Berlin. For Harvard physiological apparatus: Prof. W. T. Porter, Boston. For Auzoux's model of the brain (Fig. 70): Montaudon, Paris.

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CHAPTER XVI

BREATHING

THE diaphragm forms the bottom of the thorax. When at rest it curves upward, part of it lying on the walls of the thorax. When its muscles contract, it descends and the side parts are removed from the walls. In this way the thorax is lengthened. The pressure of the diaphragm on the organs below pushes the abdomen outward.

Other muscles act to lift the ribs and thereby to deepen and widen the thorax. According to the preponderance of the diaphragm movement or the rib movement two types of breathing are distinguished, the abdominal and the costal.

On account of atmospheric pressure the elastic walls of the lungs are obliged to follow the walls of the thorax, and thus air is drawn in. The lungs also descend slightly during inspiration, drawing after them the trachea.

Expiration is mainly passive.[1] When the inspiration-muscles are relaxed, the elasticity of the lungs makes them contract; this draws the diaphragm upward and the walls of the thorax inward, while gravity aids in lowering the ribs. The air in the lungs is thus partly forced out again. To produce forcible expiration the muscles of the abdomen may be contracted; the contents of the abdomen are pressed inward and upward and the diaphragm and lungs are forcibly moved. The ribs are also drawn downward by the same muscles, as well as by sets of special muscles.

In ordinary breathing about 500^{ccm} of air are inspired and

[1] Perhaps slightly active; TREVES, *Observations sur le mécanisme de la respiration*, Arch. ital. de biol., 1899 XXXI 130.

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expired.[1] A forcible expiration can bring out about 1600ccm more, called the 'reserved air.' The lungs are not exhausted by the deepest expiration, as there still remains 'residual air' to the amount of 800ccm. With the deepest possible inspiration an additional amount of 1600ccm can be added, called the 'complementary air.'

The movements of inspiration and expiration occur involuntarily with a definite rhythm and depth. The average frequency with adults is 18 to 20 a minute. Both rhythm and depth can be largely controlled by the will. The emotions affect frequency, depth and form of the breathings and sometimes cause characteristic noises and tones, as in sobbing, sighing, laughing, etc.

The nerves controlling the breathing muscles come from the spinal cord, where they have connection with the respiration center in the bulb (p. 193). The activity of this center depends on the nature of the blood reaching it. As the blood becomes more or less venous the breathing becomes more or less violent. Muscular activity causes an acceleration of breathing by a chemical product that enters the blood. Heat also stimulates the respiration center.

The movements of single points of the body during breathing may be conveniently studied by the method of air-transmission by means of the MAREY tambours recording on a smoked drum (p. 195). To register thoracic or abdominal movements of a person sitting or lying down, a light projection at right angles may be attached to the lever of the receiving tambour of the arrangement shown in Fig. 71, and the tambour is so placed on supporting rods that this projection rests upon the desired point of the chest or abdomen. The movements are registered in the way described on p. 198.

If preferred, the receiving tambour may have a small projection instead of a lever attached to its surface.[2] Such a tambour

[1] This is the usual statement; according to MARCET, *A contribution to the history of the respiration of man*, Croonian Lecture, London, 1897, the average of 210 experiments gave 250ccm.

[2] BERT, Leçons sur la physiologie comparée de la respiration, 290, Paris, 1870.

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is shown at *k* in Fig. 82; it may be used in any support on a person lying down or otherwise fixed so that the body will not sway; or it may be placed on one end of the adjustable calipers *rp*, arranged to clasp the thorax on any diameter and to register independently of a swaying motion.

The relations between costal and abdominal breathing can be studied by using several sets of tambours recording simultaneously on the same drum. The lengths of tubing and the amplification adjustments should be the same for all. The older doctrine of a preponderance of abdominal or thoracic breathing in the male or female sex seems without foundation except in so far as brought about by clothing.[1]

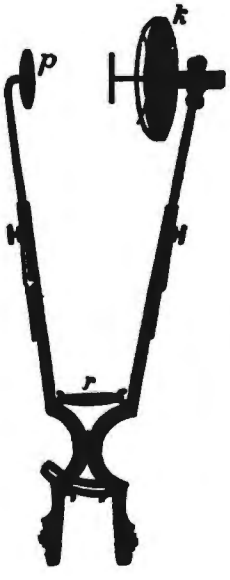

Fig. 82.

The changes in the circumference of the thorax or abdomen may be registered by means of a 'pneumograph.' In one form (MAREY) a hollow rubber tube is kept expanded by a spiral spring; this tube is closed by metal ends, one of which has a projecting outlet connected to the small rubber tube from the recording tambour. A band is stretched around the body from one end of the tube to the other. An increase in the circumference of the thorax stretches the tube and thus draws air from the recorder. In a better form of the pneumograph the tube is of metal and the ends of rubber (BERT). In still another form a tambour like that in Fig. 72 is acted upon by a band and a compound lever (MAREY). A later form (Fig. 83) comprises two tambours with adjustable amplification (VERDIN).

Some records with a pneumograph (of the first of the above

[1] FITZ, *A study of types of respiratory movement*, Jour. Exper. Med., 1896 I 677.

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kinds) around the abdomen of a male person with chiefly abdominal breathing are shown in Fig. 84. Ordinary breaths followed by several deeper ones are shown in the top line of records; it will be noticed that the movements are very small after the blood has been refreshed by deep breathing. A record of ordinary breathing interrupted by sniffing, sobs and a sigh-like sob are shown in the second record; the inspirations are very sudden. The curves for a groan and a sigh are also shown in the third record; the inspirations are not sudden, and the expirations are more gradual than in the sigh, the groan showing a specially long and irregular expiration. All these sobs, groans and sighs were produced premeditatedly. A series of premeditated laughs is also shown. Each laugh consisted of 'ho-ho-ho-ho' with falling pitch; the laugh occupied the expiration-half of each curve. The record marked '4 lines of song' shows the breath expenditure during the singing of



FIG. 83.

> "Way down upon the Swanee River,
> Far, far from home.
> Oh, darkies, how my heart does quiver,
> Far from the old folks at home."

The expiration of the breath not used during each line appears clearly each time at the end. The next to last record shows the use of the breath in speaking the verses

> "The Cities are full of pride,
> Challenging each to each;
> This from her mountain-side,
> That from her burthened beach" (KIPLING).

The inspiration occurred just before the beginning of each line. The last record shows the breath-expenditure when the

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stanza was spoken more rapidly; one deep inspiration with a slight accession afterwards is made to do for each pair of lines. The discharge of the air not used in speaking is indi-

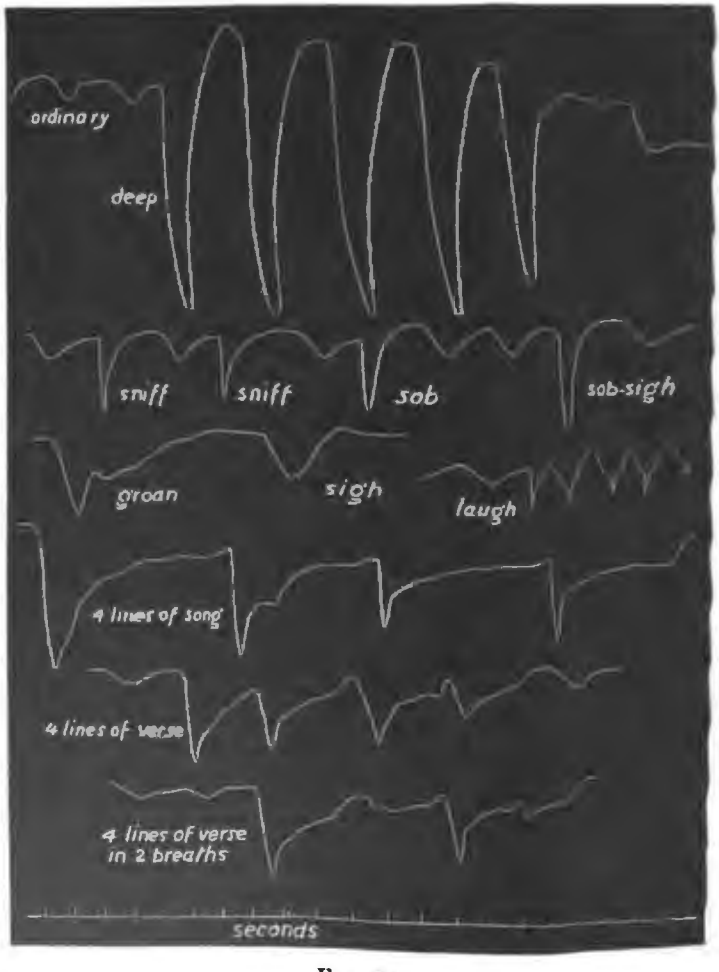

FIG. 84.

cated by the sudden rise at the end of each line. Both records were made with no intentional distribution of the inspirations. The time-line with seconds is given for all these records at the bottom.

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The records made from the surface of the thorax or abdomen give indications concerning the suddenness of inspiration and expiration and concerning the rate at which the breath is expended. They give no direct measurements of quantity or pressure. The relative amounts of breath used in single sounds can, however, be indicated with this method by repeating them a given number of times in a single expiration. The expenditure of breath was found in one case by Rousselot to stand in the following relations: fa > va > pa > ba.[1]

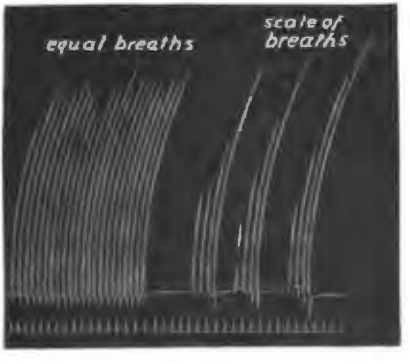

Fig. 85.

In taking records of breathing during speech it is necessary to guard[2] against apparent small inspirations at the beginnings and endings of words[3] which are in reality due to extraneous muscular contractions.[4]

To register the variations in the breath from the mouth or the nose, the receiving tambour (Fig. 71) is removed and the end of the rubber tube is placed on a short glass tube[5] which is inserted loosely in the corner of the mouth or in one nostril. The main body of air passes by, but the variations in pressure will affect the recording tambour. The curves in Fig. 85 were taken with the tube held at the corner of the

[1] Rousselot, *Les modifications phonétiques du langage*, 62, Rev. d. pat. gallo-rom., 1891 IV, V; also separate.

[2] Oussof, *Études expérimentales sur une prononciation russe*, La Parole, 1899 I 785.

[3] Binet et Henri, *Les actions d'arrêt dans les phénomènes de la parole*, Rev. philos., 1894 XXXVII 608.

[4] Grégoire, *Note sur l'action du thorax dans la phonation*, La Parole, 1899 I 718.

[5] Glass tubing may be cut by first scratching it slightly with a triangular (hard) file and then bending it with the fingers; its edges are rounded by insertion in a Bunsen flame.

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open mouth. They show a series of equal breaths and several attempts at blowing with forces in the relations 1 : 2 : 3 : 4. The variations in mouth-pressure during the recitation of four

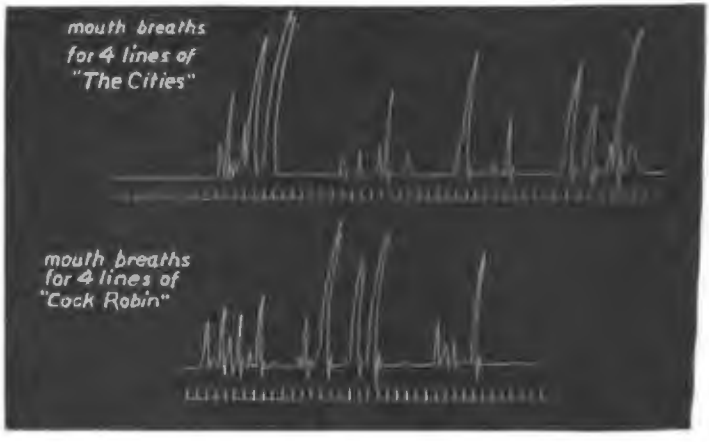

FIG. 86.

lines of *The Cities* (p. 215) and of the first four lines of *Cock Robin* are shown in Fig. 86. The expiration curves for the word du spoken in various ways have been registered by VIETOR [1] with a short tube held between the lips. The height

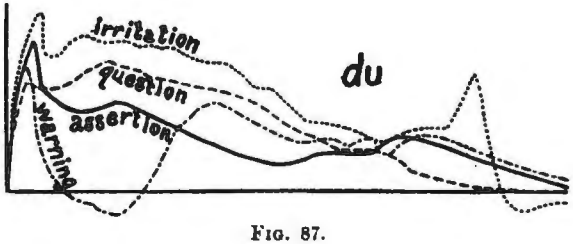

FIG. 87.

of a curve in Fig. 86 shows the force of expiration spoken in an assertion, in a question, in irritation, in warning. The full pressure from the mouth can be obtained by using a

[1] VIETOR, *Kleine Beiträge zur Experimentalphonetik*, Neuere Sprachen, 1894 I, Suppl., 25; Elemente der Phonetik, 4. Aufl., 283, Leipzig, 1898.

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mouth-piece fitting over the lips, that from the nose by a nasal olive (Fig. 88) fitting the nostril.

Attached to a speaking tube whose end fits the mouth rather closely, the MAREY tambour can be used to register the expiratory impulses and thus to give data concerning the lengths of sounds and also some information concerning their force. Since the *Y* axis in tambour records is a peculiar curve, the moments of time cannot be found by lines perpendicular to the *X* axis but must be referred to it by means of curved lines. The exact curve of the *Y* axis is readily found by using the tambour while the drum is at rest (p. 197). The special vocal tambour of ROUSSELOT[1] (Fig. 89) comprises a bent metal tube ending in a membrane of rubber which moves a very light recording point. The mouth-piece *A* passes into the tube *D* which ends in the rubber membrane *E*. The vibrations of the membrane are recorded

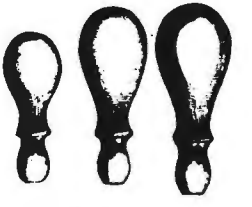

FIG. 88.

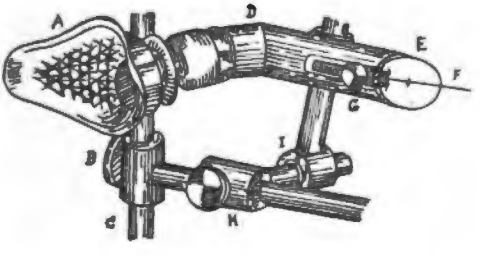

FIG. 89.

by the lever *F*, adjustable by the screw *G*. The combination of clamps *I H B* afford great adjustability on the supporting rod *C*. This tambour is adapted to registering small fluctuations in pressure such as are found in various speech sounds like r, the explosives, etc.

To give some idea of the total volume of air expended, a

[1] ROUSSELOT, *La phonétique expérimentale*, La Parole, 1899 I 9.

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mouth-piece fitting closely over the lips may be attached to a tube directly from a recording tambour for a short sound and by way of a reservoir for longer sounds. The amount of air corresponding to each degree of the excursion can be determined conveniently by attaching a graduated syringe to the tube;[1] this is best accomplished by inserting a T-tube in the rubber tube connected to the tambour and attaching the syringe to the long arm of the T. The tambour method, however, is not very accurate for this purpose. A tambour with a mouth-piece communicating with the external air may be used to indicate the rate of expenditure.

An accurate instrument that directly and proportionately records the volume of air expired or inspired is found in the breath recorder of GAD[2] shown in Fig. 90. A box-like mica cover *d* with its edges immersed in a square trough of water *t* is so balanced upon the axle *a* by the weight *g* that it is in equilibrium in any position. The air entering through the tube *r* in the bottom plate *b* raises the cover *d* and records by the arm *h*. The graduation of the record is done by sending in known quantities of air and marking the position of the pointer. For this purpose a large syringe graduated in ccm. may be attached to the tube before or after an experiment. An apparatus like this in which the records are directly proportional to the amount of air is often preferable to a tambour with which the scale diminishes rapidly as the amount increases. A special registering spirometer has been devised by MARCET.[3]

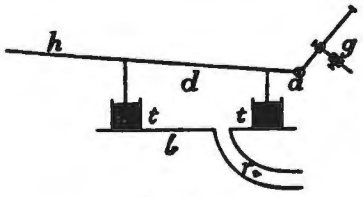

FIG. 90.

In an ordinary expiration the air is driven out by the tension of the lungs and the abdominal muscles; the pressure begins

[1] LOMBARD AND PILLSBURY, *A new form of piston recorder*, Amer. Jour. Physiol., 1899 III 186.

[2] LANGENDORFF, Physiologische Graphik, 266, Leipzig und Wien, 1891.

[3] MARCET, *Études des différentes formes de la respiration de l'homme*, Rev. méd. de la Suisse romande, 1896 601.

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with a maximum and falls to zero. For singing, a constant rate of expenditure is often required. This must be obtained by muscular resistance, such as that of the diaphragm and of the muscles around the thorax. A tracing with the pneumograph should show a steady movement of the chest or abdomen and not one of varying rapidity or of irregular character. Some of the troubles of singers arise from letting out the air too rapidly at first; these can often be cured by proper instruction in breathing, profitably aided by registering the results with the pneumograph.[1] The modulation of the voice in song requires accurately coordinated and controlled movements of the breathing muscles; this is accomplished by modifications of the usual respiratory action.

Using a VERDIN spirometer — a rather rough instrument constructed for other purposes but giving sufficiently accurate results — ROUDET[2] found that under equal conditions the rate of expenditure increased with the intensity of the sound. The vowel a sung on the note d^0 during one second at three degrees of intensity — feeble, medium, strong — showed, as averages of 20 experiments, rates of expenditure of 10.6^{ccm}, 16.4^{ccm} and 24.1^{ccm} respectively. The increase in amplitude of the vibration in a louder sound means that the glottis opens more widely for each vibration and lets out more air.

When the vowel a was sung on the notes c^0, e^0, g^0, c^1 with what appeared to be a constant intensity, the records showed a decrease of the rate of expenditure with a rise in pitch.[3] The physical intensity of a vibratory movement (p. 109) increases as the square of the frequency and the square of the amplitude; two tones of the same amplitude in the relations of 1:2 in frequency stand in the relations of 1:4 in physical intensity. To maintain the relation 1:2 in frequency while obtaining the relation 1:1 in physical intensity the relation of

[1] OLIVIER, *Étiologie et traitement de certains troubles vocaux*, La Parole, 1899 I 367.

[2] ROUDET, *De la dépense d'air dans la parole et de ses conséquences phonétiques*, La Parole, 1900 II 209.

[3] ROUDET, as before, 214.

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amplitude must be made 2:1; thus the higher the tone the smaller the amplitude, and consequently the smaller the rate of expenditure. The psychological relations of intensity — by which ROUDET judges the equality of the sounds — for sounds of different pitch presumably bear some relations resembling the physical ones. The compensation is thus a nervous and mental one. ROUDET's first explanation by an increase in the area of the glottis is unnecessary and probably erroneous; his second explanation is approximately the one I have just given.

Experiments[1] with a sung on the note d^0 with apparently the same intensity for 1^s, 2^s, 3^s showed rates of expenditure that were 13.5^{ccm}, 7.9^{ccm} and 6.2^{ccm} per second respectively. This does not show, as ROUDET supposed, that there is unconscious economy in the respiratory distribution, but that the judgment was one of equal *energy* and not one of equal *intensity*. In these experiments, as in many others, the subject presumably felt instinctively that he was to produce the same total effect in each case. The energy of a sound varies, both physically and mentally, in the same way — though not proportionately — as the amplitude, pitch and length. Two sounds are considered equal in energy ('intensity' is the usual term) when they produce the same total mental impression. A longer sound produces a more energetic effect and is instinctively lowered in pitch or amplitude when it is to be made equal to a shorter one. These experiments confirm the principle of compensation among the three factors.[2]

Measurements[3] of the rate of expenditure during different vowels sung on the note d^0 during 1^s showed for u_2 22.6, o_3 21.7, o_1 16.5, a_3 13.1, a_1 15.7, e_1 16.2, e_2 19.6, e_3 21.3, i_2 26.3^{ccm} ($_{1,2,3}$ indicate 'open,' 'medium' and 'close' respectively). As a general rule the rate of expenditure increased as the passage above the tongue diminished. ROUDET's ex-

[1] ROUDET, as before, 215.

[2] SCRIPTURE, *Researches in experimental phonetics* (*first series*), Stud. Yale Psych. Lab., 1899 VII 100.

[3] ROUDET, as before, 215.

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planation that the friction of the air in the mouth passage acts directly by back pressure, so as to produce a larger opening of the glottis whereby more air can pass, indicates merely a difference in the glottal action. The rate of expenditure is unquestionably governed by the respiratory muscles and the glottis; a particular rate is associated with each vowel for reasons still unknown, possible in reference to auditory impressions of the energy usually felt in each.

Measurements [1] of the average rate of expenditure for the vowel a pronounced in several ways gave with the glottal catch 8.9^{ccm}, with a clear beginning (the cords closed for vibration before breath action) 14.0^{ccm}, with a breathed beginning (cords not fully closed before breath action) 24.2^{ccm} and when whispered 34.4^{ccm}. Measurements [2] of six fricatives gave: s 30.6, z 27.5, f 33.5, v 27.9, š 38.6, ž 28.2. The expenditure was much greater than in vowels; it was greater for the surds than for the corresponding sonants.

ROUDET finds that an explosive has a smaller total expenditure than a fricative, but the average rate of expenditure — that is, the total expenditure divided by the duration — is incomparably greater; among the explosives both the total expenditure and the average rate are greater for a surd than for a sonant, for an aspirated form than for a pure explosive.[3] In Italian it has been shown [4] that the more closed the articulation the greater is the average rate of expenditure, for example, i > o > a.

The expenditure of breath during vocal sounds is quite variable but in ordinary speech certain constant relations are found. The following facts in regard to French sounds of Cellefrouin have been established by ROUSSELOT [5] by means of tambour records. The expenditure differs at different times

[1] ROUDET, as before, 217.

[2] ROUDET, as before, 220.

[3] ROUDET, as before, 222.

[4] JOSSELYN, *Étude sur la phonétique italienne*, Thèse. Paris, 1900; also in La Parole, 1900 II.

[5] ROUSSELOT, *Les modifications phonétiques du langage*, 65, Rev. d. pat. gallorom, 1891 I; also separate.

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of the day, with different activities, with the position (seated or standing), etc., although the person may consider the sound to have been produced with the same force. Measurements with a spirometer showed the following relations of breath expenditure for consonants followed by a to be true without exception for all subjects tested: p < f, t < s, k < tš < s < χ, b < v, d < z, g < dž < ž < γ. This indicated that fricatives required more air than explosives; nasals required less air than the corresponding surd explosives, m < p, ñ < n < t; fricative surds used more breath than fricative sonants, v < f, z < s, ž < š; finally r < l. As final sounds the fricatives required more breath than explosives, nasals less than the corresponding oral sounds, all surds more than the sonants, l more than r and ʎ about the same as j. Although some results were conflicting, the general relations of breath expenditure for the vowels were: $i_2 < i_3$, $y_2 < y_3$, $o_2 < o_3$ (for meanings of the inferior numerals see p. 222). The relaxation of articulation in one vowel as compared with another (from which it may be historically derived) is accompanied by increased rate of expenditure of breath but often also by a shortening of duration. In nasal vowels less breath was expended through the mouth than in oral ones.

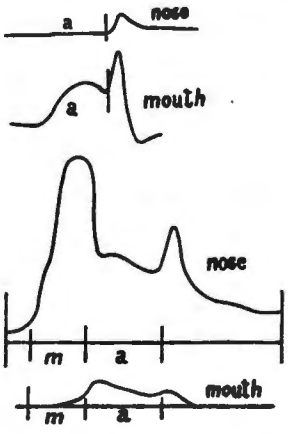

FIG. 91.

Tambour curves for the nose and mouth made by GOLDSCHEIDER[1] show clearly the final rush of breath as the cords open after a vowel is finished (a, Fig. 91). This rush does not appear when a vowel is purposely made to end softly. The relations of the two currents of air in a nasal are shown in the nose and mouth curves for ma.

[1] GOLDSCHEIDER, *Ueber Sprachstörungen*, Berliner klin. Wochenschr., 1891 XXVIII 487.

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The pressure of air may be obtained by connecting a tube
om the mouth to a water or mercury manometer. This is a
shaped glass tube with water or mercury at the bottom;
ien one arm is connected by a rubber tube to the mouth, the
ter or mercury will rise in the other arm to a height depend-
g on the air-pressure. Water records may be changed into
ercury records by dividing by 13.6. A convenient form of
ercury manometer is shown in Fig. 92. The mercury in the
-tube *m* rises along the scale according to the pressure ansmitted through the tube *e*. he apparatus can be con-eniently used in connection ith a recording tambour. he records of pressure are aken in the usual way with tambour; they are then raduated by attaching the mbour tube to *e*. By means the bulb *b*, compressed by ie plate *p* by moving the erew *s*, the apparatus attached e can be made to mark a raduation on the record for ch unit of pressure.

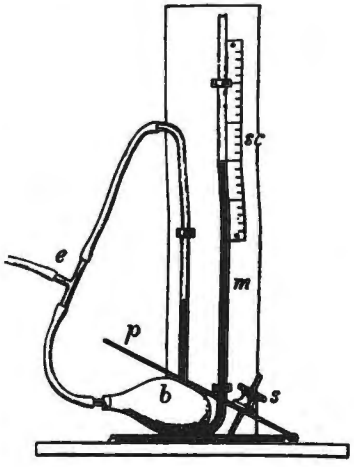

FIG. 92.

After an inspiration the chambers of the thorax are filled ith air at the atmospheric pressure; closure of the glottis and laxation of the inspiration muscles produce an increase of essure, measured through an external tracheal opening, vary-g from 3^{cm} of water in whisper to 97^{cm} in a loud cry, from to 16 in ordinary speech.[1] To indicate the pressure thin the mouth a small rubber tube from a U-shaped water nometer is inserted into the mouth and passed behind the ace of closure.[2] The effect of the glottal closure in v or b

[1] CAGNIARD-LATOUR, *Sur la pression à laquelle l'air contenu dans la trachée-re se trouve soumis pendant l'acte de la phonation*, C. r. Acad. Sci. Paris, 1837 201; Ann. d. Sci. Nat., 1837, 2me sér., VII 180, VIII 319.

[2] SIEVERS, Grundzüge d. Phonetik, 4. Aufl., 22, Leipzig, 1893.

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as compared with f or p in diminishing the pressure in the mouth appears readily. It may be suggested that the stronger articulation of the surds, even in whispering, arises from the associated habit of resisting increased air pressure.

To measure the pressure of the air during speech, WEEKS[1] used a small metal tube of 2^{mm} diameter inserted into the corner of the mouth and bent around the teeth to the center of the palate at the beginning of the arch where the tongue rarely touches. Attached to a MAREY tambour this indicated the air pressure in the mouth at each moment. With this instrument WEEKS showed that final *b*, *d* and *g* in the South German pronunciation are not the same as *p*, *t* and *k*, as they appear to the ear, but differ in being spoken with less pressure.

In a sonant sound part of the lung pressure is used in setting the cords in vibration. In a sonant explosive the remaining pressure is borne by the mouth. In a surd explosive, with open glottis, the entire lung pressure is borne by the mouth. In whispering, a small part of the pressure is borne by the glottis. With a constant lung pressure the variations of mouth pressure in surd and whispered sounds may arise from different degrees of closure of the glottis. The lung pressure can hardly be supposed to vary from one sound to another and we may well assume that the decreased mouth pressure for b_o, g_o, d_o (surd *b*, *d*, *g*) as compared with p, t, k indicates more closure of the glottis. The essential difference between b_o, d_o, g_o and b, d, g (sonant *b*, *d*, *g*) thus lies in a weakening of the glottal vibration to a whisper action but not to the condition of rest found in surd sounds. ROSAPELLY[2] has, in fact, observed — with a laryngoscope and an obstruction between the jaws — that in whispered **aba** the glottis remains of constant width whereas in **apa** it opens more widely during the p.

[1] WEEKS, *Recherches expérimentales de phonétique*, Année psychologique, 1893 I 174; summary in Maître phonétique, 1894, juin.

[2] ROSAPELLY, Mém. de la Société de linguistique, IX 488; ROUSSELOT, Principes de phonétique expér., 469, Paris, 1901.

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With a water manometer consisting of a U-tube ROUDET [1] registered the subglottal pressure in a person having an external opening into the trachea. In ordinary inspiration the pressure became at first rapidly negative and then slowly returned to zero; in expiration it became rapidly positive and slowly returned to zero. In ordinary breathing the minimum pressure usually reached -2^{cm} water while the maximum reached $+4^{cm}$; during speech the extreme figure for expiratory pressure was 20^{cm}. When **a** (as in Fr. 'pas') was sung on the note e^0 with three degrees of intensity, the pressures indicated were: feeble 11^{cm}, medium 14^{cm}, loud 19^{cm}. When **a** was sung on the three notes c^0, e^0, g^0 with apparently the same intensity, the pressures were 19.5^{cm}, 17.5^{cm}, 12.5^{cm}, as was to be expected from the fact that to be of equal physical intensity sounds of different pitches must have amplitudes inversely proportional to their frequencies (p. 109). For vowels sung on the same pitch with apparently the same intensity the pressures were: for **u** 15.0, **o** 13.3, **a** 13.3, **e** 14.5, **i** 17.0^{cm}. The pressure seemed to be slightly greater for the close vowels. In whispered vowels the pressure varied greatly; for example, from 6^{cm} to 15^{cm} for **a**. In a series kept at the same intensity the pressures were: for **u** 10.5, **o** 9.0, **a** 9.0, **e** 10.0, **i** 12.0^{cm}. The pressures for a series of syllables spoken on e^0 were: for **pa** 15, **ba** 11, **ta** 12, **da** 11, **ka** 17, **ga** 15, **fa** 12, **va** 11, **sa** 14, **za** 13, **ša** 16, **ža** 14, **ma** 15, **na** 16, **la** 13, **ra** 16^{cm}. The pressure was thus greater for the surds than for the sonants.

The air pressure in millimeters of mercury during the vowels in ordinary and ventriloquistic speech has been found to be: [2]

	a	**e**	**i**	**o**	**u**
ordinary:	10	40	30	30	50
ventriloquistic:	60	70	55	70	60

[1] ROUDET, *Recherches sur le rôle de la pression sousglottique dans la parole*, La Parole, 1900 II 599.

[2] FLATAU UND GUTZMANN, Die Bauchredner-Kunst, Leipzig, 1894.

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The amount of air actually used, however, in ventriloquism is much less than in ordinary speech; in one experiment with a spirometer 900^{ccm} were used in saying ventriloquially what required 1300^{ccm} ordinarily. The curve of inspiration traced from the abdomen rises more slowly in ventriloquism.

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CHAPTER XVII

VOCAL ORGANS

In the widest application of the term the 'vocal organs' clude all the organs directly concerned in speech and song; e nervous organs have been considered in Chapters VII and V, the breath organs in Chapter XVI; the larynx will ceive separate treatment in the following chapters.

The general outline of the organs above the lungs that are rectly concerned in speech is given in Fig. 93.

The *trachea* (*F*) is the outlet for the lungs. The rings of rtilage (upper one at *21*) keep it distended. Behind it lies e œsophagus (*D*) and the backbone (*l*). The trachea ends the *larynx* (*L*). The cricoid (*19*) and the thyroid (*18*, *T*) rtilages and the vocal cords (*20*) will be described in the apter on the larynx. In ordinary expiration the air passes rough the trachea and larynx past the *epiglottis* (*E*) into the *harynx* (*C'' C'*) through the *nasal cavity* (*A*) and out the *ostril* (*n*) on each side.

The *nasal cavity* (*A*) on each side is of very complicated rm owing to the various processes projecting into it (*2*, *3*,). The *oral cavity* (*B*) is roofed by the *hard palate* (*f*) nd the *velum* or soft palate (*11*). The *pharyngeal cavity* ''*C* may be divided by closure of the velum (*11*) across it nto two parts, the upper or nasal portion (*C*) and the lower oral portion (*C''*). In this case the entire mouth cavity from ps to larynx is made up of the oral portion (*B*) and the haryngeal portion (*C''*). The fall of the velum turns the harynx into a single cavity and separates it more or less om the oral cavity.

The muscles controlling the movement of the lower jaw

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are: 1. the *temporal* (*1*, Fig. 95), which raises it and, if it has been projected, draws it back; 2. the *masseter* (*1*, Fig. 94; *12*, Fig. 95), which raises it; 3. the *internal pterygoidal*, which raises it and may give it slight side movement; 4. the *ex-*

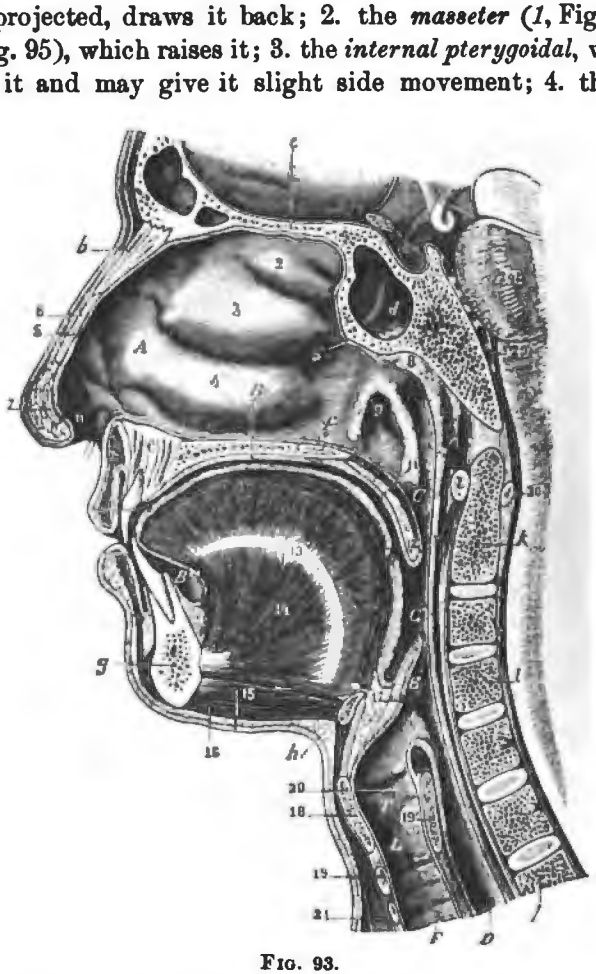

FIG. 93.

ternal pterygoidal, which projects it or twists it to one side. The last two muscles are attached to the back part of the jaw.

The *orbicularis oris* (*9*, Fig. 94; *7*, Fig. 95; *O*, Fig. 96) consists of a muscle layer formed of fibers radiating from the corners of the mouth into the upper and lower lips, some of the fibers running around the corners. When the fibers of

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the upper and lower lips act together, they constrict the mouth. Physiologically each of these muscles can be divided into an outer zone (away from the mouth) and a marginal zone. Contraction of the outer zone alone compresses the lips and projects them, that of the inner zone alone presses them back against the teeth. Each lateral half of each muscle may act independently. The *buccinator* (*11*, Fig. 95; *b*, Fig. 96) is a flat muscle at the corner of the mouth, forming a large portion of the cheek. It pulls back the corner of the mouth, closes

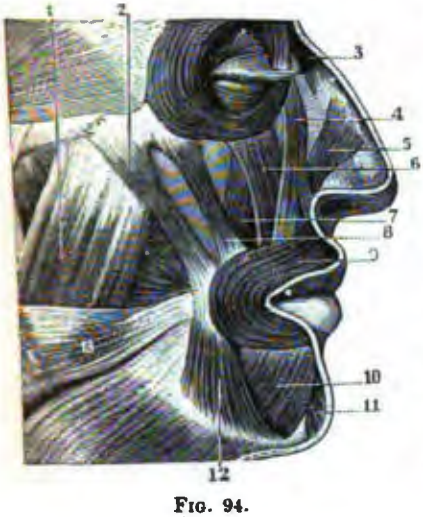

FIG. 94.

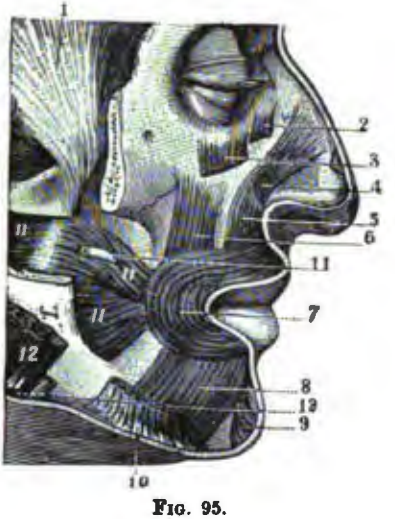

FIG. 95.

the lips and presses them and the cheeks against the teeth. The mingling of the fibers of the buccinators and the orbicularis oris is shown in Fig. 96. The *triangularis* (*12*, Fig. 94; *10*, Fig. 95; *t*, Fig. 96) draws down the corner of the mouth. The *quadratus of the lower lip* (*10*, Fig. 94; *8*, Fig. 95; *q-i*, Fig. 96) pulls the lower lip out and down. The *quadratus of the upper lip* (*q-s*, Fig. 96) is a flat muscle dividing above into the infraorbital branch (*6*, Fig. 94; *3*, Fig. 95), the angular branch (*4*, Fig. 94; *2*, Fig. 95) and a zygomatic branch whose fibers have the same insertion in the skull as the zygomatic muscle (*2*, Fig. 94). The *incisivus of the lower*

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lip (*i-i*, Fig. 96) is a small muscle covered by the quadratus of the lower lip and lying on the edge of the orbicularis from the corner of the mouth to the jaw just below the lateral incisor tooth; it pulls the corner of the mouth toward the middle and downward. The *incisivus of the upper lip* (*i-s*, Fig. 96) is a similar muscle covered by the upper quadratus; it draws the corner of the mouth inward and upward. The *canine* muscle (*7*, Fig. 94; *6*, Fig. 95; *c*, Fig. 96) raises the corner of the mouth. The *zygomatic* (*2* and *8*, Fig. 94) raises and retracts the corner of the mouth. The *mentalis* (*11*, Fig. 94; *9*, Fig. 95; *m*, Fig. 96) raises the skin of the

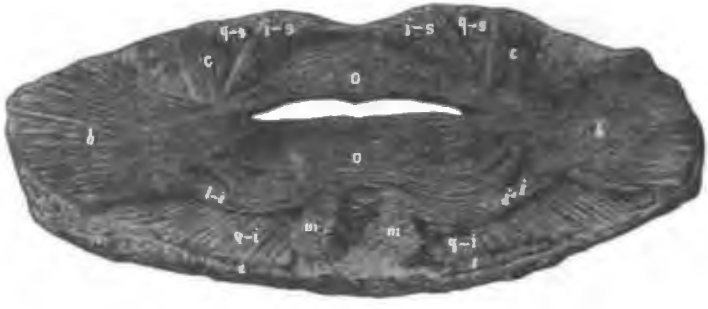

FIG. 96.

chin and thus helps to protrude the lower lip. The thin *risorius* (*13*, Fig. 94) pulls back the corner of the mouth.

The *velum*, or soft palate, (*11*, Fig. 93; *c*, Fig. 97) is a soft fold just back of the hard palate. On looking into the mouth it is seen to hang down in the back; in the center it carries the uvula (*12*, Fig. 93; *F*, Fig. 97) and on the sides it falls in two arches, the front one being the *glossopalatine* and the rear one the *pharyngopalatine* arch. The vertical portions of the arches are known as the anterior and posterior *pillars* of the velum. The velum is composed of a fibrous membrane with muscles and a mucous covering. The *palatine tonsil* on each side lies between the two pillars.

The *elevator of the velum* (*b*, Fig. 97) rising from the temporal bone and the cartilaginous wall of the Eustachian tube

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nd passing obliquely downward, serves to raise the middle ortion of the velum. The *tensor of the velum* (*e*) comes om the skull, passes downward, turns over a hoop-like bony rocess at a right angle and enters as a thin broad layer into e velum which it serves to stretch. The muscle (*a*) of the *ula* (*F*) springs from the fibrous membrane of the soft late and passes into the uvula, spreading out its fibers hich insert themselves in the mucous membrane of its sur-ce; it shortens the uvula and raises it up and back.

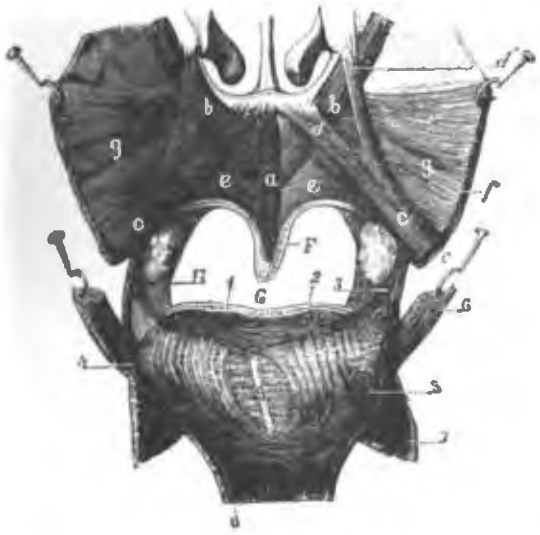

FIG. 97.

The *glossopalatine* muscle (*H*, Fig. 97; *7*, Figs. 98 and 99) nes from the tongue and passes up the anterior pillar to velum.

The *pharyngopalatine* muscle (*4*, Fig. 97) passing from the r portion of the velum descends by the posterior pillar tly to the central portion of the pharynx and partly to larynx. The muscle serves to narrow the nasopharyn-l opening and to raise the pharynx and larynx.

The *hyoid* bone (*h*, Fig. 93; *B*, Figs. 98, 99) is a

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U-shaped bone lying just above the larynx. The *mylohyoid* (*16*, Fig. 93) is a muscular layer connecting the hyoid bone to the front part of the lower jaw. Just above it near the middle is the *geniohyoid* muscle (*15*, Fig. 93; *4*, Figs. 98, 99). Also above it on each side is the *digastricus* running from the front part of the jaw partly to the loop (*13*, Fig. 98) and partly through it to the side of the skull. All three approximate the hyoid bone and the jaw.

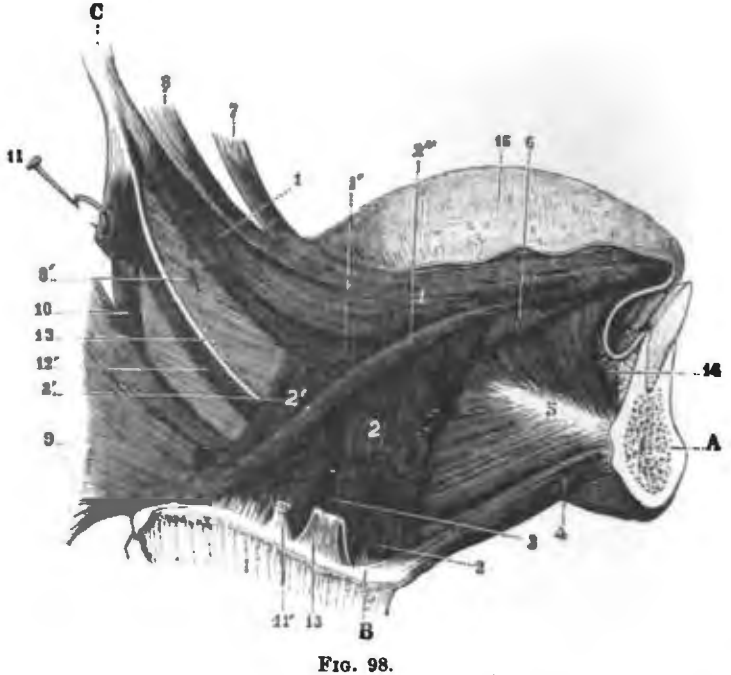

FIG. 98.

The *median septum* (*13*, Fig. 93; *9*, Fig. 97; *s*, Fig. 100) extends along the middle of the tongue.

The *styloglossus* (*1*, Figs. 98, 99; *6*, Fig. 97) runs from the styloid process (*C*) on the side of the skull to the side parts of the tongue. The two muscles draw the tongue (particularly the rear portion) up and back and press it against the soft palate. Some of the fibers also cross from one side to the other in the tongue.

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The *hyoglossus* (*2*, *2'*, Figs. 98, 99; *7*, Fig. 97) runs from e hyoid bone upward and forward to the point of the tongue. pulls the tongue back and down.

The *genioglossus* (*14*, Fig. 93; *5*, Figs. 98, 99; *g*, Fig. 100), e largest of the tongue muscles, runs from the inner surface the front of the lower jaw (*A*) into the tongue and radi-

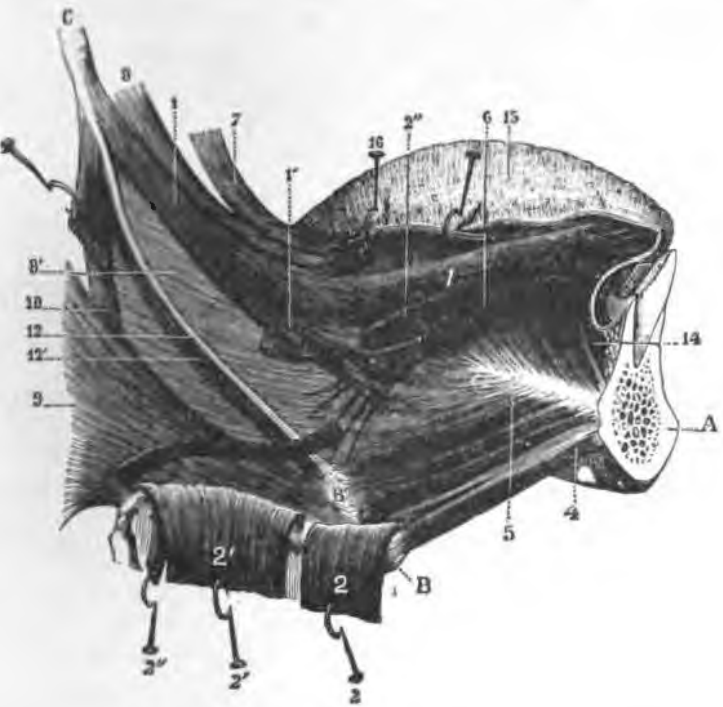

FIG. 99.

s on each side of the septum (*13*, Fig. 93) to all parts of it. e lower fibers run to the hyoid bone and serve to raise it, larynx and the tongue; some fibers also go to the epi-ttis. The median portions draw the tongue forward and d to push the point out of the mouth. The anterior fibers w the tip down and back.

The *inferior longitudinal* muscle (*6*, Figs. 98, 99; *5*, Fig.

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97) is a band passing under the surface of tongue to the apex The muscle shortens the tongue and makes it more convex lengthwise.

The *superior longitudinal* muscle (*2*, Fig. 97; *l-s*, Fig. 100 forms a layer on the upper surface with fibers running from the septum outward and forward to the free edge. It con caves the tongue upward longitudinally.

The *chondroglossus* (*2''*, Figs. 98, 99) rises from the hyoid bone and blends with the muscular substance of the tongue The muscle aids in drawing the tongue back and down.



FIG. 100.

The fibers of the *transverse lingualis* (*t*, Fig. 100), interlacing with bundles of the genioglossus, pass from the submucous layer at the sides of the tongue to or through the septum (*13*, Fig. 93); they are found in all parts of the tongue. They compress the tongue transversely and make it convex sidewise.

The fibers of the *vertical lingualis* (*v*, Fig. 100) are found near the edges of the tongue; they connect points in the upper and lower surfaces; they flatten the tongue and push out the edges.

The *frenum linguae* is a fold of mucous membrane connecting the under part of the tongue to the jaw; when too short it interferes with the movements of speech.

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Three constrictor muscles, superior, middle and inferior (*1*, *2*, *3*, Fig. 101), serve to diminish the cross section of the pharynx. The latter two also shorten the pharynx by raising the hyoid bone and the larynx.

The *superior constrictor of the pharynx* (*1*, Fig. 101; *8'*, *Figs. 98, 99*) forms a band only about 2^{cm} broad around the nasal part of the pharynx. The contraction of this muscle

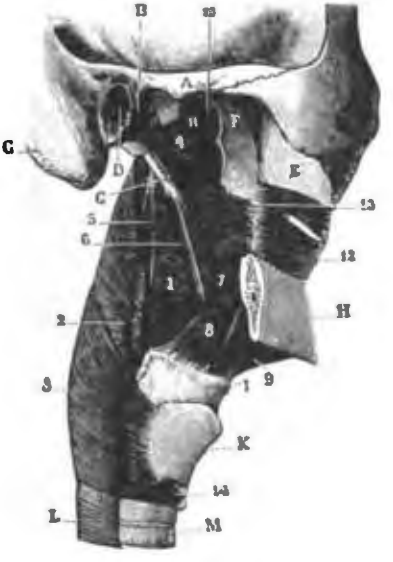

FIG. 101.

produces a ridge against which the velum presses to close the nasal opening.[1] One of its parts is the *glossopharyngeus* (*4*, Fig. 97; *8*, Figs. 98 and 99) passing to the tongue. The *middle constrictor of the pharynx* (*2*, Fig. 101; *9*, Figs. 98, 99) forms a band around the middle portion of the pharynx from the points of insertion on the hyoid bone. The *inferior constrictor of the pharynx* (*3*, Fig. 101) rises from the larynx and passes around the lower portion of the pharynx.

[1] PASSAVANT, Ueber die Verschliessung des Schlundes beim Sprechen, Frankfurt a'M., 1863; *Verschliessung d. Schlundes beim Sprechen*, Arch. f. d. path. Anat. u. Physiol. (Virchow), 1869 XLVI 1.

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Fig. 101 shows also the styloid process *G*, lower jaw *H*, hyoid bone *I*, thyroid cartilage *K*, trachea *M*, œsophagus *L*, and the following muscles: stylopharyngeus *5*, stylohyoid *6*, styloglossus *7*, hyoglossus *8*, mylohyoid *9*, buccinator *12*, cricothyroid *14*.

The action of most of the organs of articulation can be observed on a fluorescent screen when the side of the head is illuminated by a very strong RÖNTGEN apparatus.[1] Owing to the simultaneous demonstration of several organs and to the freedom of the mouth from apparatus, this method will probably be of great service. It requires a strong spark coil (250^{mm} to 500^{mm} spark), an interrupter (motor, vibrator with mercury contact, or WEHNELT'S electrolytic break), a RÖNTGEN tube, a barium-platinum-cyanide screen, battery or dynamo current, and connections.

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[1] SCHEIER, *Die Verwerthung d. Röntgenstrahlen f. d. Physiol. d. Sprache u. Stimme*, Arch. f. Laryngol., 1898 VII 116; *Ueber d. Bedeutung d. Röntgenstrahlen f. d. Physiol. d. Sprache u. Stimme*, Neuere Sprachen, 1897–98 V, Beiblatt, 40; *Zur Anwendung d. Röntgenstrahlen f. d. Physiol. d. Gesanges*, Allg. med. Centralztg., 1898 No. 37; ZWAARDEMAKER, *Sur les sons dominantes des résonnantes*, Arch. néerland. des sci., 1899 (2) II 241.

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CHAPTER XVIII

STRUCTURE AND OBSERVATION OF THE LARYNX

e larynx (*E*, Fig. 93) is situated at the upper end of the
a (*F*, Fig. 93). It comprises a framework of cartilages,
united by joints and partly bound together by liga-
and membranes.

e *cricoid* cartilage (*19*, Fig. 93; *M*, Fig. 101; *C*, Figs.
105, 107 to 111) is just above the top ring of the
ea. It is a ring, narrower in front and much enlarged
e rear.

e *thyroid* cartilage (*T*, Fig. 93; *K*, Fig. 101; *T*, Figs.
o 111) is a single large cartilage composed of two



FIG. 102.



FIG. 103.

es at the sides and front of the larynx. It rests upon the
id at the cricothyroid joints in the rear. The thyroid
minence (*2'*, Fig. 107) may be felt on the front of the
(Adam's apple). The upper and lower horns of the
oid are indicated by *b* and *b'* in Figs. 107 and 109.
two cartilages are shown in a front view in Fig. 102,
in a side view in Fig. 103.

he *arytenoid* cartilages (*A*, Figs. 104, 105) are two
ll pyramidal cartilages with triangular bases. They rest

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upon the upper edge of the posterior wide portion of the cricoid. One projection of each arytenoid cartilage, the *vocal process* (*v*, Fig. 106), carries one end of the vocal muscle (*V*, Figs.

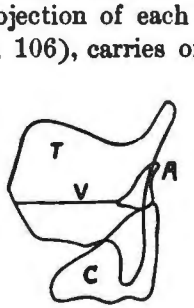

FIG. 104.

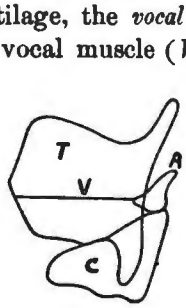

FIG. 105.

104, 105); the lateral projection is called the *muscular process* (*m*, Fig. 106). The upper corner carries a small projection called the *corniculate* (or SANTORINI) cartilage (*6*, Figs. 109, 110).

The *epiglottis* (*E*, Figs. 93, 109, 110, 111) is a thin, very flexible, elastic cartilage just above the thyroid cartilage and just behind the root of the tongue and the hyoid bone. The tension of the surrounding tissues keeps it erect.

The *thyroarytenoid* muscle (*TA*, Fig. 106) comprises fibers running from the arytenoid cartilage to the thyroid. It is often treated as consisting of two parts. The external thyroarytenoid comprises the fibers lying nearer the thyroid cartilage; the internal thyroarytenoid, or 'vocal muscle,' includes the fibers close to the glottis. There is, however, no distinct separation between the two parts. The external fibers pull the arytenoid cartilage forward as a whole. The internal fibers pull the vocal process of the arytenoid cartilage directly forward.



FIG. 106.

The *glottis* is the opening across the larynx (*G*, Fig. 106). The portion between the vocal muscles is called the *ligamentous glottis*, that between the arytenoid cartilages the *cartilaginous glottis*.

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The *cricothyroid* muscles (*CT*, Figs. 107, 108) pull the front portion of the cricoid cartilage upward around the cricothyroid joints, whereby the upper rear portion of the cricoid cartilage *C* with the arytenoid *A* moves backward and slightly downward from the position indicated in Fig. 104 to that in Fig. 105. The vocal muscle *V* between the thyroid *T* and the arytenoid *A* is thus stretched and lengthened. Owing to their slanting position, the cricothyroid muscles also compress the front of the thyroid cartilage and thus stretch the

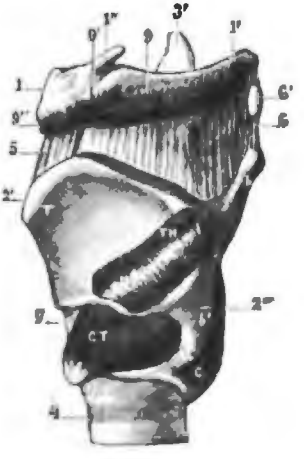

FIG. 107.



FIG. 108.

vocal muscles by moving their front point of insertion forward. The *posterior cricoarytenoid* muscle (*CAP*, Figs. 109, 110) on each side pulls the arytenoid cartilage downward and separates the vocal muscles.

Each *lateral cricoarytenoid* muscle (*CAL*, Fig. 110) runs from the upper edge of the cricoid cartilage to the muscular process and lateral edge of the arytenoid. It pulls the muscular process of the arytenoid cartilage forward and downward.

The *tranverse arytenoid* muscle (*AA*, Figs. 106, 109) pulls together the two arytenoid cartilages. It moves the

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muscular processes upward and backward, whereby the vocal processes are brought nearer together. Some of its fibers run obliquely and are often represented as separate muscles, the *oblique arytenoids* (*AAo*, Figs. 109, 110).

The *thyroepiglottic* muscles (*TE*, Fig. 110) enlarge the opening to the larynx. The *aryepiglottic* (*AE*, Fig. 110) and the *oblique arytenoid* (*AAo*, Figs. 109, 110) muscles narrow the opening.



FIG. 109.



FIG. 110.

The *thyrohyoid* muscles (*TH*, Figs. 107, 108) from the thyroid cartilage to the hyoid bone serve to raise the larynx. The *sternothyroid* from the thyroid to the breast bone serves to pull it down. The laryngeal portion of the *stylopharyngeal* (*10*, Figs. 98, 99) muscle can also energetically raise the larynx and tip it forward. The combined action of both sets of muscles holds the larynx firmly in place. The larynx rises and falls with different speech sounds, as can be felt when the finger is placed on the projection in the neck and different vowels are spoken or whispered.

Fig. 111 shows the front half of a longitudinal section of the larynx, with the epiglottis *E*, the thyroid cartilage *T*,

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the cricoid cartilage *C*, the thyroarytenoid muscles *TA* and the ventricular bands *VB*. Fig. 112 gives an enlarged section of one side of the larynx, showing the thyroid cartilage *T*, the cricoid cartilage *C*, the external and internal thyroarytenoid muscles *TAE* and *TAI*, the vocal ligament *VL*, the cricothyroid muscles *CT* and the ventricular band *VB*.

The *ventricular band* (*VB*, Figs. 111, 112) is a fold of tissue extending from the thyroid cartilage in front just above the vocal bands to the arytenoid cartilages. Muscular fibers are found in these bands.[1] The ventricular band is often shorter and thicker than that shown in the figure.



FIG. 111.

The *laryngeal ventricles* (ventricles of MORGAGNI) are small cavities, one on each side, above the vocal bands and under the ventricular bands. The opening between the ventricular band and the vocal band is often much greater than that shown in the figure.

The *mucous membrane* that lines the larynx contains an unusual number of elastic fibers that help to preserve its form amid the constant stretching it undergoes. At the edges of the thyroarytenoid muscles (*V*, Fig. 112) the elastic tissue is thickened. The edges are distinguished from the neighboring mucous covering by a difference in the epithelial cells and by the lack of glands. There is no special projecting ligament to form anything resembling a cord or a membrane. The term 'vocal cord,' 'vocal band,' or 'vocal lip' is sometimes applied to this edge, sometimes to the entire muscle.

The mucous membrane lining the larynx is supplied with glands except along the vocal ligament. These glands keep the surface lubricated. The laryngeal ventricles, being recesses or folds of the mucous membrane which have their mouths wide below and directed downward toward the vocal

[1] STEINLECHNER UND TITTEL, *Der Musculus ventricularis d. Menschen*, Sitzb. d. k. Akad. Wiss. Wien, 1897 CVI 3. Abth. 157 (structure, earlier literature).

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cords, must empty the mucus which exudes from them upon the upper surface of the cords. Somewhat of the shape of a Phrygian cap with the apex above and wound around the arytenoid cartilage, the ventricle presents an ample extent of surface on which the mucous glands may open. Their mouths may be seen extending in a few cases to within a few millimeters of the edges of the cords.



FIG. 112.

It is to be noted that many of the muscles are more or less closely united by common fibers. Thus, the thyroarytenoid and the lateral cricoarytenoid muscles are, in man, parts of a general constrictor muscle of the larynx, the cricothyroarytenoid; again the transverse arytenoid is the inner layer of an arytenoid muscle whose superficial layers send off fibers to several other muscles, particularly to the aryepiglottic.

The muscular arrangement described above is the typical one from which there are great individual differences. These individual differences probably have effects on vocal sounds, but nothing is known in regard to the details.

The movement of the arytenoid cartilages may be resolved into three components. The first is a rotation that brings the vocal processes (p. 240) closer together and at the same time tenses the cords. The second is a hinge-action that moves the vocal processes upward-outward or downward-inward; the former opens and raises the glottis, the latter closes and lowers it. The third component is a sliding action sidewise whereby the cartilages move toward each other.

The action of the muscles in producing the movements of the arytenoid cartilages may be indicated schematically by

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eans of Fig. 113. The position for respiration is shown at ; the muscles are all in a certain equilibrium of contraction. he position at *B* shows increase in the rotation-component; might be due to stronger action of the lateral cricoary- noid muscles, or to weaker action of the interarytenoid; it a position used in light whispering. Closure of the liga- entous glottis with the cartilaginous glottis open is shown *C*; the rotation component is greater than at *B*; each car- age has slid toward the other; the action of the posterior d lateral cricoarytenoids must be relatively larger or that the interarytenoid smaller. The entire glottis is closed at ; it involves chiefly the action of the lateral cricoarytenoids

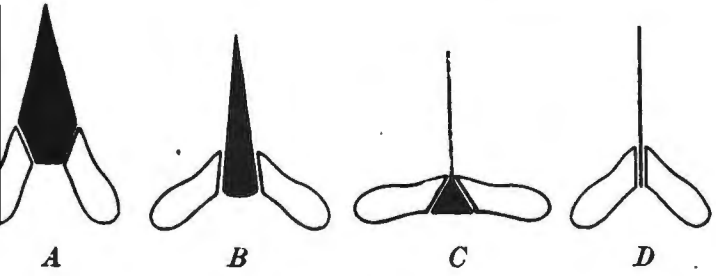

FIG. 113.

d the interarytenoid with relatively little action of the pos- ior cricoarytenoids.

Tensing of the cords by the cricothyroid would tend to se the glottis. Contraction of the external portions of the roarytenoid would relax the cords and open the glottis; t what the contraction of the internal portion would do hardly be said.

The muscles in their action on the vocal bands and glottis y be classed as 1. tensors: cricothyroid and transverse tenoid; 2. relaxers: thyroarytenoid; 3. closers (adduc- s): thyroarytenoid, lateral cricoarytenoid, transverse ary- oid; 4. openers (abductors): posterior cricoarytenoid. s to be noted that all tensors have also a closing action that all openers have also a tensing effect.

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The slant of the glottis is regulated by the interaction of the thyroarytenoids and the lateral cricoarytenoids, the former lowering the rear end, the latter raising it. The effect of the change in slant is probably to alter the direction of the air-blast; the higher position gives a more gradual convergence of the walls below the glottis while the lower position makes the convergence more sudden. The effect on the character of the tone is not known.

In swallowing, the larynx is raised, the tongue is moved backward and the epiglottis is depressed; in this way the ventricular bands in the larynx are brought against the lower part of the epiglottis and the opening is tightly closed. The glottis is also closed. The epiglottis has presumably an important function in adjusting the tone of the laryngeal cavity immediately above the vocal bands and in modifying the tone of the pharynx. The rise and fall of the larynx are due to the action of the thyrohyoid and stylopharyngeal muscles.

The cricothyroid muscle is governed by the *superior laryngeal* branch of the *vagus* nerve, the other muscles by the *inferior laryngeal* branch. The movements of the muscles are governed by sub-cerebral and cerebral centers. The former originate the movements connected with organic life, such as breathing, coughing, crying from pain, laughing, and various forms of intonation connected directly with the emotions; the latter originate the specific movements required in speech. For breathing the sub-cerebral center lies in the bulb (*B*, Fig. 70). For intonation the sub-cerebral center seems also to be in the bulb. Cerebral centers for closing and opening the glottis have been found in the cortex, both sides of the larynx being actuated by stimulation of either side of the brain. In each cerebral hemisphere there is a bilateral center for the adduction of the vocal cords;[1] a cortical center of abduction has not been

[1] KRAUSE, *Ueber d. Beziehungen d. Grosshirnrinde zu Kehlkopf u. Rachen*, Arch. f. Anat. u. Physiol. (Physiol. Abth.), 1884; SEMON AND HORSLEY, *An experimental investigation of the central motor innervation of the larynx*, Phil. Trans. Roy. Soc. Lond., 1890 CLXXXI (B) 187.

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found; separate cortical centers for the separate sides of the larynx do not exist.

The opening of the glottis and the tension of the vocal cords involve complicated muscular adjustments that have become fairly well known only since the invention of the laryngoscope.

The action of the vocal bands can be directly observed by means of the laryngoscope. Although SENN, BABINGTON and CHARRIÈRE had made mirrors for the purpose of looking down the throat, GARCIA, who had bought CHARRIÈRE'S mirror, was the first to successfully use one.[1] The development of the method was mainly due to CZERMAK.[2]

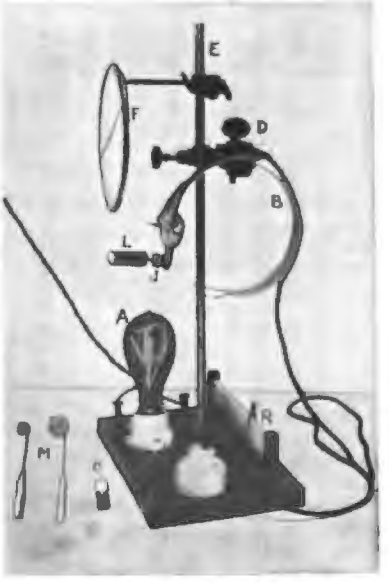

FIG. 114.

The source of illumination must be strong and concentrated. The most convenient form is that of a small electric lamp fastened to the forehead of the observer. The arrangement shown in Fig. 114 has been found adapted to the use of students. The electric lamp in the holder *L* can be turned in any direction by the ball-joint *J*; its light is focused by an adjustable lens. It may be connected to a storage battery or through a suitable resistance to the city wires. The apparatus shown in Fig. 114 comprises a lamp *A*

[1] *Rapport sur* 'GARCIA, *Mémoire sur la voix humaine*,' C. r. Acad. Sci. Paris, 1841 XII 638; *Observations on the human voice*, Philos. Mag., 1855 X 218; RICHARD, Notice sur l'invention du Laryngoscope, Paris, 1861; FRÄNKEL, *Untersuchungsmethoden d. Kehlkopfes u. d. Luftröhre*, Heymann's Handb. d. Laryng. u Rhin., I 229, Wien, 1898.

[2] CZERMAK, Der Kehlkopfspiegel, Leipzig, 1860-1863.

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of about 100 ohms resistance on a 110-volt circuit (a 32-candle-power lamp); the current of 1 ampere passes through this and a small adjustable wire resistance *R* to the laryngoscope lamp. The degree of brightness in the latter is regulated by adjusting the resistance. An extra lamp is shown at *C*. For observing others the spring *B* passes over the head of the observer. For self-observation the spring is fixed by an adjustable clamp *D* to the rod *E*, and an adjustable mirror *F* is attached to the same rod.

Oil and gas lamps with condensing lenses may also be used. Physicians frequently employ an Argand burner with a reflector fastened before the eye which looks through a small hole in the center.



FIG. 115.

A laryngeal mirror (*M*, Fig. 114) of the largest size that the subject can conveniently bear is sterilized by carefully cleaning it with a brush in a hot solution of sodium carbonate and by rinsing it before use in a 5% solution of carbolic acid. Persons with tuberculosis or other infectious diseases should have their own mirrors. The mirror should be warmed to about body temperature (tested by the hand) against the large incandescent lamp or over a flame.

The subject should open the mouth as widely as possible, the lips exposing the teeth. The tongue is stuck out (not pulled out) and the point is wrapped in a cloth and held down by the thumb and finger (Fig. 115). The subject must continue his respiration quietly and without stopping, otherwise the contact of the mirror is liable to cause retching; he is to repeat whatever sound he hears.

The handle of the mirror is held like a pencil. While the vowel **e** is being sung, the mirror is inserted quickly and evenly so that the uvula rests upon the back of the

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rror; the handle is kept at the corner of the mouth. slight further movement and turning of the mirror suffice send the light down the larynx and to reflect its picture the eye. Considerable practice is required to attain a dy and complete control of the adjustments. In the yngoscope mirror the picture appears reversed, the epi-ttis being at the top. The SANTORINI cartilages appear the view; their movements serve to indicate the tilting the arytenoid cartilages.

Measurements can be made with considerable accuracy by raduated mirror or by glancing at a millimeter scale and n estimating the distance in the laryngoscopic picture. An trument for directly measuring the width of the glottis been devised by EXNER.[1]

The character of the vibration of the vocal bands may observed by the stroboscopic method, which has been dered easy of use.[2]

With a sufficiently bright light and a camera arrangement laryngeal view may be photographed.[3] With a stereoscopic

[1] EXNER, *Das Laryngometer*, Zt. f. Instrumentenkunde, 1897 XVII 371.

[2] OERTEL, *Ueber eine neue laryngostroboskopische Untersuchungsmethode*, Centbl. f. d. med. Wiss., 1878 XVI 81; *Laryngostroboskopische Beobachtungen über Bildung der Register bei d. menschl. Stimme*, Centralbl. f. d. med. Wiss., 1878 I 99; *Ueber d. Mechanismus d. Brust- und Falsettregist.*, Beiträge z. Biol., 25, ttgart, 1882; *Das Laryngostroboskop und seine Verwendung in d. Physik, siol. u. Med.*, Archiv f. Laryngologie, III (also separate, Berlin, 1895); er *d. Laryngostroboskop*, Verh. d. Congr. f. inn. Med., 1895 331; RÉTHI, er. *Untersuch. üb. d. Schwingungstypus u. d. Mechanismus d. Stimmbänder bei alsettstimme*, Sitzb. d. k. Akad. Wiss. Wien, math.-naturw. Kl., 1896 CV 3. h. 197; *Untersuch. üb. d. Schwingungsform d. Stimmbänder bei d. verschied. angsregistern*, same, 1897 CVI 3. Abth. 66; MUSEHOLD, *Stroboskopische u. ogr. Studien üb. d. Stellung d. Stimmlippen im Brust- und Falsettregister*, h. f. Laryngol., 1898 VII 1; SPIESS, *Ein neues Laryngostroboskop*, Arch. f. yngol., 1898 VII 148.

[3] FRENCH, *On a perfected method of photographing the larynx*, N. Y. Med. Jour., , Dec. 13; *Laryngeal and postnasal photography with the aid of the arc light*, . Med. Jour., 1897, Jan. 23. (Accounts of earlier attempts and later methods ILLIAN, Münch. med. Wochenschr., 1893, Feb. 7; WAGNER, *D. Photographie ehlkopfes*, Heymann's Handb. d. Laryngol. u. Rhinol., I 1512, Wien, 1898; EL, Ann. des Mal. de l'Oreille, 1899 XXV (2) 702.)

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camera[1] double views may be obtained that appear in relief through a stereoscope.

The combination of a stereoscopic shutter and a photographic arrangement with a moving sensitive surface renders it possible to get pictures of the cords in typical stages of vibration.[2]

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[1] Garel, *La photographie stéréoscopique du larynx*, Ann. des Mal. de l'Oreille, 1899 XXV (2) 702.

[2] Sbismanowsky, *Die Anwendung d. Photographie bei Untersuchung d. Stimmbänderschwingungen*, Arch. f. d. ges. Physiol. (Pflüger), 1885 XXXVII 375; Muserold, *Stroboskopische u. photogr. Studien üb. d. Stellung d. Stimmlippen im Brust- u. Falsettregister*, Arch. f. Laryngol., 1898 VII 1.

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CHAPTER XIX

ACTION OF THE LARYNX

VIEW of the larynx from above during quiet breathing is wn in the photograph (Fig. 116) made by FRENCH. The lottis is seen as a fold curled upward at the top of picture. The arytenoid cartilages are rotated so that r vocal processes are turned outward, thereby separating rear ends of the vocal cords. The whole glottis is thus ely opened; the trachea can be seen below.

peech sounds pro- ed with this adjust- t of the larynx get r acoustic character rely from the vocal ities and not at all n the glottis; they are l to be 'surd' or 'un- ced.'



FIG. 116.

Vocal sounds produced en the cords are vi- ting are said to be 'sung' or 'intoned' when they occur ong, 'sonant' or 'voiced' when in speech.

n intonation the vocal cords are brought together. The st of air from the trachea sets them in vibration. The idity of the vibration depends on the length, tension and ding of the muscles constituting the vocal bands.

From photographs of the vocal bands during intonation s possible to make some deductions concerning the laryn- l action.

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The series of photographs shown in Figs. 117 to 121 wer taken by FRENCH[1] from the larynx of a professional con tralto. The picture for her lowest note, Fig. 117, shows th vocal bands quite short and wide, with the ligamentous glotti (p. 240) open along three fourths o its length and the cartilaginous glot tis partly open, the ligamentous glotti being linear in shape. As the voic ascended the scale the vocal band increased in length and decreased i width, until at e^1 the condition wa as shown in Fig. 118; here the carti laginous glottis has opened further the vocal bands had increased i length at least 3^{mm} in the seven notes and had become narrower. The ris in pitch seems to have been brought about by stretching the bands. With a further rise in pitch however, the condition suddenly changed. In the transition from e^1 to f^1 (Fig. 119) the bands were shortened about 2^{mm}, the cartilaginous glottis was closed and the ligamentous glot tis narrowed; the entire cavity of the larynx was reduced and the epiglottis lowered. The bands appeared to be more tightly stretched, and to be capable of vibrating only along the ligamentous glottis. The change in action was accompanied by a marked change in the acoustic quality of the tone produced. Such a change in the manner of producing tones is said to be a 'change of register,' a 'register' including all tones produced in the same manner. As the scale was followed upward, the vocal bands steadily increased in length and the ligamentous glottis gradually opened. The condition at d^2 is shown in Fig. 120; the bands had increased in length several mil-

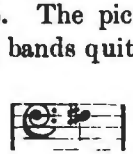



FIG. 117.

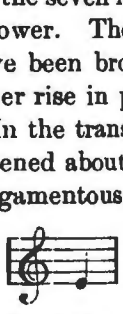



FIG. 118.

[1] FRENCH, *The action of the glottis in singing*, N. Y. Med. Jour., 1891 Jan. 31.

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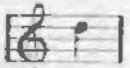
meters and the cartilaginous glottis was somewhat opened. hese facts apparently indicated a decrease in tension of the ands. The epiglottis had risen slightly. As the voice passed om d^2 to e^2 a distinct change in quality was again heard and e laryngeal conditions were seen become readjusted (Fig. 121). he vocal bands seemed slightly orter than before. There was osure of the cartilaginous glottis d a small portion of each end of e ligamentous glottis. The epi- ttis was depressed. There was ain a change of register. This s the highest note that could be ng with ease; the action in as- ding this register could not be died.



Fig. 119.

Other carefully made photo- aphs by FRENCH show both similarities and disagree- nts. They seem to establish the following conclusions regarding the action of the female larynx.



e^1



Fig. 120.

'The larynx may act in a variety of ways in the production of the same tones or registers in different individuals. The rule — which, however, has many exceptions — is that the vocal bands are short and wide and the ligamentous and cartilaginous portions of the glottis are open in the production of the lower tones; that, as the voice ascends the scale, the vocal bands increase in length and decrease in width, the aperture between posterior portions of the vocal bands increases in size, the TORINI cartilages are tilted more and more forward, and the lottis rises until a note in the neighborhood of e^1, treble clef, line, is reached. The cartilaginous glottis is then closed.

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The glottic chink becomes much narrower and linear in shape the capitula SANTORINI are tilted backward, and the epiglottis i depressed.

'When the vocal bands are shortened in the change at th lower break in the voice, it is mainly due to closure of the carti laginous portion of the glottis, the ligamentous portion no usually being affected. If, therefore, the cartilaginous glottis i not closed, there is usually no material change in the length o the vocal bands.

'As the voice ascends from the lower break, the vocal band increase in length and diminish in width, the posterior portio of the glottic chink opens more and more, the capitula Santorin are tilted forward, and the epiglottis rises until, in the neighbor hood of e^2, treble clef, fourth space another change occurs.



FIG. 121.

'The glottic chink is then reduced t a very narrow slit, in some subjects ex tending the whole length of the glottis in others, closing in front or behind, o both. Not only is the cartilaginous glot tis always closed, but the ligamentous glottis is, I believe, invariably short ened. The arytenoid cartilages are til ted backward and the epiglottis is depressed. As the voice ascends in the head register the cavity of the larynx is reduced in size, the arytenoid carti lages are tilted forward and brought closer together, the epi glottis is depressed, and the vocal bands decreased in length and breadth. If the posterior part of the ligamentous portion of the glottis is not closed in the lower, it is likely to be in the upper notes of the head register.'[1]

Concerning the muscular action whereby the changes in pitch are produced, we can hardly say more than that presumably they are mainly brought about by the interaction of the cricothyroid and the thyroarytenoid muscles. The former stretches the bands (p. 241). The latter can make them more tense by contraction of its fibers (p. 240), whereby the pitch would be raised, or it can shift the weight toward the

[1] FRENCH, as before.

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dle, whereby the pitch would be lowered. Changes in , in tension and in length of the vibrating portion can be luced by the muscles attached to the arytenoid cartilages 239). The intimate connections of all these muscles with other muscles of the larynx (p. 244) would suggest gen- changes in any change of register.

he rise in pitch through several octaves evidently cannot produced by continuous stretching of the bands. For a of seven tones the bands shown in Figs. 117 and 118 were tched about 3mm. As this voice had a compass of about octaves, a total lengthening of 10mm to 12mm would be ded at the same rate. The impossibility of such a stretch- indicates the necessity of a change of method in pro- ing the tones.

t was asserted by GALEN that the edges of the glottis e an essential factor in the production of voice;[1] he ns to have supposed them to act by forcing the breath orm a jet whereby the air in the vocal cavity was aroused ibration as in a labial pipe. DODART recognized the fact t the pitch of the voice depends on the tension of the vocal ds.[2] According to FERREIN the width of the glottis no influence on the pitch of the tone, and the bands essentially strings set in vibration by the air as the string violin is aroused by a bow.[3] He was the first to make periments on membrane strips stretched over a tube and the larynx removed from the human body.

Three views have been held concerning the manner in ich the vocal bands vibrate.

For some purposes a vocal band may be considered as tring stretched between two points with its entire mass centrated in a material point at the center; the laws its vibration can then be deduced mathematically.[4] For

[1] GALEN, De usu partium, Lib. VI, cap. 2.

[2] DODART, *Mém. sur les causes de la voix, etc.*, Mém. de l'Acad. des Sc. de Paris, 0. 1706, 1707.

[3] FERREIN, *De la formation de la voix de l'homme*, Mém. de l'Acad. des Sc. de is, 1741.

[4] RAYLEIGH, Theory of Sound, 2. ed., I § 52, London, 1894.

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vibrations so small that the additional stretching during the elongation is negligible, we have

$$T = 2\pi\sqrt{\frac{am}{2s}}$$

where T is the period of vibration, s the tension, a the length and m the mass. Thus the period increases with an increase of length, an increase of mass, or a decrease of tension. This last statement, more general than the equation, is valid for the slowest mode of vibration of any stretched string; the fall in pitch with increase of length, increase of mass and decrease of tension can be readily illustrated on any stringed instrument.

For most purposes, however, we must consider the distribution of the mass of the string along its length. The ideal musical string is 'a perfectly uniform and flexible filament of solid matter stretched between two fixed points.' The strings of most musical instruments approach the ideal closely.

The free vibrations of a string consist of the sum of a series of harmonics whose periods are the natural periods of the whole string, a half of the string, a third of the string, etc. This can be easily shown by setting a violin string in vibration and then touching it exactly in the middle; the lower tone ceases but the tone of half the string continues to be heard. The higher tones may be similarly found. Such a series of tones is often called a *note*; the component tones are called *partials*. The lowest partial is called the *first partial* or *fundamental*. The higher partials are called *second*, *third*, . . . *partials* or *first*, *second*, . . . *overtones*. For example, the note of 100 vibrations a second from a piano string would consist of the partials 100, 200, 300, 400, 500, 600, . . . in various intensities; the first partial, 100, would be the fundamental and the others would be overtones (p. 72).

The vibrations of strings maintained by a blast of air as in an Æolian harp are in a plane transverse to the direction of the wind.[1] In the vocal bands such an action would tend to compression sidewise, that is, to a cushion action.

[1] RAYLEIGH, *Acoustical observations*, Phil. Mag., 1879 (5) VII 161.

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The vocal bands are sometimes treated as membranes stretched across a channel. J. MÜLLER[1] made experiments on membranous lips, whereby he showed that the width of the opening had little influence on the period, that the period depended chiefly on the tension and on the damping and that small membranes could be made to give very deep and powerful tones. He treated the larynx as a pipe with membranous reeds whose periods followed the rules for strings. That membranes can be made to give deep tones only when stretched on soft supports that also vibrate, that the cords can be treated as ordinary membranes only in falsetto tones, and that in falsetto tones they have nodal points — these are conclusions drawn by C. MÜLLER.[2]

Membrane pipes have been made in various ways and have been studied to some extent.[3] They form convenient instruments for illustrating the effect of tension on the pitch of the membrane but are decidedly liable to mislead in implying that the vocal bands vibrate like membranes and that the tension is obtained wholly by bringing the points of support further apart. A convenient model is that of CZERMAK[4] or that of LUDWIG.[5] The simple form shown in Fig. 122 will serve every purpose. Two opposite points of the thin-walled rubber tube are each caught between the thumb and finger: the tube is then stretched till the sides come together. A blast of air through the tube sets the edges in vibration. The period of this vibration depends on the tension, which can be regulated by the fingers.

The vocal bands may also be treated as elastic cushions that yield by compression. The vibrations of cushions have, so far as I am aware, received no extended treatment. The

[1] MÜLLER, Handbuch d. Physiol. d. Menschen, II 179, Coblenz, 1840.

[2] MÜLLER, *Untersuchungen über einseitig frei schwingende Membranen und deren Beziehung zum menschlichen Stimmorgan*, Schr. d. Ges. zur Beförd. d. ges. Naturw. z. Marburg, 1877 II 102, 166, 167.

[3] HURBERT, *Sur le mode de vibration des membranes, et le rôle du muscle thyro-aryténoïdien*, C. r. Acad. Sci., Paris, 1891 CXII 715.

[4] CZERMAK, Gesammelte Schriften, II 71, Wien, 1879.

[5] LUDWIG's künstliche Kehlköpfe, in PETZOLD's Katalog.

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possibility of a cushion action of the vocal bands was suggested by EWALD [1] and MÜSEHOLD.[2] The blast of air pushes the edges of the cushions to one side either through compression of the projecting cushions themselves or through yielding of the walls. 'This view is favored by the fact that the vocal bands are not of a nature and shape to readily vibrate transversely. The true shape is given in Fig. 112; the usual diagrams in works outside those specially pertaining to laryngology give a quite erroneous idea of them. The vocal bands suggest a pair of cushions suitable for compression,

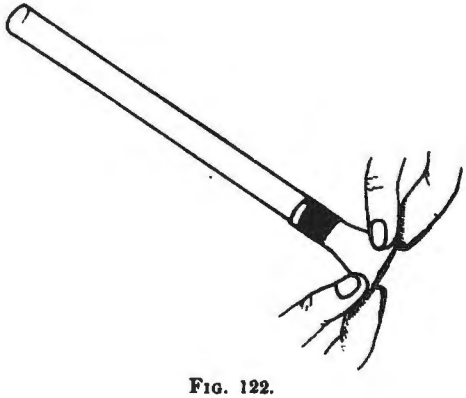

FIG. 122.

and not a pair of membranes. When the bands are closed by the action of the cartilages, the air is retained behind them until the pressure is great enough to force them open, the pressure being regulated by the tension of the vocal muscles constituting the bands. When they have been forced apart to emit the puff of air, they close again and remain closed until the pressure is again sufficient to open them.' [3]

The character of the vibrations of the vocal bands seems clearly indicated by the following additional facts.

[1] EWALD, *Physiologie des Kehlkopfes*, Heymann's Handbuch d. Laryng. u. Rhin., I 181, Wien, 1898.

[2] MUSEHOLD, *Stroboskopische u. photogr. Studien üb. d. Stellung d. Stimmlippen im Brust- u. Falsettregister*, Arch. f. Laryngol., 1898 VII 1.

[3] SCRIPTURE, *On the nature of vowels*, Amer. Jour. Sci., 1901 XI 309.

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Observations[1] of the vocal cords of men singing in the chest register showed that the cords touch along their whole length; that in loud tones they have a slightly rounded form, especially in the middle, indicating strong contact in the middle with lighter contact at the ends; that in weaker tones the line of contact appears even and thin while the top of the cords becomes flatter. These observations made it clear that a vibration of the cords in the axial direction of the larynx did not occur, and established the fact of cushion action. Observations on the head register showed that the vocal cords did not touch but were separated by a more or less weakly elliptical slit; the exact method of vibration was not established.

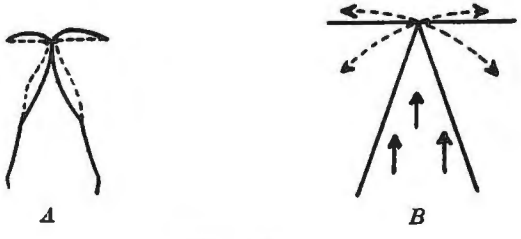

FIG. 123.

Observations[2] by the stroboscopic method showed that in singing in the chest register the glottis opens to a spindle-like slit and then closes completely along its whole length; that the cords move sidewise, that is, outwards, and not crosswise in the direction of the axis of the larynx. Observations on the head register showed that the edges of the cords did not touch, but did not afford a decision concerning the direction of their vibration. Fig. 123 *A* (MUSEHOLD) shows the edges of the bands just touching (dotted line) at rest, and tightly pressed together as in singing in the chest register (full line). Fig. 123 *B* (MUSEHOLD) shows the directions in which the bands yield to the pressure of air from the trachea.

[1] MUSEHOLD, as before, 8.
[2] MUSEHOLD, as before, 12, 16.

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From the foregoing observations we may draw fairly reliable conclusions concerning the manner in which the vocal bands execute their vibrations.

In regard to the chest register the theory stated by GARCIA[1] seems established. 'The vocal cords close the passage for the air and offer resistance to it. As soon as the air attains a sufficient pressure, it separates the cords and produces an explosion, but at the same moment they come together again on account of their elasticity and because the pressure below has ceased, ready for a new explosion. A series of these compressions and expansions, or explosions, caused by the pressure of the accumulated air and the reaction of the glottis, produces the voice. . . . It is not necessary for the glottis to close again completely after each opening in order to produce the explosion; it is sufficient that it should present a resistance to the air sufficient to develop its elasticity.' The action of the lips in blowing a trumpet, as recently established by the stroboscopic method,[2] is closely like that of the cushion action of the cords.

In the chest register the vocal bands probably always vibrate throughout their entire thickness, and never along the edges only.[3]

In regard to the head register it seems probable that the thyroarytenoids do not contract — at least strongly;[4] that the change in the tension of the cords is produced by stretching; that the cords have somewhat sharper edges than in the chest register; that the direction of vibration may deviate more or less from the transversal direction. The action may be similar to that of a stretched string with a mass of soft material attached to it, or to that of a cushion with the main tension along its edge. It is possible that the edge of the band moves neither axially nor transversely and not even in a straight line but in a more or less complicated curve.

[1] GARCIA, *Beobächtungen üb d. menschl. Stimme*, Monatsschr. f. Ohrenheilk., 1878.

[2] MUSEHOLD, as before, 19.

[3] MUSEHOLD, as before, 18.

[4] EWALD, as before, 200.

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In regard to the course of a vibration executed by the bands no reliable data are at hand except those obtainable from speech curves (Part I). These indicate regularly for the chest register more or less sudden movements separated by intervals of rest (p. 39). Concerning the head register we have no published information.

Different adjustments of the weight of the muscle substance within the vocal bands would produce differences in the character of the vibration and consequently puffs of different forms (p. 96). These differences in adjustment may be produced by differences in the groups of fibers contracted. The character of the voice in singing or speaking doubtless arises largely from these differences in the action of the bands. The effect of different loads on the action of a vibrating string may be readily illustrated. A string — for example, a violin string — is stretched between two supports. By loading the string with little blocks of paper or by pressing cotton wads against it at different points the character of the tone may be made to vary as a result of the modification of the overtones. The effect in vibrating cushions is not so readily demonstrated.

It has been suggested (SWAIN) that the ventricular bands may possibly descend and touch the top surfaces of the vocal bands during intonation and thus modify the character of the vibrations by acting as dampers, loads or nodal supports.

According to STÖRK,[1] when the larynx is strongly illuminated below the cords by a light through the neck and is observed with a laryngoscope, the light is seen in increasing brightness through the cords as the pitch rises until in the head register there seems to be only a thin membrane in front of it. This shows merely that in high notes the time of closure diminishes in comparison with the time of opening.

That the vocal muscle possesses the ability to contract differently in its different parts is shown by an experiment described by EWALD.[2] Across the end of a tube two frog-

[1] STÖRK, Klinik der Kehkopfkrankheiten, Stuttgart, 1876.

[2] EWALD, *Physiologie des Kehlkopfes*, Heymann's Handbuch d. Laryngologie u. Rhin., I 202, Wien, 1898.

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muscles were placed to form an artificial larynx. The muscles were stretched by causing them to contract by means of electric currents. A note was produced when a blast of air was driven through the apparatus. By shifting the electrodes the inner or the outer portions of the muscles could be made to contract separately. Different distributions of the weight in the vibrating muscles produced changes in pitch. In this way considerable changes could be produced while the total contractile force remained constant. This experiment of EWALD'S does not prove that the tension of the cords remains constant and that the changes in pitch are entirely produced by different degrees and distributions of the contraction. It is much more probable that the differences in distribution aid in great changes in pitch, but that the finer adjustments are derived from differences in the tension of a portion already contracted; this would involve combined changes in the tensions of the thyroarytenoid and the cricothyroid muscles.

According to OERTEL[1] and KOSCHLAKOFF[2] the vocal bands in the head register vibrate in two longitudinal segments with nodal lines running along not far from their edges. The narrow strip between the nodal line and the edge makes extensive movements while the portion beyond the nodal line makes only small ones. It may be suggested that the greater weight of the outer portion would make its smaller vibrations equivalent in energy to the more extended ones of the inner portion.

According to RÉTHI'S observations[3] on the head register by means of the stroboscopic method, the edge of the vocal cord rises for a vibration and then falls while a ridge-like wave passes from the edge along the top surface outward, no nodal lines being seen; the phenomena were explained by the contraction of the internal portion of the thyroarytenoid

[1] OERTEL, as on p. 249.

[2] KOSCHLAKOFF, *Ueber d. Schwingungstypen d. Stimmbänder*, Arch. f. d. ges. Physiol. (Pflüger), 1886 XXXVIII 473.

[3] RÉTHI, *Exper. Untersuch. üb. d. Schwingungstypus u. d. Mechanismus d. Stimmbänder bei d. Falsettstimme*, Sitzb. d. k. Akad. Wiss. Wien, math.-naturw. Kl., 1896 CV 3. Abth. 197.

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nuscle while the external portion was relaxed. In the middle egister the action was similar to that in the head register.[1]

Studies of vowels sung and spoken in the chest register eem to require the assumption of cushion action of the ands, as indicated by the following facts. The movement nparted to the air by a freely vibrating membrane is neces- arily of the nature of a sinusoid (p. 2) or a sum of har- nonic sinusoids (p. 13). That the movement is not of such nature in sung and spoken vowels of the chest register has een proven by recorded speech curves (p. 41). The vibra- ons of cushions may be of any degree of sharpness or smooth- ess from a practically instantaneous explosion to a move- ent as regular as that of a fork. Such vibrations appear the various speech curves. Vibrations of a sinusoid char cter can arouse only harmonic resonance vibrations, whereas xplosive vibrations require no such adjustment of the reso- ating cavity. The evidence is conclusive (pp. 21, 39) that sung and spoken vowels a harmonic relation between the esonance tones and the cord tone is not necessary. In con- dering the tone aroused by the cords it seems necessary to eat it not as a note composed of a series of partials (p. 90) t as a series of puffs. These facts are conclusive in regard the cushion action in the chest register. Similar data for e head register are not at hand.

When the vocal cords close to obstruct the air passage, e greater the breath pressure the more energetic must be e muscular action in order to maintain the closure. Even nen the cords are vibrating the tension and firmness of sure must increase as the pressure increases in order to event the cords from simply being forced apart and produc- g a breathy tone. That this is actually the case has been own by MUSEHOLD (p. 259). According to MÜLLER[2] an

[1] RÉTHI, *Untersuch. üb. d. Schwingungsform d. Stimmbänder bei d. verschied. istern*, Sitzb. d. k. Akad. Wiss. Wien, math.-naturw. Kl., 1897 CVI 3. Abth.

[2] MÜLLER, Ueber d. Compensation d. physischen Kräfte am menschl. Stimm- an, 1839.

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increase in the pressure of the air produces an increased 'passive' tension of the vocal membranes and consequently a higher note; this can be readily demonstrated by the instrument shown in Fig. 122. To maintain a sound on the same note this passive tension must be compensated by a relaxation of the active tension. This theory would be apparently incontestable if the cords were membranes, as MÜLLER supposed. It has been shown to be inadequate by the observations of MUSEHOLD; the cords do not relax but contract more firmly as the breath pressure rises. The maintenance of a constant period of vibration in spite of the firmer closure may, I suggest, be due to a redistribution of the contraction in the different fibers, the fibers along the edge contracting more strongly while those in the interior relax and act not only to diminish the total tension of the cords but also as loads to lengthen the period.

When the same note is sung by different persons or by the same person in different conditions, the ear will readily detect differences in the character of the sound. Persons can be distinguished by their voices when speaking and singing. There are undoubtedly individual differences in the action of the vocal bands and in the adjustments of the vocal cavity. The changes in the character of a note coming directly from the glottis are brought about by differences in the structure and action of the larynx. On the theory that the cords execute vibratory movements like most musical instruments these differences arise from the differences in the strengths of the partial tones (p. 95). On the theory that the cords produce puffs like a siren they arise from the shape of the puff (p. 96).

The character of the voice depends also on the condition of lubrifaction of the larynx. It must necessarily be the case that a wet wall of whatever resisting quality must produce sound waves of a different nature from a dry or nearly dry surface, and this must especially apply to the vocal cords. Any influence, whether physiological or pathological, which tends to modify the amount and the consistency of the lubri-

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cient mucus, must also influence the vocal tone. A large rt of the modification of the voice in attacks of laryngitis ust be due to this change in the mucus.

Changes in the tones from the cords are also brought about adjustments of the sizes, necks and apertures of the series of vities above them; these are brought about by rise and fall the larynx, by changes in the position of the epiglottis, ngue, velum, jaw, lips, by changes in the tension in the alls of the cavities, etc. It is doubtful for the human sub- ct, if the laryngeal ventricle, even during very strenuous onation, is dilated sufficiently to greatly modify the quality the tone. We know that this occurs in some animals in hich these ventricles seem to serve the purpose of resonators. he ventricular bands may perhaps in some way affect the aracter of the voice tone.

Voices may be classed roughly as soft and sharp. The soft ice has a character resembling that of a flute or a tuning rk, that is, a tone with mainly low partials. The soft ice is most readily produced when the head is slightly clined forward and the larynx lowered. The length of e mouth cavity favors low tones and the softness of the lls would hinder the development of high tones. The lips e generally held rather close, to hinder the exit of high nes. The tongue is drawn back and the soft palate raised close the nasal opening. On the vibration theory the bands emselves may be supposed to swing in a way to develop ly low overtones. GRÜTZNER[1] supposes them to vibrate thout touching at the edges. It may be suggested that the justment of the muscular load within the bands might be pposed to dampen the higher overtones (p. 295). On the plosion theory the puffs are of smooth shape; they might en approximate the sinusoid form (p. 2). In the production the sharp voice the larynx is high, the head is generally ped back, the muscular adjustments are firm, the mouth

[1] MERKEL, Die Functionen d. menschl. Schlund- u. Kehlkopfes, Leipzig, 2; GRÜTZNER, *Physiologie d. Stimme u. Sprache*, Hermann's Handbuch d. siol., I (2) 106. Leipzig, 1879.

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is open and the tongue depressed; the epiglottis is hal erected. On the vibration theory these adjustments favo the development of high partials and their exit from th mouth; the vocal bands are supposed to strike sharply agains each other and the load is not adjusted to avoid the over tones. The sound is like that of a membrane striking against a solid edge (GRÜTZNER). A screeching tone is a exaggeration of the sharp tone (GARCIA). The adoption o the striking of the bands into the vibration theory practically replaces it by the explosion theory. On the explosion theory the glottis closes and opens in a way to produce puffs whose shape is not smooth.

Experimental records from the larynx are generally con cerned with its vertical displacement or with the pitch of the tone it produces.

The rise and fall of the larynx can be registered by tam bours with special projecting arms.[1] The rise of the larynx for high tones and its fall for low ones indicate activity of the thyrohyoid and sternothyroid muscles. Movements dur ing internal speech have been similarly registered.[2] Ob servations with RÖNTGEN rays showed that for **a** the hyoid bone is still while the larynx is somewhat raised. The larynx is higher for **a** than for **u**, lower than for **i**. For **e** it is somewhat lower than for **i**; for **o** somewhat higher than for **u**. As **a** is made to pass into **i** both hyoid bone and larynx rise, maintaining their relative positions. As **a** is changed to **u**, the larynx sinks and the hyoid bone is pushed forward somewhat. For **a** the cavity bounded by the larynx, the base of tongue, the rear wall of pharynx and the soft palate is only moderately large; it is large for **e**, still larger for **i** and narrowest for **u**. For rise in pitch the epiglottis rises, and likewise the reverse. Observations on over thirty singers showed that with the falsetto voice the epiglottis is

[1] v. KRZYWICKI, Ueber die graphische Darstellung der Kehlkopfbewegungen beim Sprechen u. Singen, Königsberg, 1892; ROUSSELOT, Principes de phonétique expérimentale, 98, Paris, 1897.

[2] CURTIS, *Automatic movements of the larynx*, Amer. Jour. Psychol., 1900 XI 237.

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arly upright, and that the larynx is raised and brought ar the hyoid bone.[1]

The pitch of the tone from the larynx may be determined several ways.

To register from the outside of the larynx, a tube is fitted htly into the bottom of a small round box[2] (Fig. 124); edges may be cut to fit closely on the neck over the ynx; it may be covered with a rubber membrane.[3] A ber tube transmits the air vibrations from this box to a AREY tambour (p. 195), whereby they may be made to ord themselves on a drum.

ROSAPELLY's electric interrupter for the larynx consists of mall weight on a spring whose inertia closes an electric cuit when its supporting frame is jarred.[4]

ROUSSELOT[5] has used a carbon microphone to interrupt an ctric current in accordance with the movements of the sound spoken. tead of a telephone plate the fluctu- ons in the magnet included in the cuit were communicated to an arma- e held by a membrane of varnished parchment; the move- nts were registered by a recording arm.



FIG. 124.

The microphone known in America as the BLAKE trans- ter and a very light and carefully made time-marker may used for the same purpose, as may also a carefully adjusted e key (Fig. 66).

The methods of registering the vibrations in the speech nds issuing from the mouth are mentioned in Part I; a

SCHEIER, *Ueber d. Verwerthung d. Röntgen-Strahlen f. d. Physiol. d. Sprache imme*, Arch. f. Laryngol., 1898 VII 126; *Ueber d. Bedeutung d. Röntgen- len für d. Physiol. d. Sprache u. Stimme*, Neuere Sprachen, 1897-98 V, att, 40.

ROUSSELOT, *Les modifications phonét. du langage*, 15, Rev. des pat. gallo- ns, 1891 IV, V (also separate); Principes de phonétique expérimentale, 97, , 1897.

MEYER, *Stimmhaftes H*, Neuere Sprachen, 1900 VIII 261.

ROSAPELLY, *Essai d'inscription phonétique*, Travaux du lab. de Marey, II

ROUSSELOT, *Les modifications*, as before, 14; Principes, 106.

ROUSSELOT, *Les modifications*, as before, 16; Principes, 127.

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proper interpretation of the records gives the period of th
cord vibrations at each moment (p. 62).

The sounds from the larynx may be grouped under th
terms ' tone,' ' whisper,' ' breath ' and ' catch.'

In song and ordinary speech the sounds are mainly tones
it seems quite probable that the cords execute their vibration
in the same general way for the tones in both cases. Accord
ing to DONDERS [1] and HELMHOLTZ [2] the edges vibrate freely i
song, whereas in speech they strike. HERMANN'S [3] result
for sung vowels would indicate that even in song the actio
is not that of a freely swinging membranous reed; the vowe
show that the tone from the bands consists of a series of pos
tive puffs of air separated by longer or shorter intervals
silence (p. 39). My own curves show conclusively that i
speech the puff from the bands is of an explosive nature gi
ing a positive blow to the air in the mouth cavity and that th
sharpness of the explosion differs in different vowels. Th
action in singing, as indicated by HERMANN'S curves,
probably of a similar nature, the explosion being a mo
gradual one.

The difference between song and speech lies apparently n
in the kind of vibration executed by the cords but in the ma
ner in which the tone of the voice runs up and down i
pitch. The difference seems to have been correctly perceive
by ARISTOXENUS,[4] who in discussing *κίνησις φωνῆς* oppos
κίνησις συνεχής to *κίνησις διαστηματική*. The first term ma
be translated as 'change in pitch of the voice,' the secon
as 'continuous change,' and the last as 'change by steps.
The continuous change he considers to be characteristic
speech as opposed to song. 'Now the continuous move
ment is, we assert, the movement of conversational speech

[1] DONDERS, *Over de tongwerktuigen van het stem- en spraakorgaan*, n. p., n. d.

[2] HELMHOLTZ, Die Lehre v. d. Tonempfindungen, 5. Aufl., 169, Leipzig, 189

[3] HERMANN, *Weitere Untersuch. ü. d. Wesen d. Vokale*, Arch. f. d. ges. Physio
(Pflüger), 1895 LXI 192.

[4] ARISTOXENUS, Harmonica, I § 25, p. 8, Meib. The passages are collecte
by JOHNSON, *Musical pitch and the measurement of intervals*, Thesis, Baltimor
1896.

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when we converse the voice moves through a space in
a manner as to seem to rest nowhere.'[1]
song the intention is to maintain the voice on successive
s at a constant pitch for each one, while in speech the
n is seldom constant. The effort at a constant pitch
ssarily fails as do all attempts at constant muscular con-
tion (p. 202); the result is an average pitch with a prob-
error (p. 201) whose size depends on the accuracy of
cular control (p. 202) under guidance of the ear.
he constancy with which a tone can be maintained is a
ter of considerable importance that has not yet been in-

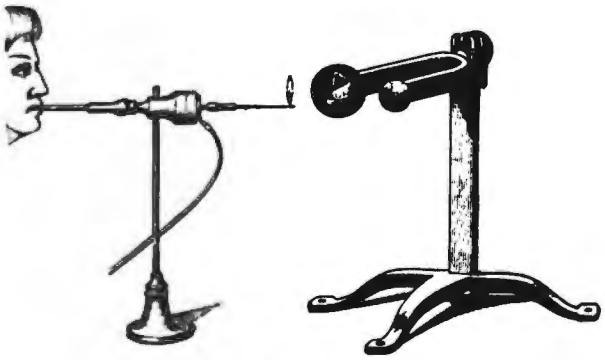

FIG. 125.

igated. It may be demonstrated by singing in unison
a fork or an organ pipe; the beats due to the differ-
s are readily heard. It may also be observed optically by
pparatus devised by HENSEN.[2] The flame of a mano-
ic capsule (Fig. 18) in front of a mirror on the end of a
g of a vibrating fork (Fig. 125) is seen to have one point
. 125) for a tone sung with the ratio of frequency 1 : 1

[1] ARISTOXENUS. Harmonica, I § 28, p. 8, Meib., quoted by JOHNSON, *The of the voice in the theory of ancient music*, Trans. Amer. Philol. Assoc., XXX 47.

[2] HENSEN, *Ein einfaches Verfahren zur Beobachtung der Tonhöhe eines gesunge- ons*, Arch. f. Anat. u. Physiol. (Physiol. Abth.), 1879 155.

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(unison) to that of the fork, two points (Fig. 126) with the ratio 2 : 1 (octave), three points (Fig. 127) with the ratio 3 : 1 (duodecime), etc. With the ratios 3 : 2 (fifth) there are three points (Fig. 128) but the flames appear twisted together, with 4 : 3 (fourth) four points (Fig. 129), and with 5 : 4 (major third) five points (Fig. 130). With the least variation in pitch from the exact ratio the figure seen in the mirror appears to rotate around a vertical axis. The greater the variation the more rapid the rotation. When the tone is



FIG. 126.



FIG. 127.



FIG. 128.



FIG. 129.



FIG. 130.

too low, the flame appears to move in the direction in which the points are directed; when too high, in the opposite direction. The mirror-fork may be provided with sliding weights for altering the pitch.

The accuracy with which a tone can be reproduced by the voice has been investigated by KLÜNDER.[1] Two small phonautographs, each consisting of a recording point attached to a rubber membrane on the end of a tube, were arranged to record simultaneously on a smoked drum. One of them recorded the vibrations of a tone from an organ pipe, the other

[1] KLÜNDER, *Ueber die Genauigkeit der Stimme*, Arch. f. Anat. u. Physiol. (Physiol. Abth.), 1879 119.

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e from a voice attempting to repeat the same tone. The lts showed under favorable circumstances an average error itch of $\frac{1}{10}$ of 1%, reaching sometimes 1½%.

convenient method of measuring the accuracy of repeti- is the following. In a darkened room a white siren disc series of holes from 90 to 110 in number is placed on axle of the siren motor (Fig. 59). The resistance of motor (p. 10) is adjusted until a blast from the tube ugh the series of 100 holes produces a tone of the de- l pitch, found by comparison with a tuning fork or other rument of known periodicity. A manometric flame (Fig. is held opposite the holes at one side. The standard is produced for a moment by a blast on the siren tube; person tested then reproduces it by singing into the trum- of the manometric capsule. The vibrations of the flame se one of the series of holes to remain apparently still le the others appear in progression or regression; the ıber of this series from that used for the blast is ed. The difference of this number from the row that used for the blast will indicate the error in pitch. the number be n; then the tone sung was in error by

× frequency of the tone produced by the blast. For

mple, if the siren had been adjusted so that the tone of blast through the series of 100 holes was $a^1 = 435$, and if third row from the blast-row toward the outer edge stood while the voice attempted to repeat this tone, then the

e of the voice was $\frac{3}{100} \times 435 = 13$ vibrations too high.

The method may be used to determine the accuracy in king unisons, fifths, octaves, etc., also the dependence of ıracy on the interval that elapses between the tone heard the tone sung, also tone memory, etc. These problems still uninvestigated. Instead of the manometric capsule ice-key (Fig. 66) in the primary circuit of a spark coil e the contact wheel in Fig. 59) may be made to produce ks between two metallic points or flashes in a GEISSLER or

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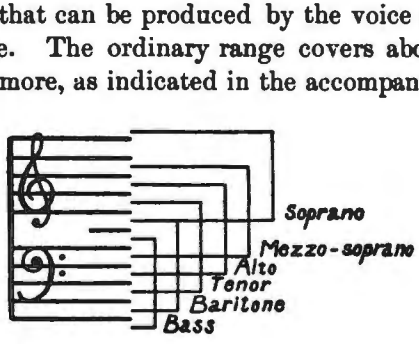
PULUJ tube, whereby more brilliant illumination is obtained Various other modifications are possible.[1]

The notes that can be produced by the voice are limited t a small range. The ordinary range covers about an octav and a half or more, as indicated in the accompanying diagram



A 'register' is the range of the voice within which it pro duces tones of the same general acoustical quality. Th tones in such a register are presumably produced by simila action in the larynx; the two uses of the term 'register probably coincide with these two closely united phenomena

In most persons two typically distinct registers are present The 'chest register,' with resonance vibrations generally fel in the thorax, has a strong and smooth acoustic color an requires little effort. The higher 'head register' of a thin ner acoustic character has a resonance apparently in th head; the tones are produced with more effort. The larynx i raised for head tones and there seems to be a general extra muscular effort. The head register is often called the 'fal setto register.'

Several other registers have been found. The 'middl register' includes notes higher than those for which the chest register easily provides naturally, but for which the head register is not required. The 'deep bass register' lies below the chest register; the arytenoid cartilages are not brought together as in the chest register, whence results a 'breathy' tone. The 'straw bass register' lies below the previous register, the muscles of the larynx are not stretched

[1] SCRIPTURE, *Elementary course in psychological measurements*, Stud. Yale Psych. Lab., 1896 IV 135.

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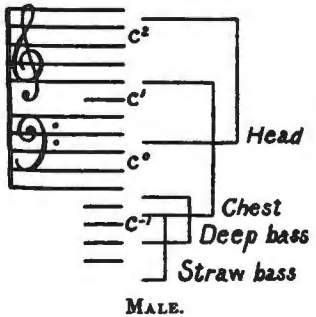
so much as usual, the larynx appears tipped backward, the vocal bands are quite relaxed but are brought close together. The tone is not only breathy but also somewhat rattling.[1]

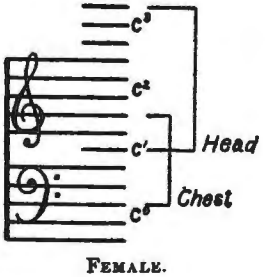
It is probably the case that each person may possess several registers. The usual instruction in singing aims at an ability to pass from one register to another without a very noticeable change in the character of the notes; among the Alpine jodelers the aim is to develop the registers separately and distinctly.

MACKENZIE has reported observations on four hundred singers.[2] The chest register was generally used throughout by pure sopranos, among whom were NILSSON, ALBANI and VALERIA; the contraltos almost invariably used the head register for the high notes; the mezzo-sopranos used both registers; the tenors generally used both, though a few used the chest register only; the barytones and basses used the chest register only.

For typical voices the notes may be assigned to the different registers as indicated by the following diagrams. It will be noticed that several tones may be made in either register.



MALE.



FEMALE.

The glottis may be closed sufficiently to vibrate but yet to allow the continuous escape of breath. The result is known in vocal music as the 'breathy tone;' pictures of the glottis in

[1] For details concerning these two registers see GRÜTZNER, *Physiologie d. Stimme u. Sprache*, Hermann's Handbuch d. Physiologie, I (1) 89, Leipzig, 1879.

[2] MACKENZIE, Hygiene of the Vocal Organs, 35, London, 1888.

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two such cases are shown in Figs. 131 and 132;[1] they were from pupils of a vocal instructor who taught a breathy tone.



FIG. 131.



FIG. 132.

In whispering, a current of air is blown through the glottis. The laryngeal action differs somewhat in various kinds of whisper.

The arytenoid cartilages may be brought toward each other with the points tilted forward, while the vocal cords are relaxed, and bulging in the middle (Fig. 133).[2] The epiglottis may be considerably depressed over the opening. The glottis in these forms is used for soft whispering.



FIG. 133.

Still rougher whisper sounds may be produced by pressing the base of the epiglottis against the ventricular bands and the upper edges of the arytenoid cartilages, which are themselves brought close together. The three slits thus produced meet at right angles. When these slits are tightly closed and made to vibrate along their edges by strong breath pressure, the peculiar Arabic *ain* is produced.[3] The vibra-

[1] CURTIS, Voice Building and Tone Placing, Figs. 41 and 42, New York, 1896.

[2] CZERMAK, Der Kehlkopfspiegel, Leipzig, 1863; Ges. Schriften, I 551, Leipzig, 1879.

[3] CZERMAK, as before, Ges. Schriften, 552. SWEET's supposition of a vibration occurring in the larynx *below* the glottis involves an anatomical impossi-

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tion is from the edges of the arytenoids and the ventricular bands, not from the cords.

Records made by ROUSSELOT [1] indicate that a vibration of constant period — in one case $\frac{1}{12}$ of a second — is present in all the whispered vowels; this would indicate that the vocal cords vibrate at least to some extent in whispering. A laryngoscopic observation in one case showed during whispering the vibration of a fixed polyp on one of the cords, indicating a vibration of the edge of the cord. Such a whisper might be termed a 'sonant whisper.'

The form of the glottis in whispering is variable.[2] In some persons the entire glottis is open, forming an isosceles triangle (*B*, Fig. 113) in others only the cartilaginous glottis is open (*C*, Fig. 113). The former position gives a soft whisper, the latter a strong one. Of 58 persons examined with the laryngoscope 34 showed the former condition and 24 the latter when they were told to whisper. In producing a soft whisper the cords are approached hardly at all; with a medium whisper the ligamentous glottis is closed and the ventricular bands are somewhat approached; with a very strong whisper the cartilaginous glottis is closed to a small opening, the ventricular bands are in contact and the epiglottis is much depressed. This typical action is not universal; some subjects keep the glottis widely open even in loud whispering; others close the ligamentous glottis even in soft whispering; with still others the ends of the glottis are closed, leaving a small elliptical opening in the middle, for a soft whisper.

It seems plausible to suppose that between a full tone used in speech and song and a completely toneless whisper there may be numerous gradations of breathy tone and sonant whisper.

When the cord glottis is adjusted to vibrate while the car-

bility; SWEET, *ðí ærəbik ðrout saundz*, Maître phonétique, 1895 X 79; PASSY, *le gytyral*, Maître phonétique, 1895 X 99.

[1] OLIVIER, *De la voix chuchotée*, La Parole, 1899 I 26.

[2] OLIVIER, as before, 28.

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tilage glottis remains open, a combination of tone and whisper may be produced, as occurs in groaning.

When the glottis is slightly narrowed, a rushing noise may be produced; there are many degrees of this 'glottal breath sound,' or one form of h. That the glottis is somewhat narrowed in the usual h seems to have been settled by observations of CZERMAK and BRÜCKE.[1] Much narrowing produces an h of heavier character than the ordinary h.

Many articulations are used to produce the sounds that may be grouped as h-sounds. The friction may occur in the glottis, just above it, with the velum near the pharynx wall, between the tongue and velum, etc. Tones are imposed on the h-sound by the resonance cavities; the assertion that the adjustment of these cavities is the same as that of the neighboring vowel is probably erroneous for English speech.[2] The American h is apparently like the British h in not having the same adjustment as the following vowel.

The h may be weakly or strongly sonant. The sonant h was prescribed by the Sanskrit grammarians;[3] it is used in some modern languages.[4]

Several examples of sonant h are to be found in the records at the end of this volume. In the words 'You had it' on Block V (Plate VII) of the JEFFERSON record the liquid ɹ changes to u in line 6, the u continues during the first half of line 7, the æ of 'had' appears in the latter half of line 7 and passes into d in the middle of line 8. At no time from the ɹ to the d do the cords cease to vibrate, as can be

[1] CZERMAK, *Physiol. Untersuchungen mit Garcia's Kehlkopfspiegel*, Sitzber. d. k. Akad. Wiss. Wien, math.-nat. Kl., XXIX 557; Gesammelte Schriften, I 551, Leipzig, 1879.

[2] LLOYD, in VIETOR, El. d. Phon., 4. Aufl., 22, Leipzig, 1898.

[3] MEYER, *Stimmhaftes H*, Neuere Sprachen, 1900 VIII 261; *tsum ſtimhaftn ha*, Maître phonétique, 1901 XVI 87. Tâittirîya Prâtiçâkhya, ii. 47, ed. by WHITNEY, Journ. Amer. Oriental Soc., 1871 IX 77; MICHAELIS, *Ueber das H und die verwandten Laute*, Arch. f. d. Studium d. neueren Sprachen (Herrig), 1887 LXXIX 49, 283.

[4] MEYER, as before; KLINGHARDT, *Stimmhaftes H*, Neuere Sprachen, 1901 IX 85; PASSY, *H vocalique*, Neuere Sprachen, 1901 IX 245.

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nly seen in the curve; yet the record speaks a distinct h had.' Since the cord tone does not cease this must be a ant h. Two other cases appear in the *Cock Robin* records. h is distinctly heard in 'saw him' of 'I saw him die.' curve in Plate II shows the vowel ɔ beginning at the of line 6 and increasing in amplitude during the first half he line. The last quarter of the line shows the i of 'him.' ween the ɔ and the i there is a region of diminished ampli- le, corresponding to the h. The record conclusively shows t at no time during the three sounds does the cord tone se. The h is therefore sonant. A fainter h is heard in w him' of 'Who saw him die?'; it is so faint that it aped my ear when listening to the gramophone record in st studying the curves and I therefore recorded the sounds sɔim. I have described them above (p. 63) in this way. a carefully listening again to the record I could distinctly d certainly hear the h in this case also. The curve, how- er, in Plate I line 1 shows only a very slight weakening tween the ɔ and the i just to the right of the middle of the ne. The sonant h in this case has vibrations as strong as ose of a large part of the ɔ. The presence of the h in all e above cases was apparent to other ears than mine. The rves show that the cords do not relax their tension during ese cases of sonant h. The regularity of the period and its reement with the cord periods of the neighboring vowels dicate that there is no very great readjustment in the larynx. One view of the mechanism of sonant h is that the glottis ens while the cords are vibrating and that this permits an cape of air with a rushing noise (not appearing in my curves) hile the cords continue to vibrate. This involves fairly con- ant tension in the vocal cords in spite of the opening of the ottis. The action is like that of the sonant whisper. This ould probably be the vocal action corresponding to SEEL- NN'S view[1] of the nature of the Greek *spiritus asper* and is as being strong and weak breathy beginnings of vowels.

[1] SEELMANN, Die Aussprache des Latein, 255, 262, Heilbronn, 1885; PAUL, ber vokalische Aspiration und reinen Vokaleinsatz, Leipzig, 1888.

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The speech curves considered suggest another view. This is that the cords continue to vibrate during the intervocalic h with no disturbance, the glottis remaining closed as in the adjacent vowels, and that the h is produced by narrowing the air passage either by bringing the ventricular bands close together or by partially closing the epiglottis down over the larynx. I find that I can sing a breathy a, e, etc. indefinitely long with some closure that is behind and below the tongue. According to this view the sonant h is a sonant fricative of the same class as j, ɣ, etc. with the passage narrowed above the vocal cords. It thus differs radically from the ordinary breathed h.

To the ear the surd and sonant h-sounds do not differ very much. As forms of articulation they must differ. The surd h is usually a glottal fricative. The sonant h may be a glottal fricative produced by closing the ligamentous glottis for the tone while the cartilaginous glottis remains open for the friction,[1] or by opening the glottis somewhat while the cords are still vibrating,[2] or by narrowing the air passage above the cords without altering the glottal adjustments (as explained above).

The speech sound known as the 'glottal catch' is made by closure of the glottis and sudden opening; the time of closure appears to the ear as silence; the opening may appear as an explosion unless it is masked by the following vocal sound, or it may be so gradual that it is not heard.

The glottal catch may be used to replace an occlusive of another kind. I have repeatedly observed this in my child of 12 to 18 months as a substitute for t and k, as in teˈəwɔˈ 'take a walk,' miˈ 'meat.' This child had never heard a glottal catch used as a speech sound. A similar use of the glottal catch to separate words occurs in the attempt to separate with special distinctness such combinations of words as duˈit

[1] Czermak, *Ueber d. Spiritus asper und lenis, etc.*, Sitzb. d. k. Akad. d. Wiss. Wien, math.-naturw. Kl., 1866 LII (2) 630, Anmerk. 1; also in Gesamm. Schriften, I 756, Leipzig, 1879.

[2] Meyer, as before.

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'do it,' **slai·tiəz** 'sly tears.' In the latter case there is no glottal explosion because the t-closure occurs before the glottis is opened. A frequent pronunciation of 'camp-meeting' is **kæm·mitiŋ**; the mouth adjustment for m is kept between the two vowels, and the occlusive effect is produced by inserting a glottal catch in the middle. The explosion of the catch is in this case nasal. The use of a glottal catch at the beginning of a vowel often occurs in **ˌa·ˌa·ˌa** 'ah, ah, ah' repeated in as an exclamation of warning. It is sometimes used to end vowels, as occasionally **haˌ** used for an exclamation of surprise, or even in **hwoˌ** 'whoa.'

In the Scottish dialect of Glasgow the glottal catch accompanies intervocalic t, as in **bət·ər** 'butter,' or may replace it, as in **bəˌ·ər.**[1]

The glottal catch is the regular beginning of initial vowels in North German; it disappears from a word whenever the vowel in the union of speech is no longer felt to be an initial one; thus, **ˌain fər ain** 'ein Verein, but **herain** 'herein' instead of **herˌain.** The failure of foreigners to use the glottal catch in speaking German produces a strange impression on the native ear.

The glottal catch appears as the Danish stöd, by which, for example, **maˌlər** 'maler, [he] paints' is distinguished from **malər** 'maler, painter.'[2]

The glottal catch seems to occur also as the Arabic *hamza*, which is a regular consonant represented in the alphabet; the closure, however, seems to be reinforced by pressing the base of the epiglottis over the closed glottis.[3]

The equivalence of a glottal catch to other consonant articulations has been observed in some experiments by MIYAKE.[4] In beating time with the finger while a syllable was regularly repeated, the finger-beat occurred 1. at the

[1] PASSY, *Étude sur les changements phonétiques*, 155, Thèse, Paris, 1891.

[2] VIETOR, Elemente d. Phonetik, 4. Aufl., 25, Leipzig, 1898.

[3] CZERMAK, *Physiol. Untersuchungen mit Garcia's Kehlkopfspiegel*, Sitzb. d. k. Akad. Wiss. Wien, math.-nat. Kl., 1858 XXIX 557; Ges. Schriften, I 555, Leipzig, 1879.

[4] MIYAKE, *Researches on rhythmic action*, Stud. Yale Psych. Lab., 1902 X 54.

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beginning of the consonant in a syllable composed of consonant and vowel; 2. at the beginning of the vowel in a syllable composed of an English vowel with a smooth beginning; 3. ahead of the vowel by the regular consonant time in a syllable composed of a vowel begun with a glottal catch.

The usual attempt to explain the glottal catch as a slight cough is a blunder; the bulb centres (p. 193) for the two activities are not the same and the muscular action is probably quite different.

References

For the history of the theories of cord action: Wright, *The nose and throat in medical history*, The Laryngoscope, 1901-02; also separate. For the action and treatment of the cords in singing: Mackenzie, Hygiene of the Vocal Organs, London, 1888; Curtis, Voice Building and Tone Placing, New York, 1896; Stockhausen, Gesangsmethode, Leipzig.

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CHAPTER XX

TONES OF THE VOCAL CAVITIES

WHEN a blow is struck on the wall of a cavity or over an opening, the molecules of air adjacent to the wall or the opening are driven toward the neighboring molecules. This produces a wave of condensation and rarefaction which is propagated through the cavity. A negative blow, such as that produced by a pull on the wall or the sudden removal of an object from an opening, propagates a wave of rarefaction similarly.

The excitation of the air of the cavity may arise from a single momentary impulse, from a succession of such impulses or from a series of impressions of a more or less wave-like character.

The simplest conditions can be represented by supposing a piston moving without friction in a rigid cylinder closed at one end; for most purposes we can consider the air in the cylinder to act as a spring in resisting the movement of the piston. With a condition of constant density the period of the vibration resulting from a blow will depend on the mass of the piston and on the strength of the spring, that is, on the size of the cavity. In moving through an opening the air moves approximately as an incompressible fluid. From the mass of the air and the elasticity of the cavity, the period of vibration can be calculated.

The period of a cavity of the volume S communicating with the external air by a long cylindrical neck of the length L and the area A can be shown [1] to be

$$T = \frac{2\pi}{a}\sqrt{\frac{LS}{A}}, \qquad (1)$$

[1] RAYLEIGH, Theory of Sound, 2d ed., II § 303, London, 1896.

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where a is the velocity of sound (p. 4). If the radius of the neck is R, the area will be πR^2 and the formula for the period will be

$$T = \frac{2\sqrt{\pi} \cdot \sqrt{LS}}{aR}. \qquad (2)$$

The period is lengthened by enlarging the cavity, or by increasing the length of the cylindrical neck; but it is shortened by enlarging the area of the neck.

The ease with which the air flows in and out through the cylindrical channel, or the conductivity of the channel, diminishes as the length is greater, and increases as the area increases. The degree of conductivity can be expressed[1] by

$$c = \frac{A}{L}, \qquad (3)$$

where A is the area and L the length of the channel. The period of the channel will be

$$T = \frac{2\pi}{a}\sqrt{\frac{S}{c}}, \qquad (4)$$

where S is the volume of the channel and a the velocity of sound. Less conductivity corresponds to increased mass of the piston, with a resultant lengthening of period, and greater conductivity to decreased mass with a resultant shortening of period. Owing to the loss of movement at the open end of the cylindrical tube, the conductivity c as calculated above needs a correction which is found to be at least $k = \frac{1}{4}\pi R$ for each end; this must be added to L. The correction is exactly this for an infinitely long tube with an infinite flange at the open end. For an unflanged end it is equal to about $0.6R$, when the wave length is great in comparison with the diameter. Thus, instead of the formula (3) above we should write[2]

$$c = \frac{\pi R^2}{L + 2k}. \qquad (5)$$

[1] RAYLEIGH, as before, § 304.

[2] RAYLEIGH, as before, §§ 307, 309, 314.

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Some experimental determinations by SONDHAUSS[1] in the e of resonators without necks showed that the influence of aperture depended mainly upon its area, although a very ngated shape produced a rise in pitch; his empirical for- la gave for the pitch of the cavity

$$n = \frac{1}{T} = 52400 \frac{\sqrt[4]{A}}{\sqrt{S}}, \qquad (6)$$

unit being the millimeter. For flasks with long necks he nd

$$n = 46705 \sqrt{\frac{A}{LS}}. \qquad (7)$$

The latter formula supposes that the neck is so long that correction for the open end may be neglected, the former t it is so short that the length itself may be neglected. In ctice, formulas (4) and (5) will generally be required. Various theoretical and experimental data have been given HELMHOLTZ[2] and ELLIS.[3]

When a cavity has more than one aperture, the separate ductivities are to be added if the apertures are so far rt that they can be considered as acting separately. This he case in the mouth, the labial aperture being at the end posite to the pharyngonasal aperture. In the case of a vel like i the front and the rear cavities on either side the elevation of the tongue have each two apertures.

The main vibration of the air in a cavity is frequently ompanied by other vibrations of shorter periods. These rations in cavities with narrow necks are relatively of y much shorter period.

Owing to dissipative forces the vibration excited by the w of the piston will die away as explained on p. 5.

[1] SONDHAUSS, *Ueber d. Brummkreisel u. d. Schwingungsgesetz d. kubischen fen*, Ann. d. Phys. u. Chem., 1850 LXXXI 235, 347; RAYLEIGH, as before, 0.

[2] HELMHOLTZ, Lehre v. d. Tonempfindung, 5. Aufl., 73, Beilage II, Braunschweig, 1896.

[3] ELLIS, notes to translation of HELMHOLTZ, Sensations of Tone, London,

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The effect of repeated blows on a system with a period of free vibration has been considered on p. 12.

The vibrations in cavities whose three dimensions are very small compared to the wave length and whose communication with the external air is by small holes in the surface have been investigated by HELMHOLTZ.[1] A later treatment is by RAYLEIGH.[2] The topics discussed include the cases where a mass of air confined almost entirely by rigid walls communicates with the external atmosphere by one or more narrow passages, where there is a contraction making a double cavity, where there is a long tube in connection with a reservoir, where there are lateral openings, where the openings are of different forms, where the necks are of different shapes, where the cavities are not regular tubes, where the cavities are not straight tubes, etc. It is evident that these are to a great extent just the problems involved in the action of the vocal cavities in producing speech sounds, and that the same methods can be used to investigate their action. For example, a mathematical treatment of the vibration period of the mouth cavity, as affected by its size, its apertures, its internal neck formed by the tongue, the labial tube, the labial and nasal openings, etc., with such modifications as may be needed to account for the lack of rigidity in the walls and the special deviations from the general conditions, would be of as great value to phonetics as similar treatments of like problems have been to physics and other sciences. These problems have not yet been attempted in spite of their great importance.

The preceding general considerations find many practical applications to the vocal cavities. As the walls of the cavities are not very rigid, the formulas given above are not strictly applicable; just how closely approximate they are, it is impossible to say; a mathematical treatment including

[1] HELMHOLTZ, *Theorie der Luftschwingungen in Röhren mit offenen Enden*, Journal f. reine u. angew. Math. (Crelle), 1859 LVII 1.

[2] RAYLEIGH, *On the theory of resonance*, Phil. Trans. Roy. Soc. Lond., 1871 CLXI 77; Theory of Sound, 2d ed., II §§ 303–322, London, 1896.

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ding walls seems to be still lacking. Yielding walls gthen the period of vibration and increase the factor of tion.

The vocal cavities may be made to produce sound waves striking the hand against the open mouth, or by suddly removing it from the mouth, or by snapping the finger of the mouth; also by striking a blow on the cheek, and various speech movements.

For a blow on the cheek with the mouth closed the piston 281) is represented by the flesh of the cheeks. The air in the mouth resists the blow. The period of vibration results is long owing to the large mass of the cheeks also to the weakening of the elastic force by the yielding s of the mouth. When the mouth is open, there is no resistance to the movement of the cheek as when the th is closed. The blow on the cheek drives the air out veen the lips. The air between the lips now takes the e of the piston and any effect on the cheeks is negligible omparison.

When the hand is struck against the open mouth the cavity ives an impulse of condensation or a positive blow. When finger is snapped out of the mouth it receives one of rareon, or a negative blow.

lows may also occur by the release of compressed air. is the case in the explosive occlusives. In these there closure of the air passage by the lips (p, b), by the tongue ast the teeth or palate (t, d, k, g) or by the glottis (ʻ); air is compressed behind the closure and, on being red, strikes a positive blow on the cavity in front and a tive blow on the one behind.

he puffs from the vocal bands are capable of arousing in the cavities of the air passage. There are at least heories of the manner in which the complex note heard nging or in speech is derived from the vibrations of the s.

cording to one theory the note produced directly by the tions of the bands consists of a series of partial tones of

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different intensities (pp. 72, 106, 256), and the vocal cavities reinforce some of them by resonance. For illustration we may suppose the notes from three different pairs of vocal bands *A*, *B*, *C* to be composed of partials having relations of intensity as indicated by the sizes of the figures: —

A — **1** 2 3 4 5 6 7 8 9 10

B — **1** 2 3 4 5 6 7 8 9 10

C — **1** 2 3 4 5 6 7 8 9 10

Although the three notes will appear of the same pitch, their characters will be different, the note of *A* being thin and flute-like, that of *B* rich, and that of *C* piercing and sharp. These relations are modified by the resonating cavities of the chest, pharynx, mouth and nose, so that some of the partials are reinforced. In this way the even partials might be reinforced in the case of *A* so that the voice obtains something of the character of *B*. Likewise certain arbitrary partials might be so reinforced in the case of *C* that it also becomes somewhat like *B*. To attain these results the system of cavities must be carefully adjusted to resonate to the tones desired.

The second theory would suppose the bands not to vibrate but to open momentarily and then close again in a series of movements (p. 260), whereby the resulting air movement is not a vibratory one of a sinusoidal (p. 3) or a harmonic (p. 13) nature but is a series of brief puffs. The air movement direct from the cords is thus not like that of a smooth vibration but that of a series of explosions. The curve of explosion, that is, the sharpness of the explosive rise and fall, may be different in different cases. The effect on the ear will be a tone of the pitch of the frequency of the explosion, to which there may be added higher tones — not necessarily harmonic in relation — arising from the character of the curve of explosion (p. 94). Owing to the blows struck by the explosions from the cords the cavities add tones of free vibration (p. 2). That for the chest register this

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theory is certainly the correct one has been shown on pages 259–260; for the head register the matter has not been finally settled.

The size of the cavity within the mouth can be varied by movements of the tongue and jaw; the size and shape of the openings may be altered by adjustments of the lips, velum, palatine arches, epiglottis and glottis. The tongue may also divide the mouth into two or even three cavities with necks between them. The pharyngeal cavity is subject to great modifications by contraction of its muscular walls, by movements of the tongue, and by the rise and fall of the larynx; its apertures are greatly varied by the velum, tongue and epiglottis. The tracheal cavity seems to be capable of little variation. The entire system of cavities forms a compound one. Its natural period depends on the sizes of the component cavities, on the necks between them, and on the sizes and shapes of the openings.

Several methods may be used to determine the natural period of a cavity.

One method consists in holding vibrating bodies before the opening and noticing which one is most loudly reinforced. Forks of different pitch may be held before the mouth; the period of the fork producing the loudest resonance may be considered as that of the mouth cavity under the given circumstances. This method has been used to determine the period of the mouth cavity adjusted for different vowels, although the adjustment of the mouth under these circumstances may differ considerably from the actual adjustment in speaking. HELMHOLTZ'S [1] determinations for his own voice (North German) were as follows: —

Vowel:	dull u	bright u	o	a	$e_2(\ddot{a})$	$e_1(e)$	i	œ	y
Tones:	f^0	f^1	b^{1b}	a^2	d^2+g^3	f^1+b^3	f^0+d^4	$f^1+c^{\#5}$	f^0+g^3

The 'bright u' was like the French *ou*. In musical notation the results are as indicated on next page.

[1] HELMHOLTZ, Lehre v. d. Tonempfindungen, 5. Aufl., 177, Braunschweig, 1896.

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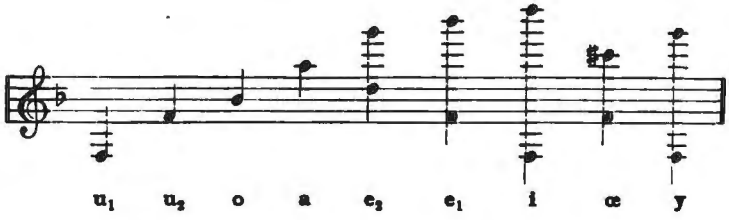

AUERBACH'S results (German) by the same method [1] were: [2]

Vowel:	u_1	u_2	o	ɔ	a	e_1	i	y	œ	$e_2(\ddot{a})$
Tone:	g^1	c^2	c^2	c^2	g^2	g^2	c^3	g^2	c^3	g^2

or in musical notation



The same method is used in a modified form to determine the period of the chest cavity. When the voice is made to rise and fall in pitch, certain tones will be felt to be reinforced in the chest.

Another method consists in blowing across the opening of the cavity; in this way the pitch of a bottle is readily obtained.[3] 'Although good results have been obtained in this way, our ignorance as to the mode of action of the wind renders the method unsatisfactory.' [4] The pitch of the mouth cavity may also be obtained by a similar method, whispering; the resultant tone is noted by comparison with some musical instrument.[5] The whisper-method is inaccurate

[1] AUERBACH, *Untersuchungen ü. d. Natur d. Vokalklanges*, Diss., Berlin, 1876; also in Ann. d. Phys. u. Chem., 1876 Ergb. VIII 177; *Zur Grassmann'schen Vokaltheorie*, Ann. d. Phys. u. Chem., 1878 IV 508.

[2] AUERBACH, *Die physikalischen Grundlagen d. Phonetik*, Zt. f. franz. Spr. u. Lit., 1894 XVI 144.

[3] DONDERS, according to GRÜTZNER, *Physiologie d. Stimme u. Sprache*, Hermann's Handbuch d. Physiol., I (2) 160, Leipzig, 1879.

[4] RAYLEIGH, Theory of Sound, § 314, London, 1896.

[5] DONDERS, *Ueber d. Natur d. Vokale*, Archiv f. d. holländ. Beiträge z. Natur- u. Heilkunde, 1858 I 157; KRÖNIG, *Notiz üb. Vokallaute u. üb. eine nat. Stimmgabel*,

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chiefly because the ear is incapable of correctly assigning the pitch of the complex of tones in the whispered sound. The results of different observers[1] are so completely discordant with one another and with those of the later accurate methods that they do not seem worth considering. The TRAUTMANN vowel-system,[2] based on whisper-observations, asserts that the resonances form two septime accords of the notes g^2 and g^3 respectively; this is contrary to the facts ascertained by more accurate methods.

Still another method consists in striking a blow on the wall of the cavity. Blows on the larynx have been tried.[3]

None of these subjective methods gives any reliable results.

In the first place the judgment of the ear concerning the pitch of a sound is largely influenced by the presence of other sounds; a complex of resonance tones is not heard as a strong lower tone with higher ones added, but as a tone of a pitch that may be quite different from the actual pitch of the lowest tone.[4] The resonance of a vowel-position is just such a complex of tones and is inevitably heard of a pitch not that of its lowest component. The results obtained by the preceding methods give the *pitch-impressions* of various mouth positions, and, in as far as these mouth positions represent the positions for the vowels, they are of value as phenomena of hearing. They are of no value for determining the resonance tones in a spoken vowel.

Another objection, that is fatal to any method in which the cords are not used, lies in the inevitable difference in muscular adjustment when any change is made. It can be readily demonstrated by psychological apparatus that a muscular adjustment or movement becomes immediately altered with any change in attention or other muscular

Ann. d. Phys u. Chem., 1876 CLVII 339; TRAUTMANN, Die Sprachlaute, 46, Leipzig, 1884-86; STORM, Englische Philologie, 97, 2. Aufl., Leipzig, 1892.

[1] TRAUTMANN, Die Sprachlaute, 46, 48, Leipzig, 1884-86.

[2] TRAUTMANN, as before, 40.

[3] AUERBACH, *Bestimmung d. Resonanztöne d. Mundhöhle durch Percussion*, Ann. d. Phys. u. Chemie, 1848 III 153.

[4] STUMPF, Tonpsychologie, II 406, Leipzig, 1890.

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adjustments of the body. The passing of a thought through the mind or the moving of a finger can be shown by physiological and psychological methods to affect to a greater or less extent the muscles of the walls of the blood vessels, of respiration, of the larynx, of the sweat glands, etc. This is due to the extremely delicate coordination of all the sensitive and contractile parts of the body by means of the nervous system. It is unquestionable that the removal of laryngeal action changes the articulation in the mouth to some extent.

At best the foregoing results apply only to sung vowels, since in spoken vowels the cavities undergo constant change and there is no means of knowing which part of the vowel is represented.

Only the objective methods of determining the resonance tones are to be trusted. These methods are two: 1. synthesis of elements that produce an actual speech sound, 2. analysis of an actual speech sound into its elements.

The synthetic method consists in manufacturing sounds that approximate speech sounds. The closer the imitation the greater the likelihood that the principles employed are the same as those of the vocal organs.

The speaking machines of KEMPELEN[1] and FABER[2] were built on a study of the action of the vocal organs. The vowel instruments of WILLIS, HELMHOLTZ and LLOYD were designed to determine the resonance tones of the voice.

With cylindrical resonators of known pitch acted upon by vibrating reeds WILLIS[3] found the tones necessary to produce sounds resembling the English vowels in the words *no*, *nought*, *paw*, *part*, *pad*, *pay*, *pet*, *see*, to be c^2, $e^{\flat 2}$, g^2, $d^{\sharp 3}$, f^3, d^4, c^5, g^5 respectively. Just what sounds occurred in these cases cannot be accurately stated; they appear to have been o,

[1] KEMPELEN, Mechanismus d. menschl. Sprache, 1791.

[2] TECHMER, Phonetik, Fig. 7a, Leipzig, 1880; also in Int. Zt. f. allg. Sprachw., 1884 I Fig. 11.

[3] WILLIS, *On vowel sounds, and on reed organ-pipes*, Trans. Camb. Philos. Soc., 1830 III 231.

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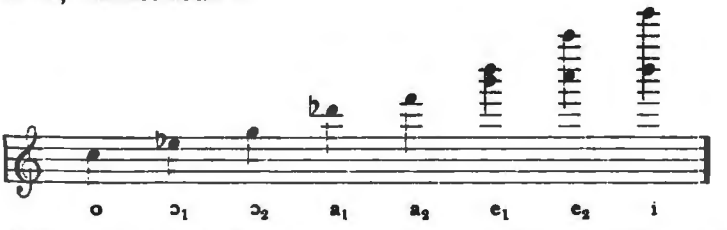
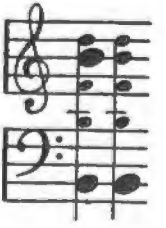
ɔ$_1$, ɔ$_2$, a$_1$, a$_2$, e$_1$, e$_2$, i (the numerals indicating varieties of a sound). With spherical resonators used in a similar way HELMHOLTZ[1] obtained the same results as WILLIS for o, ɔ$_1$, ɔ$_2$ and a, but different ones for the last three, namely, b^3 for e$_1$, c^4 for e$_2$, and d^4 for i. The following musical notation indicates the results: first four notes, WILLIS and HELMHOLTZ; fifth, WILLIS; last three upper, WILLIS; last three lower, HELMHOLTZ.



In these two methods the action of the cords in emitting puffs of air was imitated by reeds.

With a series of forks before resonators HELMHOLTZ obtained[2] a good o followed by u on the note b^{-1} by using the tones indicated by the adjacent notes with intensities as indicated by their sizes. The other vowels seem not to have been successfully imitated. The failure of the method seems mainly due to the maintenance of the tones of the resonators by a constant supply of energy, whereas in the vocal organs they are intermittently aroused in the chest register (p. 259) and possibly also in the head register.



By sending a blast into bottles of different sizes with different necks LLOYD[3] has imitated some of the whispered vowels; calculations of the periodicities of the body and neck gave the periods of the resonance tones. Different relations between the resonance periods of body

[1] HELMHOLTZ, Lehre v. d. Tonempfindungen, 5. Aufl., 199, Braunschweig, 1896.

[2] HELMHOLTZ, as before, 200.

[3] LLOYD, *Some researches into the nature of vowel-sounds*, Thesis, Liverpool, 1890; *Speech sounds: their nature and causation*, Phonet. Stud., 1890 III 251; 1891 IV 37, 183, 275; 1892 V 1, 129, 263; Neuere Sprachen, 1897–98 V, Beiblatt, 1.

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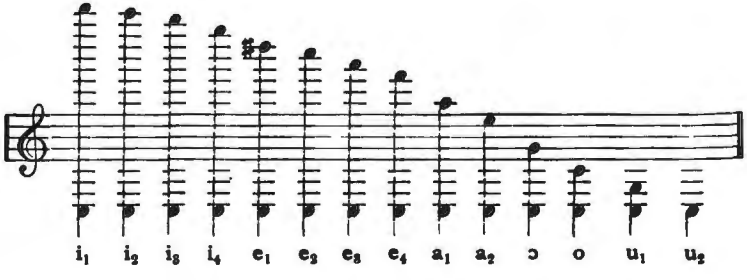
and neck gave sounds resembling different whispered vowels. The ratio between the two resonances required to produce a vowel was termed its 'radical ratio.' The results were as follows (the letters of the notation are to be understood as arbitrarily indicating the vowels in the key words):

Sound resembling vowel whispered in:	*bean*	*bin*	*pity*	Welsh *un*	Fr. *dé*
Radical ratio:	37	31	29	23	19
Notation:	i_1	i_2	i_3	i_4	e_1

Fr. *maison*	Fr. *bête*	*men*	*man*	*father*	*fall*	*foal*
17	13	11	7	5	3	2
e_2	e_3	e_4	a_1	a_2	ɔ	o

book	*pool*
1½	1
u_1	u_2

The vowel sound occurred whenever these two ratios were present, regardless of what the actual notes were. For a lower resonance tone of c^0 the vowel-like sounds would have tones [1] as in the following notation:



The vowel character is said to depend primarily on the 'radical ratio,' although the vowels actually produced have normally certain definite ranges for their tones.

The results may have some application to the tones of whispered vowels, depending on the closeness of the imitation. They give no information concerning the tones of spoken and sung vowels, as such sounds were not produced. It is probably true that in each vowel a certain relation of cavity

[1] VIETOR, Elemente d. Phonetik, 4. Aufl., 34, Leipzig, 1898.

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ies occurs; this is the supposition of the WHEATSTONE-ELMHOLTZ overtone theory. Some of these relations have en determined by PIPPING and HERMANN (pp. 21, 23, 48); ey are utterly different from LLOYD'S ratios. It is not true at the cavity tones may be of any pitch, as has been abun-ntly shown by the results described in Part I.

Another method consists in using puffs of air to arouse justable cavities. A carefully trued siren disc (p. 90) runs a slit in a coupling connecting the two ends of opposite rtions of a blast pipe; the adjustments must be so accurate at little air escapes. The blast is brought to some musical strument, such as a flageolet, acting as a cavity giving usical tones. The puffs of air, like those from the vocal shions (p. 257), blow the pipe intermittently, producing sonance effects like those of magnetic impulses on a damped ring (p. 7) and thus imitating the vocal action (p. 260). he blast may be divided into two portions by a Y-tube and o instruments used at the same time; or two independ-t blasts may be arranged at different points on the siren. he investigations with this instrument have not yet been mpleted.

The analytic method has been applied in two ways.

An analysis has been attempted by singing a tone before series of resonators in the manner mentioned on p. 73. me approximate success might be attained for a tone ng with perfect constancy on a given note, a condition at can at best be satisfied with only a fair degree of accu-cy (p. 269). The resonators, however, respond somewhat other tones than their own (p. 73).

The analysis by means of registered curves of speech has en described in Part I; at the present time it is, in some its forms, the only method whose results can be trusted. he tones for the sung vowels, in as far as determined by this ethod, have been given above (Swedish, p. 21; Finnish, 22; Russian, p. 25; American, pp. 28, 50; German, p. 48). hese tones represent the lowest ones of the system of cavi-es; the higher tones are still undiscovered. Most of these

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lowest tones are probably mouth tones in the sense that they are specially sensitive to modifications of the oropharyngeal cavity with its various apertures and necks. Some, however, may be trachea tones. PIPPING[1] considered as chest tones the low ones found in the neighborhood of the note 250 in a series of Finnish vowels (p. 22). The lower resonance tone of constant pitch found in a number of cases of **a** in **ai** ('I, eye,' etc.) may possibly arise from the chest instead of the mouth and pharynx; in seven recorded cases[2] the frequencies were as follows: 'I,' 286; 'I,' 286; 'I,' 286; 'I,' 286; 'I,' 360; 'eye,' 435; 'fly,' 256. The resonating chamber for these tones can hardly include the lungs, as the lung capacity is undergoing continual change during respiration. The trachea and the bronchial tubes with their hard walls seem better suited for resonance and are more appropriate in size; their capacity remains approximately constant; their accordion-like structure permits minor adjustments. The size of the chest cavity has been shown to vary as the musical scale is sung.[3] This was supposed to occur for the purpose of reinforcing the cord tone by resonance (p. 13).

The attempt has been made to calculate the resonance tones for the vowels from maps of the mouth-pharynx cavity. LLOYD gives[4] the following frequencies: m*a*rine 2816, p*i*t 2500, r*ei*n 2112, th*e*re 1508, m*a*n 1431, f*a*ther 1082, l*aw* 834, n*o*te 623–444, p*u*t 528, br*u*te 314–287. So little is known concerning the resonances of a compound cavity and the methods of mouth-mapping are still so crude that at present no reliance can be placed on such calculations.

The cavity tones of the consonants have been studied only by HERMANN (p. 43). The acoustic characters of conso-

[1] PIPPING, *Zur Phonetik d. finnischen Sprache*, Mém. de la Soc. finno-ougrienne, XIV, Helsingfors, 1899.

[2] SCRIPTURE, *Researches in experimental phonetics (first series)*, Stud. Yale Psych. Lab., 1899 VII 54.

[3] SEWALL AND POLLARD, *On the relations of diaphragmatic and costal respiration, with particular reference to phonation*, Jour. Physiol., 1890 XI 159.

[4] LLOYD, *The interpretation of the phonograms of vowels*, Jour. Anat. Physiol., 1897 XXXI 251; *On consonant sounds*, Proc. Roy. Soc. Edin., 1897-98 XXII 241.

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nants depend largely on the tones in their explosions or noises; the relations of these tones to their modes of articulation have been observed but not experimentally recorded.

The cavity tones in a vocal sound probably always include more than two tones. These tones change with the constantly changing shapes of the cavities and probably never remain constant. The cavity tones with the cord tone form a more or less musical harmony which changes by more or less sudden gradations at each instant. The simultaneous and successive relations of harmony among these tones determine the character of the sounds spoken.

Certain differences in acoustic character run through the speech of a person; other differences run through a family; others through a community, a dialect, a region, or a country. These differences arise partly from the different forms of the cord vibrations (p. 264), from the different systems of tones from the vocal cavities, and from the courses of each of these tones in the vocal harmony.

References

For the phenomena of resonance: see References to Chap. I. For summary of data on vowel-resonance: Viëtor, Elemente d. Phonetik, 4. Aufl., 27, Leipzig, 1898.

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CHAPTER XXI

TONGUE CONTACTS: METHODS OF PALATOGRAPHY; AMERICAN, IRISH AND HUNGARIAN RECORDS

FOR describing the positions of the tongue different terms for the various regions have come into use. A convenient arrangement is that of LENZ[1] given in Figs. 134, 135. The letters on the diagram in Fig. 135 are those used by JESPERSEN.[2] A diagram showing the vertical section through the vocal cavities may be called a 'sagittal diagram.' The diagram recording the contact of the tongue with the palate is called a 'palatogram.'

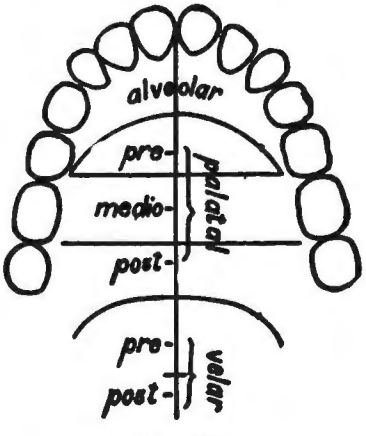

FIG. 134.

The contacts of the tongue with the roof of the mouth are stated in compound terms, in which the first part indicates the main portion of the tongue that touches, and the second the main portion touched. The tongue articulations are classed as 'dorsal' (referring to the top of the body of the tongue) and 'marginal,' with subdivision of the latter into 'frontal' and 'lateral.' An articulation of the extreme point is often termed 'apical.' The roof articulations are indicated

[1] LENZ, *Zur Physiol. u. Gesch. d. Palatalen*, Diss., Bonn, 1887; also in Zt. f. vergl. Sprach., 1888 XXIX 1.

[2] JESPERSEN, The Articulations of Speech Sounds represented by Analphabetic Symbols, Marburg, 1889.

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by the names, 'dental, alveolar, pre-, medio-, postpalatal, pre-, postvelar, uvular and pharyngeal.' Fig. 135 indicates a dorsal-postpalatal articulation. The term 'cacuminal' (or 'cerebral,' or 'inverted') is applied to a frontal articulation, in which the point of the tongue is turned up and back. The frontal-prepalatal articulation is thus a cacuminal one. Cacuminal articulations are found in various Dravidian and Sanskrit sounds, in some pronunciations of the English r, in several French and Swedish dialects, etc. The terms 'lateral' and 'central' refer to the openings between the

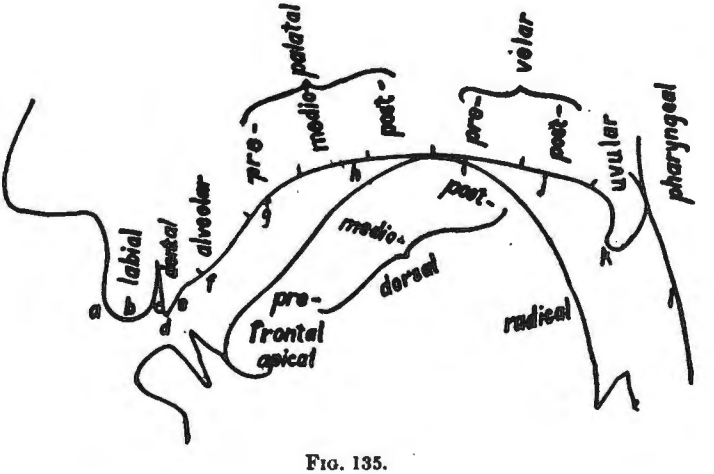

FIG. 135.

tongue and the surfaces of the mouth. A lateral opening occurs, for example, in l.

For describing the positions of the tongue in forming vowels several general terms have come into use. 'Front, mixed, back' or 'anterior, neutral, posterior' indicate that the tongue is raised toward the front, middle or back part of the palate. 'High, mid, low' refer to the degree of elevation. 'Narrow' or 'close' indicates that 'the tongue and flexible parts of the mouth are made tense and convex in shape;' 'wide' or 'open' indicates that they are flattened.[1]

[1] SWEET, The History of Language, 17, London, 1900.

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The points at which the tongue touches the palate (and, to some degree, the velum) in forming sounds can be registered by a mixture of meal and mucilage[1] or by carmine water color or Chinese ink[2] spread over the previously dried tongue. The sound is spoken naturally; the mouth is at once opened and the marks on the palate are observed with a small dental or laryngeal mirror in the mouth and a larger mirror in front. The results obtained are called 'palatograms.'

This method has developed into the use of a thin shell-like 'artificial palate.'[3] It is covered with chalk and placed in the mouth; after the speech sound is made, it is removed and examined at leisure. KINGSLEY'S palate is shown in Fig. 136. Owing to the cutting away of some of the sides of the posterior velar portion parts of the articulation are lost in some speech sounds; usually the artificial palate is still further limited by being cut off at the last teeth. The results of an experiment may be marked on a plaster cast[4] (Fig. 137), drawn on a diagram, or photographed.[5]

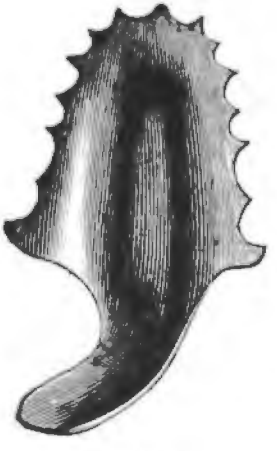

FIG. 136.

A cast of the palate may be made either with dental modeling compound or with plaster of Paris.

A portion of the modeling compound is held in hot water till softened; it is then placed in a dentist's mouth tray, or, if

[1] COLES, Trans. Odontolog. Soc. Grt. Britain, 1871 n. s. IV 110.

[2] GRÜTZNER, *Physiologie d. Stimme u. Sprache*, Hermann's Handbuch d. Physiol., I (2) 204, Leipzig, 1879.

[3] KINGSLEY, *Illustrations of the articulations of the tongue*, On Oral Deformities, London, 1880; also in Internat. Zt. f. allg. Sprachwissenschaft, 1887 III 225; BALASSA, *Phonetik d. ungarischen Sprache*, Internat. Zt. f. allg. Sprachwiss., 1889 IV 130.

[4] KINGSLEY, as before.

[5] HAGELIN, Stomatoskopiska undersökningar af franska språkljud, Stockholm, 1889.

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that is lacking, on the end of a wide flat stick. The operator, standing behind, bends back the head of the subject and inserts the soft compound into his open mouth, pushing it up firmly against the palate. It is kept against the palate until fairly hard, then removed by loosening first at the back, and dipped in cold water to completely harden it. A plaster cast is now to be made from the form thus obtained. This is rubbed with soapy water and surrounded by a wall of clay or wax. The cup-like dish thus obtained is filled with water. Fresh plaster of Paris, mixed with water to a rather thin paste, is poured in this dish; it is allowed to remain till it hardens, which it should do in about 20 minutes. On removing the wax by softening in warm water, a model of the palate will be found.

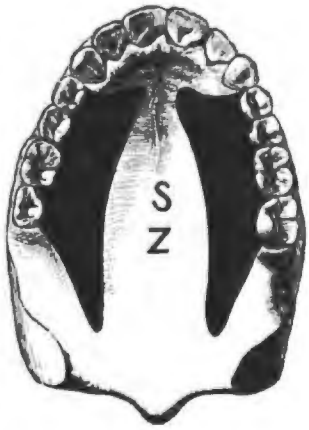

FIG. 137.

If plaster of Paris is used instead of modeling wax for the original impression, it is mixed to the consistency of batter. The tray is filled. The subject bends the head forward. Standing on one side, the operator pushes the tray into the mouth and against the palate. It is held in place till the plaster feels hard in the mouth. The tray is then rocked slightly till the plaster is loosened from the teeth. The surface of the negative cast thus obtained is colored with ink or dye and then covered with sandarac varnish. The positive cast is then made from this just as from that in modeling compound. The negative cast is removed from the positive by chipping it off till the colored surface appears.

The surface of the model thus obtained is rendered adherent by plunging it into a bath of stearine or wax; it is then rubbed with a stiff brush dipped in powdered graphite until it is entirely coated. A saturated solution of copper

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sulphate in water with 10% of sulphuric acid is poured into a jar. In this a porous battery cup is placed; the cup contains a piece of zinc in pure water. A wire from the zinc supports the plaster model in the copper sulphate solution; this wire must make electric contact with the graphite coating. After the copper begins to deposit on the surface a few drops of sulphuric acid are added to the water around the zinc. The thickness of the deposit of copper is examined from time to time; it should be sufficiently thick in about twelve hours. It is then detached. It is blackened by boiling it in a solution of sodium sulphite or by covering it with black Japan varnish.

It is generally preferable to have a dentist make a cast and a *thin* plate of metal[1] or celluloid[2] in his own way.

An artificial palate may be made in a simpler fashion by using thin tough filter paper.[3] A drop of oil is poured on the mold; a sheet of filter paper wet with water is applied to it carefully, — tearing rather than folding it if necessary. A paste is made of chalk powder and strong liquid glue or cement without a bad taste; a thin layer is spread over the paper. Another sheet of paper (wet, if possible; dry, if time presses) is put over the first and pressed into the depressions carefully with the fingers and a small blunt stick. The whole is set aside to dry. When half dry, it is well to press it again carefully into the mold. When fully dry (half a day or more) it is coated with black enamel or varnish. These paper palates cannot be used long without being dried over a fire or a flame. They can be rendered waterproof by pouring oil on them when half dry.[4]

The quickest method[5] — often the only one possible in traveling — is to use a sheet of tinfoil of 0.2^{mm} thickness or

[1] HAGELIN, as before.

[2] VIETOR, *Kleine Beiträge zur Experimentalphonetik*, Neuere Sprachen, 1894 I Suppl. 35.

[3] ROUSSELOT, Principes de phonétique expérimentale. 57, Paris, 1897.

[4] JOSSELYN, *Étude sur la phonétique italienne*, 2, Thèse, Paris, 1900; also in La Parole, 1900 II 422.

[5] ROUSSELOT, as before, 58.

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two sheets united by a flexible rubber varnish. If one side has previously been covered with this varnish, it suffices to press it against the palate at the time of the experiment with the thumb or a slightly pointed stick; the sheet is then removed, and the edges cut off around the teeth. To make it adhere more strongly to the palate, the sheet may be coated on its upper side with strong paste.

For an experiment the inner surface of the artificial palate is oiled, and sprinkled with powdered chalk or some similar substance; it is inserted with chalked fingers; the sound is spoken; and the palate is at once removed. The parts touched by the tongue appear black, the chalk having been removed where the tongue pressed heavily and moistened where it touched lightly. The result may be sketched on a plaster cast made for the purpose, or may be photographed. A convenient method of recording results is to sketch them on a diagram of the person's palate printed from a zinc block made from a drawing showing the outline of the artificial palate.

It must be constantly borne in mind that contacts may occur outside the limits of the artificial palate. The plate of KINGSLEY loses at the sides of the velum and those of most other investigators lose everything back of the hard palate. TECHMER'S plate included the sides of the velum.

To obtain records for a sound in the interior of a word, such words should be selected as give no other records or no records which can be confused with the one desired.[1] Thus the l gives clear traces in the front of the palate for 'blanc' (tonic), 'blanchir' (initial atonic), 'blanchisseuse en gros' (initial tonic distinct from accent of phrase), 'va chez M. Blanc' (tonic preceded by a number of syllables).

To compare analogous sounds they are spoken in analogous words and the tracings are superimposed. For example, the record for the vowel in 'long' is compared with those for the vowels in log, lɔg, lag in order to determine its character. Sounds may be tested by their effects on known articula-

[1] ROUSSELOT, *Études de prononciations Parisiennes*, La Parole, 1899 I 547.

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tions of other sounds. Thus anterior vowels tend to make the **k** mouillé; tracings for various forms of **kav** show[1] that a_1 makes the **k** mouillé and is distinct from a_2 and a_3 (the inferior numerals indicate contacts of different backwardness).

Palatograms of some of his American sounds have been given by KINGSLEY.

The contact surfaces were recorded for the vowels **e** in **kēn** 'cane' (Fig. 138), and **i** in **sī** 'see' (Fig. 139). The tongue evidently divides the mouth cavity into two portions connected by a neck. For **i** the anterior portion is smaller than for **e** and the neck is narrower and longer; the posterior portion is apparently not greatly changed. Concerning the tones of the cavities under such conditions we can hardly say more than that at least one of the tones for **i** will be higher than the corresponding one for **e**; this is actually the case in all the experimental determinations (pp. 21, 23, 25, 26, 48, 287, 288). The contact for **t** (Fig. 140) shows complete alveolar contact of the tongue. If this contact was marginal, the release was probably quick with a sharp explosion; if predorsal, slower with a slight following aspiration. The mouth cavity was apparently large; the tone of the explosion of **t** has been registered only for a German example (p. 48); no comparison can be made with this **t** as the contact for HERMANN'S **t** was not recorded. The **n** (Fig. 141) shows complete alveolar contact; although the mouth cavity appears to be nearly the same in size as that of the **t**, the opening of the nasal aperture must lower its tone. The **k** is postvelar (Fig. 142); the **g** is also postvelar but slightly further forward (Fig. 143); the projection to the rear in the middle of KINGSLEY'S artificial palate (Fig. 136) rendered it possible to record such backward contacts; the contacts probably extended further to the sides than in Figs. 142 and 143 but could not be recorded on account of the narrowness of the projection; concerning the nature of the release and the tones of the explosions of the **k** and **g** nothing is known. A

[1] ROUSSELOT, as before, 548.

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omewhat more forward velar contact occurs in η (Fig. 144); haryngeal and tracheal cavity tones were presumably present. The backwardness of the contacts for k, g, η is remarkable when the palatograms are compared with those of other anguages. For f and v the tongue seems to rise slightly

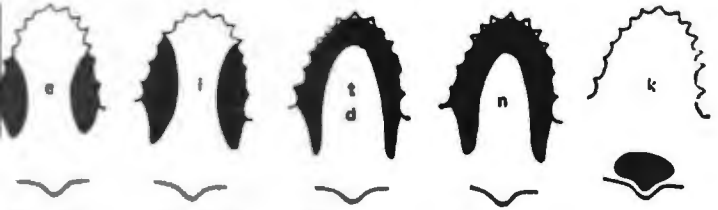

Fig. 138. Fig. 139. Fig. 140. Fig. 141. Fig. 142.

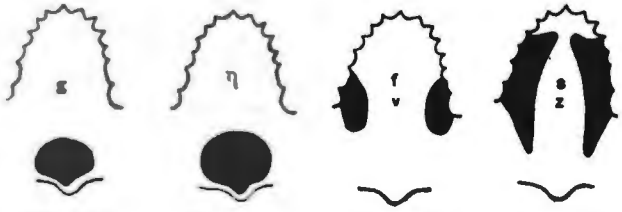

Fig. 143. Fig. 144. Fig. 145. Fig. 146.

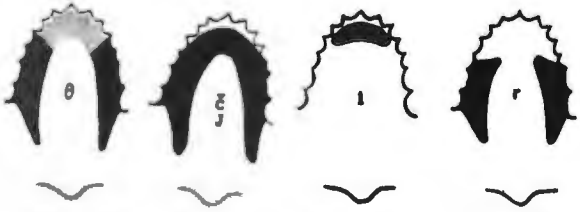

Fig. 147. Fig. 148. Fig. 149. Fig. 150.

the postpalatal and prevelar regions (Fig. 145); similar ecords may be occasionally found in the work of other ob- ervers. This rise presumably influences the cavity tones roused by the friction at the aperture of the cavity and eard in the fricative noise; in the case of v it must also nfluence the cavity tone aroused by the cord tone.

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KINGSLEY'S s (Fig. 146) shows a very short narrow nozzle-like opening with a gradual approach and a very free exit; the laws governing the action of such apertures have been treated in works in hydrodynamics, but their acoustic applications have not been made. The record for KINGSLEY'S š and ž was so nearly identical with that for e (Fig. 138) that the same diagram was used for both; the nozzle is broad and the cavities large, indicating perhaps a soft rushing sound with low tones.

The record for θ (Fig. 147) shows firm contact at the sides and loose contact in front. The record for č, ǰ (Fig. 148) is that for the sounds heard in 'church' and 'judge.' These consist of an occlusive t- or d-sound with a fricative release producing a rushing sound instead of the explosive release of an ordinary t or d. It is customary to assume that these are consonant diphthongs and to indicate them by tš and dž. It is quite possible, however, that the fricative release may not be of the character supposed; moreover, the occlusive and fricative elements may be too closely fused to permit us to consider the sounds as diphthongs. Similar cases will be found in the following chapters.

The l (Fig. 149) shows frontal-alveolar contact; the rear portion of the tongue is generally supposed to be raised but no record appears. In r (Fig. 150) the front portion of the tongue is turned up against the palate.

It must be added that the identity of the contacts for t and d, f and v, s and z, š and ž, č and ǰ, is due to the failure of KINGSLEY to distinguish the finer differences. In general the surd has a more extended contact than the corresponding sonant. This indicates stronger muscular action, as would be expected from the fact that part of the lung pressure is used to make the cords vibrate in a sonant (p. 244). This relation of corresponding surd and sonant as strong and weak is a general one.

Some palatograms by ROUSSELOT[1] of the sounds of an

[1] ROUSSELOT, *L'enseignement de la prononciation par la vue*, La Parole, 1901 III 587.

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American showed results in general like those by KINGSLEY but with several exceptions. The relations of contact were θ > ð, č > J as usual, but t < d, s < z, š < ž contrary to the general rule. ROUSSELOT believes that in such a case the surds t, s, š are made as whispered sounds and not surd ones. He apparently implies that the closure of the glottis for whispering uses some of the lung pressure and requires less closure in the mouth. This is a valid explanation for less pressure in whispered t than in surd t; it is inadequate for less pressure in whispered t than in sonant d, for the vibrating cords in d let less air pass than the narrowed glottis in whispered t.

Palatograms of a native of Neale, County Mayo, Ireland,[1] showed many 'subpalatal' vowels, that is, vowels in which the elevation of the tongue was too feeble to reach the artificial palate or too far back to reach its rear boundary; such were a, e (generally), u, o, ə. The consonants p, b, m, f, v were likewise subpalatal. The two classes of vowels are much more clearly separated in Irish than, for example, in French, where all vowels leave traces on the artificial palate. The action of the broad Irish vowels a, o, u is quite distinct from that of the thin ones e, i in palatalizing the preceding consonants; the phenomenon occurs for e and i with a regularity that does not appear in most other languages. In addition to the data of special interest in regard to Irish, ROUSSELOT points out some that are of general importance: 1. reciprocal influence of vowels and consonants; 2. influence of syntactic groupings or of morphology on the articulations; 3. great variations in the articulations of sound without loss of auditory identity; 4. differences of force between initial and final consonants, and between a final consonant followed by a vowel and one followed by a consonant in the next word; 5. the existence of k, g, t, d and s mouillé in Irish also.

Using KINGSLEY'S method, BALASSA gives diagrams of his own Hungarian sounds.[2]

[1] ROUSSELOT, *Les articulations irlandaises*, La Parole, 1899 I 241.

[2] BALASSA, *Phonetik d. ungarischen Sprache*, Internat. Zt. f. allg. Sprachwiss, 1889 IV 130.

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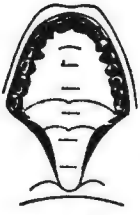
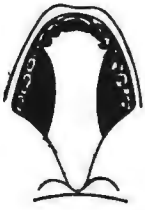


u

FIG. 151.



e_2

FIG. 152.



i

FIG. 153.



œ

FIG. 154.



y

FIG. 155.



k_1

FIG. 156.



k_2

FIG. 157.



ɾ

FIG. 158.



ň

FIG. 159.



j

FIG. 160.



s

FIG. 161.



š

FIG. 162.



l

FIG. 163.



n

FIG. 164.



t

FIG. 165.



ts

FIG. 166.



tš

FIG. 167.

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No contacts appeared for a_1 'v*á*rn*á*;' a_2 '*a*lm*a* ' [a_1 and a_2 having the same tongue position, with lip retraction for a_1 and lip projection for a_2]; o_1 '*ó*ta;' o_2 '*o*k*o*s;' e_1 '*e*st*e*;' f '*f*a;' v 'vér;' p '*p*iros;' b '*b*or;' m '*m*ost,' 'ha*m*vad;' ŋ hang;' r 'va*r*.'

Figures 151 to 167 give the contacts for the other long vowels, liquids and surds: u '*ú*t;' e_2 '*é*let;' i 'tí*z*;' œ 'szőllő;' y 'hű,' k_1 '*a*k*a*rok;' k_2 '*k*evés;' т '*ty*uk;' medio-palatal ñ '*ny*ul;' j 'ha*j*o;' s '*sz*áraz;' š '*s*as;' l '*l*ó;' n 'né*p*;' t '*t*e;' ts 'apá*cz*a;' tš '*cs*ászar.' The short vowels have slightly different contacts; the sonants were assumed to have nearly the same contacts as the corresponding surds.

The palatograms clearly indicate a classification into rear and front vowels, usually called 'deep' and 'high' on account of the difference in pitch. These two classes, a, o, u, and e, i, œ, y, show themselves in the phenomena of 'vowel harmony' (p. 121). The middle vowels are lacking entirely in modern Hungarian.

The rearwardness of the l is noteworthy. After t, d the l-contact is made at the same place as for those sounds. The ancient *l*-mouillé has become j or z in most dialects, l in the others.

In the 'consonant diphthongs' ts tš the first portion is not the same as the ordinary t, but an occlusion at the places for the second portion. They are affricates, that is, occlusives with fricative releases. According to the palatograms the former seems to be an affricated t, the latter an affricated т. The tš is said by BALASSA to be the same as KINGSLEY'S č, but Fig. 148 has hardly any resemblance to Fig. 167.

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For dental materials: S. S. WHITE DENTAL MFG. CO., New York.

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CHAPTER XXII

TONGUE CONTACTS: GERMAN RECORDS

DIAGRAMS of their own palatal records for German soun
have been given by GRÜTZNER[1] (b. 1847 at Festenberg
Kreis Polnisch-Wartenberg, Schlesien), TECHMER,[2] VIETO
(a native of Nassau), and LENZ.[4]

GRÜTZNER'S diagrams (painted tongue) of continuous
produced sounds are given in Figs. 168 to 172. For l (Fi
168) the tongue is pressed against the palate just above t
front and side teeth, with a small opening opposite the fir
molar on each side. The velum closes the nasal cavit
The auditory character of the l changes only slowly as t



l r t s š

FIG. 168. FIG. 169. FIG. 170. FIG. 171. FIG. 172.

region of articulation is advanced or retracted. The openin
in l may be on one side only. The curves of the Germa
l have been given by WENDELER (p. 19) and HERMAN
(p. 43). GRÜTZNER'S articulation for r is given in Fig

[1] GRÜTZNER, *Physiologie der Stimme und Sprache*, Hermann's Handbuch d
Physiologie, I (2), 204, 207, 219, 221, Leipzig, 1879.

[2] TECHMER, Phonetik, 30, Tafeln III–IV. Leipzig, 1880; *Naturwiss. Analy*
u. Synthese d. hörbaren Sprache, Internat. Zt. f. allg. Sprachwissenschaft, 1884
140, Tafeln III–IV.

[3] VIETOR, Elemente der Phonetik, 4. Aufl., 307, 308, Leipzig, 1898.

[4] LENZ, *Zur Physiologie und Geschichte der Palatalen*, Diss., Bonn, 1887; al
in Zt. f. vergl. Sprachf., 1888 XXIX 1.

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169. The curves for r have been recorded by DONDERS, WENDELER (p. 19) and HERMANN (p. 44). GRÜTZNER'S t (Fig. 170) is alveolar and dental at its moment of closure. His s (Fig. 171) shows the touching of the tongue against the teeth and alveolæ with the narrow opening in front. The channel is very small. GRÜTZNER'S š (Fig. 172) is one of a possible series of rush sounds that begins with s and changes as the tongue articulates further backward. The lower pitch of š as compared with s was observed by KEMPELEN. Curves of the vibrations in t, s, š and their corresponding sonants have been obtained by HERMANN (p. 42).

VIETOR'S diagrams (artificial palate) of continuously produced sounds are given in Figs. 173 to 183, which contain also lines indicating the positions for the related American and French sounds as obtained by KINGSLEY and ROUSSELOT.

VIETOR'S close i (Fig. 173), as in **libn** 'lieben' is formed with the tongue so high in the middle that the breath makes a rushing noise; the lips are not generally drawn back. His **y** (*ü*) (Fig. 174), as in **ybriç** 'übrig,' has a tongue position not quite identical with that of i, with the lips not in the neutral i position but in the projected and rounded u position. For his e_1 (Fig. 175), as in **re** 'reh,' the tongue does not rise so high as in the previous cases. His **œ** (*ö*) (Fig. 176), as in **šœn** 'schön,' combines an approximate e_1 position of the tongue with an o position of the lips. The e_2 (Fig. 177), as in **ber** 'bär' in his pronunciation, has a still larger opening. Figs. 178 to 183 give the consonant articulations for ç as in **iç** 'ich,' s as in **ist** 'ist,' š as in **šœn** 'schön,' t as in **ton** 'ton,' r (lingual) as in **rabə** 'rabe,' and l as in **libə** 'liebe.'

VIETOR'S ç (Fig. 178) may be considered as a development in the series s — š — ç by regression and lengthening of the tongue articulation. The transversal extent of the articulation in ç varies with the preceding vowel.[1]

In VIETOR'S s (Fig. 179) the narrow stream of air passes out through a partially dorsal contact of the tongue, differing

[1] VIETOR, Elemente d. Phonetik, 4. Aufl., 174, Leipzig, 1898.

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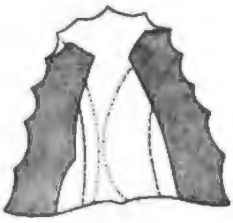
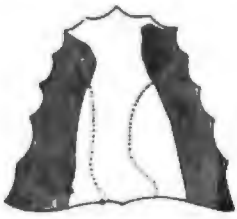


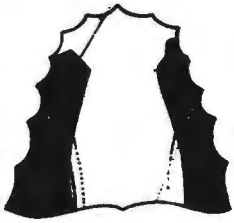
i

FIG. 173.



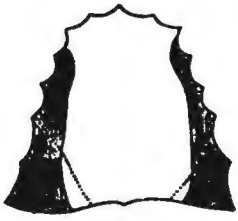
y

FIG. 174.



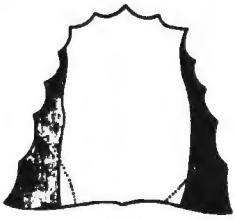
e_1

FIG. 175.



œ

FIG. 176.



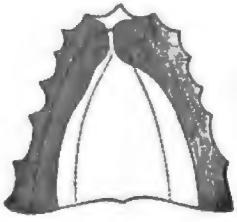
e_2 (ä)

FIG. 177.



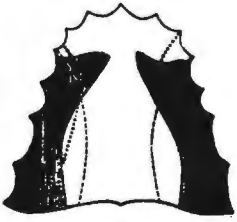
ç

FIG. 178.



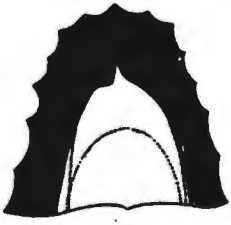
s

FIG. 179.



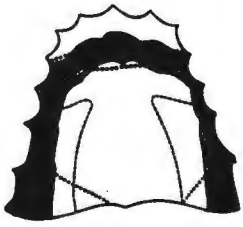
š

FIG. 180.



t

FIG. 181.



r

FIG. 182.



l

FIG. 183.

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rom the apical contact of GRÜTZNER (Fig. 171). The hiss-ng noise of the s is probably made by the friction in the passage and not by the impact against the teeth as VIETOR supposes. In VIETOR's š (Fig. 180) a broad stream of air passes between the tongue and the gums; the articulation is dorsal-alveolar or dorsal-postdental. It differs little from that of GRÜTZNER (Fig. 172).

In VIETOR'S t (Fig. 181) the articulation closely resembles that for s without the opening; the pressure is strongest in front of and around the notch shown in the figure.

VIETOR'S r (Fig. 182) has an alveolar contact with the front of the tongue further back than GRÜTZNER'S (Fig. 169). It is generally sonant with no rushing noise; before or after surds the cord tone is often partly or entirely lost. The number of beats is variable.

For l the contact is alveolar and along the front teeth (Fig. 183); it is firmest along the molars, lighter in front; the chief opening is at the eye teeth and the first molars.[1]

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[1] VIETOR, as before, 214.

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CHAPTER XXIII

TONGUE CONTACTS: FRENCH AND ITALIAN RECORDS

THE Parisian dialect is being subjected to a careful study by ROUSSELOT;[1] the published palatograms show the following facts. The results are interesting in view of the growing claim of Parisian to be considered as standard French.

In Paris three forms of **a** are clearly distinguished. The 'medium **a**' as in 'patte' is pronounced with the muscles of the tongue and lips completely relaxed; the tongue is left at rest in the mouth, the jaw is lowered, the larynx emits a sound that resonates softly and hollowly in the cavity; this **a** is indicated in ROUSSELOT'S notation by *a*, in ours by a_2. The 'close a,' as in 'pâte' or 'ah!' is pronounced with tense muscles, the tongue drawn back and the lips slightly contracted; it tends toward ɔ; it is indicated by *ȧ* (ROUSSELOT) or by a_3. The 'open a,' as in 'cave,' is pronounced with the tongue slightly raised in the front portion and slightly depressed in the rear, while the lips are slightly separated; it is indicated by *à* or by a_1. The artificial palate may show no records of these forms of **a**, but ordinarily they appear at the back portions with the contacts increasing in the order a_1, a_3, a_2, as shown in Fig. 184. When a_2 and a_3 occur in atonic syllables they become a_1, the relaxation in force bringing an associated relaxation in articulation. When a_1 receives an oratorical accent, it becomes a_3, the extra force bringing an extra effort in articulation.

Three very distinct forms of **e** may be recognized in Paris: e_1 (*è*), 'open **e**,' as in 'fait'; e_2 (*e*), 'medium **e**,' as in 'Eh

[1] ROUSSELOT, *Études de prononciations parisiennes, I. Les articulations étudiées à l'aide du palais artificiel*, La Parole, 1899 I 481.

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FIG. 184.

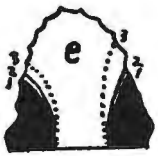

FIG. 185.

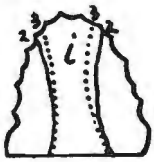

FIG. 186.



FIG. 187.

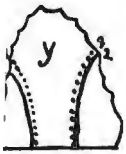

FIG. 188.



FIG. 189.

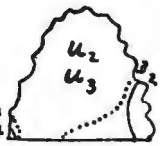

FIG. 190.

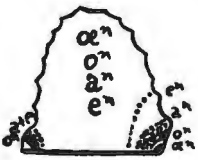

FIG. 191.



FIG. 192.



FIG. 193.



FIG. 194.



FIG. 195.



Fig. 196.



FIG. 197.



FIG. 198.

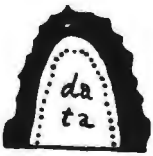

FIG. 199.



FIG. 200



FIG. 201.



FIG. 202.



FIG 203.



FIG. 204.

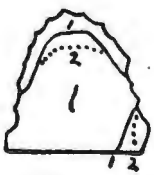

FIG. 205.

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bien!'; and e_3 (*é*) 'close e.' The e_1 and e_3 are readily isolated. As e_2 occurs only in an accented syllable before a consonant or in an unaccented syllable, the Parisian isolates it with difficulty; in certain provinces e_2 has an independent value. The same conditions are found in general for the other medium vowels i_2, y_2, o_2, u_2, $œ_2$. The palatograms (Fig. 185) show increasing contacts in the order e_1, e_2, e_3. Changes occur as the results of differences in stress just as for a. The explanation for $e_3 \rightarrow e_2$ when unstressed is the same as for $a_3 \rightarrow a_1$. The change $e_1 \rightarrow e_2$ (open to medium) when unstressed results from the fact that the relaxation of the internal tongue muscles along the septum produces a widening of the tongue and more contact along the palate. The same reasons explain certain changes of long e_1 to short e_3 in speech, that is, of a tense open vowel to a relaxed close one.

Two very different Parisian i's were found, namely, i_2 (*i*), a medium i, and i_3 (*í*), a close i. The i_2 is followed by a consonant or is unstressed, as in $mi_2ni_2st\ de_3\ bo_3z\ a_1r_2$ 'ministre des beaux arts.' Both i's appear in i_2si_3 'ici,' fi_3ni_2 'fini' and in i_2l 'il' and i_3l 'île.' The palatograms show less contact for i_2 than for i_3 (Fig. 186). The changes $i_3 \rightarrow i_2$ and $i_2 \rightarrow i_3$ are analogous to those for e (above).

Parisian speech has three forms of œ: $œ_1$ (*œ̀*), 'open œ,' as in 'heure'; $œ_2$ (*œ*), 'medium œ,' as in 'je parle'; and $œ_3$ (*œ́*), 'close œ,' as in 'eux.' The palatograms show increasing contacts in the order $œ_1$, $œ_2$, $œ_3$ (Fig. 187). The palatogram for $œ_1$ corresponds closely to that for a_2; those of $œ_2$ and $œ_3$ are quite different from that of e_1. Accented $œ_1$ regularly becomes $œ_3$ when the syllable loses the accent.

The so-called 'mute *e*' in French is, if sounded, $œ_3$ when named, $œ_2$ in a phrase, and $œ_1$ when accented. In other investigations ROUSSELOT indicates this sound by a special symbol corresponding to ə of this book. As a final, the 'mute *e*' does not entirely disappear; it at least modifies the preceding consonant.

The two forms of y are y_2 (*u*), 'medium y,' as in 'pudeur'; and y_3 (*ú*), 'close y,' as in 'pur' (Fig. 188). The y contacts

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occur within the region for those of **e** (Fig. 185), just as do those for **œ** within the region between **a** and **e**.

There are the three forms of **o**: o_1 (*ɔ̂*), 'open **o**,' as in 'or'; o_2 (*o*), 'medium **o**,' as in 'botte'; o_3 (*ó*), 'close **o**,' as in 'beau.' Their contacts do not differ greatly. The extremes o_1 and o_3 are shown in Fig. 189; o_2 is seldom distinguishable from the others except in combinations.

There are two forms of **u**: u_2 'medium **u**,' as in 'boule'; u_3 'close **u**,' as in 'cou.' The palatograms (Fig. 190) — not from the same subject as for Figs. 184 to 189, owing to an anomaly for **u** — show more contact for u_3 than for u_2.

The nasal vowels rarely have the same contacts as the corresponding oral ones. The palatograms for the same subject that furnished Figs. 184 to 189 showed the contacts for $œ^n$, o^n, a^n, e^n (Fig. 191) all to lie in the **œ**-region (Fig. 187). The records seem to indicate correspondences of tongue position between $œ^n$ and $œ_1$, o^n and o_1, a^n and a_3, e^n and an intermediary between a_2 and e_1.

The contacts for **k** and **g** show many varieties of a typical form (Figs. 192, 193), depending on the adjacent sounds.

The **ĸ** and **ɣ** sounds are those known as '*k*- and *g*-mouillé.' Their contacts are further forward than those for **k** and **g** even in the combination **kj** and **gj**; comparisons are shown in Figs. 192 and 193. These **ĸ** and **ɣ** sounds are distinct from the **k** and **g** sounds both in place of articulation and in the nature of the explosive release.[1] The treatment of **ĸ** and **ɣ** as 'soft' or 'mouillé' forms of **k** and **g** arises from their interchangeability in French speech and from the use of the same letters to indicate them. The 'mouillure of *k* and *g*,' that is, the change of **k** and **g** to **ĸ** and **ɣ**, occurred with one subject before i_2, e_2, $œ_2$, a_1 but not constantly; it happened generally only in a moment of negligence, and in rapid rather than slow speech. Two examples of constant occurrence were $lœ_2\ ma_1r_2ĸi_3\ d\ ka_2r_2a_2ba_3$ 'le marquis de Carabas' and $lœ_2\ šo_2ko_2la_3\ ma_1r_2ĸi_3$ 'le chocolat Marquis' (r_2 = uvula **r**).

The contact for **ȷ** (consonant **i** as in 'yeux') is shown in

[1] Lenz, *Zur Physiologie u. Geschichte d. Palatalen*, Diss., Bonn, 1887; also in *Zt. f. vergl. Sprachf.*, 1888 XXIX 1.

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Fig. 194. The sound which has replaced the *l*-mouillé has contacts as shown in Fig. 195 in baɟe 'bâiller' (*1*) and br$_2$ij 'brille' (*2*). Its practical identity with ɟ of Fig. 194 is evident.

The sounds š, ž, s, z (Figs. 196, 197, 198) have contact surfaces that are small in comparison with those of the corresponding American and German records.

The contact surfaces for t and d in ta and da are shown in Fig. 199 (t > d). They are somewhat more extended in te and de and still more in ti and di, ty and dy. The sounds i and y incite to the still greater contact that characterizes the *t*- or *d*-mouillé. These have the next distinguishable contacts in front of ʀ and ɣ with a softer release than those of t and d; they may be indicated by τ and δ. This mouillure is heard ordinarily in familiar words, as 'turguet,' 'naturel'; it occurs constantly in the interjection 'naturelment!'

The n contact involves an anterior occlusion (Fig. 200); it depends somewhat on the following vowel (ni > ne). In the combination nji (Fig. 201) the occlusion for n is a very small one along the front teeth and undoubtedly along the sides while the contact for ɟ occupies considerable space at the sides as usual.

The ñ, so-called *n*-mouillé, has a contact utterly different (Fig. 202) from that of n.

The contact of l varies considerably. An ordinary initial l is illustrated in Fig. 203, a medial l in Fig. 204. The influence of final 'mute *e*' on the contact for l is shown in the records (Fig. 205) for 'bal' (*1*) and 'balle' (*2*).

HAGELIN'S excellent photographs of palatograms by several French speakers[1] are not available for reproduction.

ROUSSELOT'S[2] diagrams for the contacts of the tongue in his native dialect (Cellefrouin in Charente) were obtained from himself by means of observation with a mirror, by the use of an artificial palate and by employing small rubber bulbs in the mouth.

[1] HAGELIN, Stomatoskopiska undersökningar af franska språkljud, Stockholm, 1889.

[2] ROUSSELOT, *Les modifications phonét. du langage*, 23, Revue des patois gallo-romans, 1891 IV, V; also separate.

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In the fricatives **z** and **s** the tongue scarcely touches the edges of the palate (the outside lines in Fig. 206), less for **z** than for **s**; the passage for the air current is not indicated. ROUSSELOT'S **s** and **z** are quite different from any of the others yet given; several of HAGELIN'S figures show openings more like those of the German and English diagrams. For **n**, **d** and **t** the tongue touches the palate on all sides, covering more of the central portion as the contact rises from **z** and **s** through **n**, **d**, **t**. French **t** and **d** are regularly dorsal-alveolar or else frontal-postdental as given by HAGELIN (see also Fig. 199); the dorsal-palatal **t** and **d** of ROUSSELOT seem unusual and hard to understand when we consider the nature of the release of such backward contacts; I am inclined to consider them as palatalized **t** and **d**, or the so-called *t*- and *d*-mouillé.

In the pairs **s**, **z** and **t**, **d** the surd has the greater contact surface, indicating stronger articulation (p. 304).

In ROUSSELOT'S labials **p**, **b**, **f**, **v**, **m**, the tongue is in repose, touching the palate with its edges at the rear teeth. The line across each corner in Fig. 207 marks the front limit of contact for **p**, **b**, **f**, **v** spoken with a following **r** or **l**, and also for **m**. For **m** there is a slight rise of the lower jaw. The differences in articulation for these sounds are produced at the lips.

ROUSSELOT'S palatals **ȷ** (consonant **i** as in 'yeux'), **š** (as in 'cache'), and **ž** (as in 'je') have side contacts as shown in Fig. 207. In the French **š** the tongue is placed along the teeth, sometimes far to the front, and even all around (HAGELIN); the opening is quite different from that of German **š** (Figs. 172, 180) and the air passage is much thinner and wider.

For **k** and **g** the tongue is raised across the palate, the marked variations seem to show the influence of the following sounds, as may be seen in Fig. 208 from **k(o)**, **g(o)**, **k(i)**, **g(i)**, **k(ȷ)**, **g(ȷ)**, **g(l)** and **k(l)**, the line in each case marks the front limit of contact. In general the surds have more extensive contacts than the sonants. In **kȷ**, **gȷ**, the occlusions seem rather to have become **ϰ** and **ɣ**. ROUSSELOT'S **k** before **i** is quite different from the cases given by HAGELIN.

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The w (Fig. 208) has about the same contact as g(o) an the lip position of u.

For l (Fig. 209) and r (Fig. 210) the tongue touches th palate in about the same regions, for l more than for r.

When consonants are grouped, the first consonant some times tends to accommodate itself to the following one. Thi is not shown in ROUSSELOT'S palatograms of p(l), p(r), b(l) b(r), etc. (Fig. 207), but does appear in the records for p(j b(j), f(j), v(j) (Fig. 211) and in those for s(j), t(j) (Fig 212); it is quite marked also for k(j), g(j), k(l) and g(l (Fig. 208), the k and the g contacts being much advance toward the lips and strongly palatalized.

The record for ʎ, or '*l*-mouillé,' (*l*̂, Fig. 209) shows that it i a very different sound from l. When followed by j as in 'lieux the contact (*l*̂$_j$, Fig. 209) indicates an even greater contact tha for ʎ alone although it resembles it more than that for l.

The record for ñ (*n*̂, Fig. 212), or '*n*-mouillé,' shows contact utterly different from that for n (Fig. 206). Whe followed by j, the contact (*n*̂$_j$, Fig. 212) indicates a soun differing somewhat from ñ and still more so from n, but lyin between ñ and n. The conclusion is evident that ʎ and are not in any way to be considered as composed of l + and n + j, although in this dialect ñ was always derive historically from nj and ʎ partly from lj. The records seem to indicate, moreover, that the combinations are ʎj and ñ rather than lj and nj.

The anterior limits of the regions of contact in ROUSSE LOT'S forms of a are given in Fig. 213; a_2 is the vowel produced by ROUSSELOT with the least effort (as in 'Paris') a_1 (as in 'partir') requires a slightly greater opening of th mouth and retraction of the tongue; a_3 (as in 'pâte') in volves a still further retraction of the tongue to leave a large cavity in front. Fig. 213 shows successively larger contacts for the neutral and anterior vowels in the order a_3 'pâte,' a^n '*enfant*,' a_1 'partir,' a_2 'Paris,' e_1 'fête' and e^n 'vin,' e_2 'église,' e_3 'maison,' i_2 'Rivoli,' j 'yeux,' i_3 'ici.' A similar series of contacts is seen in Fig. 214; the contacts increase

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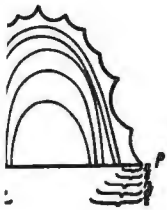
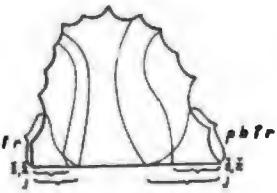


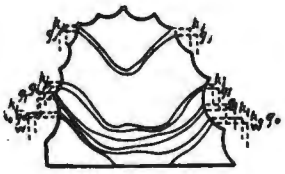
z, s, n, d, t

FIG. 206.



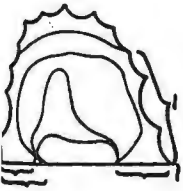
p, b, f, v, š, ž, j

FIG. 207.



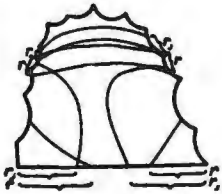
k(j), g(j), k(l), g(l), g(l), k(l), k(o), g(o), w

FIG. 208.



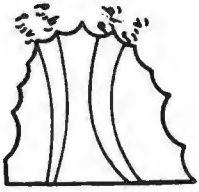
l, ʎ, l(j)

FIG. 209.



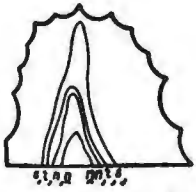
r, r(j)

FIG. 210.



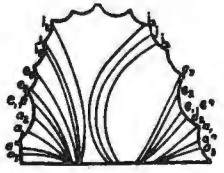
p(j), b(j), f(j), v(j)

FIG. 211.



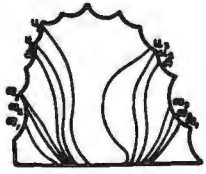
s(j), t(j), n(j), ñ

FIG. 212.



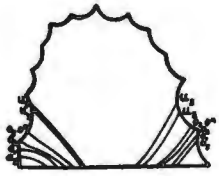
a_3, a^n, a_1, a_2, e_1, e^n, e_2, e_3, i_2, j, i_3

FIG. 213.



$œ_1$, $œ_2$, $œ_3$, ų, y_2, y_3

FIG. 214.



a_3, o_1, o_2, o_3, o^n, u_2, u_3

FIG. 215.

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in the order $œ_1$ 'h*eu*re,' $œ_2$ 'h*eu*reux,' $œ_3$ 'heur*eux*, f*eu*,' ($ẅ$) 'l*ui*,' y_2 (u_2) '*u*tile,' y_3 (u_3) 'fend*u*.' The back vowe a_3 'p*â*te,' o_1 '*or*,' o_2 'ch*o*col*a*,' o_3 'chap*eau*' and o^n '*on*,' u 'b*ou*che,' u_3 '*ou*,' form another series of steadily increasin contacts (Fig. 215).

Comparison of ROUSSELOT's own records with the Parisia ones shows instructive resemblances and differences. The orde of increasing contact is a_3, a_1, a_2 (Fig. 213) instead of a_1, a a_2 (Fig. 184). For e (Fig. 213) the order is the same (Fig 185) but the contacts are all further back; his e sounds ar evidently all more open and nearer to the a sounds than th Parisian ones are. For i (Fig. 213) the records are closel similar (Fig. 186). The same is true for œ (Fig. 214 and Fig 187). The contacts for y (Fig. 214, u_2, u_3) occur in th region for i (Fig. 213) and not in that for e (Fig. 213) as i the Parisian records (Figs. 188, 185, 186). The contacts for and u (Fig. 215) are practically the same as the Parisian one (Figs. 189, 190). The nasal vowels show the following rela tions of tongue contact ($\approx$ indicates 'approximates'): $a^n \approx a$ (Fig. 213), $e^n \approx e_1$ (Fig. 213); $œ^n$ is not given; the palatogram give $o^n = o_3$ but the graphic records of tongue elevation an pressure (Figs. 256, 259) indicate $o^n \approx o_1$. The records fo n, s, z, š, ž, ȷ, k, g, l, show general agreement. The record fo '*l*-mouillé' (Fig. 209) shows a true ʎ and not its usual sub stitute ȷ (Fig. 195). In the combination 'lȷ' the contact show that the first sound is ʎ rather than l. There is likewise true ñ (Fig. 212), with indication that 'nȷ' is ñȷ rather than nȷ. ROUSSELOT's r (Fig. 210) is evidently the lingual r and not the uvular one, or '*r* grasseyé.'

Palatograms taken in the province of Nivernais, France, showed a gradual unperceived geographical and phonetic progression from š and ž at the Loire boundary to s and z at the opposite side; the Latin words 'capellum' and 'gambam,' for example, having become clearly $ša_2pjo$ and $ža_2mb$ at Chaulgnes and se_1pjo and za_2mb at Chaumard.[1]

[1] MEUNIER, *Emploi de la méthode graphique, etc.*, La Parole, 1900 II 67.

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Palatograms of Italian sounds[1] show that there are two distinct forms of a as in a_1ma_2 (Fig. 216), three forms of e as in $kre_1de_2re_3$ (Fig. 217), two of i as in i_1ni_2 (Fig. 218), three of o as in $po_1po_2lo_3$ (Fig. 219), and two of u as in $virtu_1$ and ru_2more (Fig. 220).

These palatograms and all the following ones, unless otherwise stated, are from a physician, a native of Terni (Perugia), who, after living in many of the large cities of Italy, had settled at Siena (Tuscany).

The t and d are regularly dental (Figs. 221, 222). The palatograms for ka, ki, ko (Fig. 223) and ga, gi, go (Fig. 224) show the different forms of k and g depending on the following vowel; in all these forms the point of the tongue was against the lower teeth. The records for ča and či (Fig. 225) show that č includes the contacts for ᴛ (backward t) and ȷ (consonant i) and not those for t and š; the fact seems also to have been established that the entire contact for ᴛ + ȷ was made at the same time. According to JOSSELYN it is quite wrong to consider č as composed of the articulations t and š, or even as composed of a succession of articulations. The contacts for ȷa and ȷi were, for this subject, practically the same as for ča and či. With other subjects the ȷa and ȷi showed a tendency toward a fricative form (Figs. 226, 227). The contact for ts as in 'zio' (Fig. 228) resembles that of t (Fig. 221) but covers a smaller surface; that for dz as in 'dozzina' is like that for ts with the tongue less firmly against the palate in the rear. JOSSELYN seems to consider ts, dz to be nearly as closely unified as č, ȷ. For s (Fig. 229) the contact is against the alveolæ with a short opening near the middle; for z (Fig. 230) the contact surface is slightly less. For š (Fig. 231) the channel is very wide. The l (Fig. 232) involved a frontal-prepalatal contact but in another subject was frontal-dental (Fig. 233). The rolled r and fricative r did not differ in contact (Fig. 234). The almost complete closure in the prepalatal region for the fricative r

[1] JOSSELYN, *Étude sur la phonétique italienne*, Thèse, Paris, 1900; also in La Parole, 1900 II 422, 449, 673, 739; 1901 III 41.

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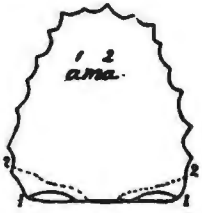
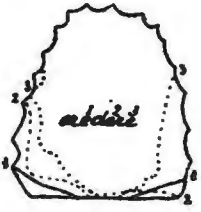


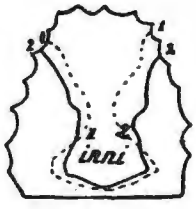
a

FIG. 216.



e

FIG. 217.



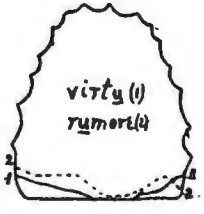
i

FIG. 218.



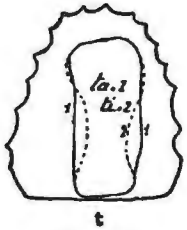
o

FIG. 219.



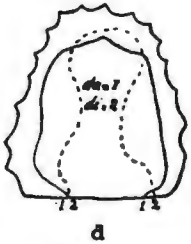
u

FIG. 220.



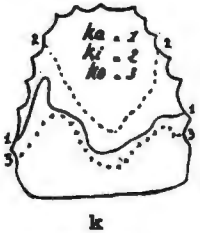
t

FIG. 221.



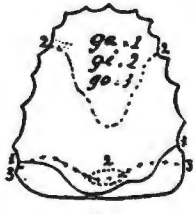
d

FIG. 222.



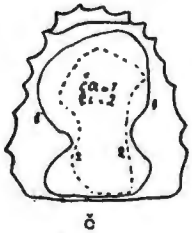
k

FIG. 223.



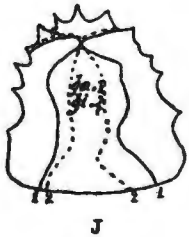
g

FIG. 224.



č

FIG. 225.



J

FIG. 226.

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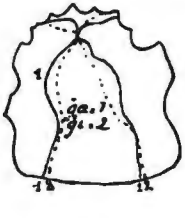
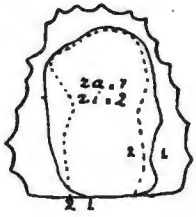


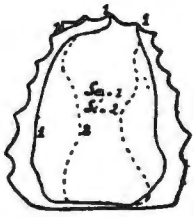
J

FIG. 227.



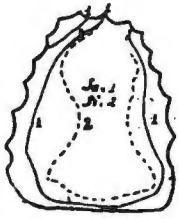
ts

FIG. 228.



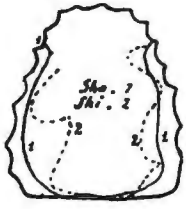
s

FIG. 229.



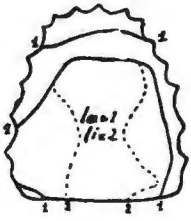
z

FIG. 230.



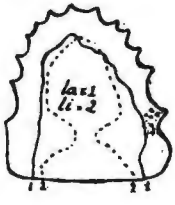
ž

FIG. 231.



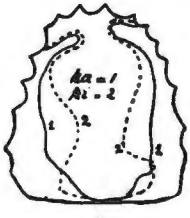
l

FIG. 232.



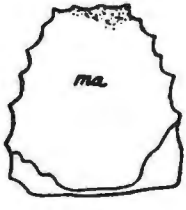
l

FIG. 233.



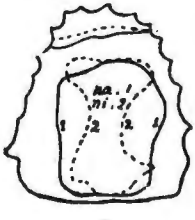
r

FIG. 234.



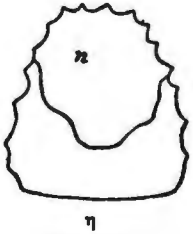
m

FIG. 235.



n

FIG. 236.



ŋ

FIG. 237

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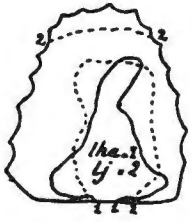
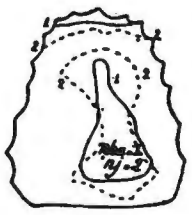
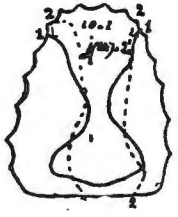


ʎ, lj
FIG. 238.



ñ, nj
FIG. 239.



j, i
FIG. 240.

may be made complete by a slight movement; in such case if the sides of the tongue are not sufficiently firm th lateral escape of the air will produce an **l**, or if they are fir the velum can descend and produce an **n**; such phonet changes are common in the Romance languages. In th change from fricative **r** to **s** the closure may readily becom complete and produce an intermediate **t**, as in **pwo dart** for **pwo darsi**. The articulation for **m** (Fig. 235) is post palatal with occasional alveolar contact of the tongue tip The **n** is frontal-prepalatal (Fig. 236) or dental. The recor of *ng* in '**vengo**' shows a postpalatal **ŋ** (Fig. 237), quit different from the prepalatal **n** (Fig. 236). The dorsal con tact for ʎ or *l*-mouillé (*1* in Fig. 238) is very different fro the frontal contact in **lj** (*2* in Fig. 238). There does no appear to be so much difference in the case of **ñ** and **nj** (Fig 239). The **j** in **jeri** '**ieri**' (*2* in Fig. 240) is clearly distinc from the vowel **i** in **io** (*1* in Fig. 240) although somewha resembling it.

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CHAPTER XXIV

TONGUE POSITIONS AND MOVEMENTS

THE regulative sensations (p. 191) coming to consciousness from the tongue are rather indefinite; they seem to be derived mainly from the contacts of the mucous surfaces. The main guidance for tongue movements is found in the sounds heard.

In the production of a speech sound the tongue makes more or less complicated movements. As in the case of all muscular action the tongue is never still and never occupies exactly the same position for any period of time. If a certain range of variation of position is or must be considered negligible, then it can be said to remain in a given position for the time its movements are confined within that range. Thus in the production of i the tongue rises and then falls; there is no moment at which it is perfectly still. Even in producing i for a considerable period of time the tongue is constantly fluctuating in its position. In a spoken i it maintains no such position for any great length of time but passes from the position for the previous speech element through all the positions involved in producing i and then to the position for the following element. The manner in which the tongue goes through the series of changes is certainly as characteristic of a speech movement as its position at any moment; acoustically the *changes* in the rush of air and in the cavity tones are as important as the conditions at any one moment. The usual custom of assigning some one position as the characteristic of a speech movement is often misleading. Thus a diagram showing the point of the tongue

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pressed against the gums is described as a frontal-alveolar articulation, and a t produced in this way is said to be frontal-alveolar, whereas the chief characteristics of this t may lie in the manner in which the closure is made and released.

The use of the term 'articulation' has sometimes resulted in a misconception of the nature of speech movements. 'Articulation' is a term applied to the joints, whose bones are said to articulate; it is not applied to the movement of the bones; an articulation is a relatively fixed thing. The tongue, however, does not 'articulate' with the palate but touches it at various points in various ways. The movement of the tongue is the characteristic of the speech action; its contact with the palate — even if this be called an 'articulation' — is in both time and extent only a small portion of the whole speech action. Phonetic writers seem to have been confused by a quite different use of the word 'articulate.' In such phrases as 'he articulates distinctly,' it refers to the intelligibility of the sounds by the ear; this has no reference whatever to precision of the vocal movements, but to the likeness of the sounds produced to those we are accustomed to hear. Some writers also seem to have had in mind the incorrect theory that a spoken word consists of a series of distinct sounds united by glides; supposing that the distinctness of articulation (that is, for the ear) would depend on the precision with which the separate sounds were made and marked off, they would naturally think of some connection between the auditory articulativeness and the motor precision of movement. In this book I have, for want of a better word, often used 'articulation' in the usual way, but the reader should not forget that it refers merely to vocal movements, that it has no connection with the distinctness of speech and that it implies no action of the organs in any way resembling articulation in the joints.

In studying the diagrams of the positions of the tongue it must be constantly borne in mind that they give only phases of the movements in speech. These phases are usually obtained by producing the sound continuously as in singing.

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In song the tongue assumes fairly constant positions for considerable lengths of time and these positions are approximately the same on different occasions. It is thus possible to map out the positions with considerable accuracy, although the work requires a long time.

A careful education of the sense of touch in the mouth renders it possible to feel the movements of the tongue with greatly increased accuracy. By repeatedly touching the surfaces inside the mouth with the finger the sense of location can be made more definite. Observation in a mirror is aided by inserting into the mouth a small incandescent lamp on a handle.

Several observers have given diagrams of what they considered to be the positions of the tongue during speech sounds. Among the early sets that by MERKEL[1] was carefully obtained. His sagittal diagrams show the positions of the tongue while he emitted various sounds continuously.

In GRANDGENT'S[2] determinations of the mouth positions the sound was spoken (or imagined), a ruler was inserted to measure the distances from the upper front teeth to 1. the rear pharyngeal arch, 2. the front pharyngeal arch, and 3. a point half-way between the latter and the rear edge of the palate. This method was used to obtain a series of sagittal diagrams[3] of GRANDGENT'S sounds and of the German sounds of HOCHDÖRFER, a native of Magdeburg. GRANDGENT'S speech is a good approximation[4] to the Boston dialect; but it differs considerably from other American and English dialects. In some respects the Boston dialect has English characteristics, using **paθ**, **baθ**, for 'path,' 'bath,' etc. The form of GRANDGENT'S palate is a fairly typical one.

[1] MERKEL, Physiologie der menschlichen Sprache (physiologische Laletik), Leipzig, 1866; this is a thorough revision of the last section of MERKEL, Anatomie und Physiologie des menschlichen Stimm- und Sprachorgans (Anthropophonik), Leipzig, 1. Aufl., 1857, 2. Aufl., 1863.

[2] GRANDGENT, *Vowel measurements*, Pub. Mod. Lang. Assoc., 1890 V 148.

[3] GRANDGENT, German and English Sounds, Boston, 1892.

[4] RAMBEAU, *Bemerkungen*, Neuere Sprachen, 1895 II 528.

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The diagrams for HOCHDÖRFER'S sounds are given in Plates XVII to XXII at the end of this volume, those for GRANDGENT'S sounds in Plates XXIII to XXVI. Each figure for a sound includes a sagittal diagram of the mouth cavity, a transverse diagram showing the opening between the tongue and the roof of the mouth at its narrowest part, and a front diagram of the position of the lips. The sounds are indicated by key words. The following account resembles the original in general, though differing at a few points.

The upper figure in Plate XVII shows HOCHDÖRFER'S uvula r. In producing this sound a deep channel is formed in the back part of the tongue, in which the uvula lies. The breath-pressure raises it, a puff of air occurs in the mouth, and it falls. As the vocal cords are vibrating at the same time this produces a series of puffs of tone (p. 19). Often only one such puff is used in speech; the rate at which the puffs come depends on the muscular adjustment and the breath-pressure. The tongue position resembles that for HOCHDÖRFER'S ə in **malə** 'male' (Plate XIX) to which final r in words like **biə** 'bier,' **vasə** 'wasser,' is actually reduced by many Germans in ordinary conversation.

HOCHDÖRFER'S χ is a hiss produced in the back of the mouth by a broad stream of air escaping between the inner part of the tongue and the lower edge of the velum. The uvula rests on the tongue without vibrating. In some dialects, however, it is caused to vibrate; this makes it like the uvula r without a tone from the cords. His ç is a hiss from a narrow passage between the alveolæ and the fore-part of the tongue; the point of the tongue is against the lower teeth. His j (*j* as in *ja*) is a sonant buzz with the tongue closer than in ç and with the lips less open; the point of the tongue is raised. His š is a dull hiss made by a broad stream of air between the tongue and the palate, and modified by the position of the lips and teeth. His s is a sharp hiss with the tongue close to the teeth. The auditory characteristics of these sounds lie in the hiss mixed with groups of tones of different pitch. The hiss is produced mainly between the

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tongue and the palate; the teeth have little effect. The tones depend on the combinations of resonance chambers formed in the oral cavity by the positions of the lips, tongue, velum, jaw and larynx. The chief resonance tone can be varied by rise and fall of the larynx without destroying the character of the sound; thus s can be whispered through a range of an octave, š through a somewhat smaller range and ç and χ through a still more limited one. The acoustic curves for these sounds from HERMANN'S voice have been given on p. 42.

GRANDGENT'S r (Plate XXIII) is a slight buzz with the upturned tongue-point near the palate. His w position closely resembles that of u (Plate XXIV). His j position differs little from that for i (Plate XXVI); the tongue and lip passages are opener than for HOCHDÖRFER'S German j. GRANDGENT'S š and s have the tongue-apex raised higher than HOCHDÖRFER'S German š and s. In pitch his š seems to the ear higher than his s and also than HOCHDÖRFER'S s. In GRANDGENT'S θ the air escapes through the spaces between the upper front teeth and between the notches of these teeth and the edge of the tongue. The resonance tones differ from those of f (with the lower lip against the upper teeth) on account of the different cavities formed by the positions of the tongue and lips.

In the back vowels u, o, ɔ (Plates XVIII and XXIV) the tongue rises in the back and leaves a large cavity in the front of the mouth. Where the palate is low, this space is gained by drawing the tongue more strongly back (Plate XVIII) than otherwise (Plate XXIV). The rounding of the lips includes greater projection for HOCHDÖRFER than for GRANDGENT. The palate and tongue positions form a regularly descending series in the order shown in these two Plates.

The vowel positions in Plates XIX and XXV have unrounded lips, except ə in hət 'hurt' and ə in malə 'male.' When the Germ. ə is used for *er*, the lower jaw is somewhat higher. These two vowels are much alike for HOCHDÖRFER and GRANDGENT both in sound and in position. It should be noticed that the pronunciation of *o* in 'hot' by GRANDGENT

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is rather like a than ɔ. GRANDGENT'S vowels in Plate XXV differ in sound from any of HOCHDÖRFER'S.

The front vowels in Plates XX and XXVI are unrounded. The short e and i seemed to be the same in sound for the two speakers; the long e and i differed slightly for the two. the ä in 'bär' appeared quite unlike the æ in 'bat' and noticeably different from the æ in 'fairy.'

The front rounded vowels of HOCHDÖRFER did not correspond to anything in English. They were produced in two ways; the commoner method is shown in Plate XXI, the other in Plate XXII.

To obtain the curve of the surface of the tongue several methods have been devised by ATKINSON. In one of them a strip of vulcanized rubber about 1mm thick and 7mm to 8mm wide, softened in boiling water, is inserted as far as possible in the mouth and fixed to the upper front teeth (Fig. 241). The desired sound is produced; the strip is bent into position by the tongue and is allowed to harden. The cooling may be hastened by a jet of cold water. It then shows the curvature of the tongue and its relation to the front teeth. The exact shape of the palate is obtained by a dental mold; this is sawed in half to give the sagittal section; the rubber tongue curve attached to this aids in completing the sagittal diagram of the phase of greatest movement. Such a tongue curve has been used in teaching vowel positions to the deaf[2] and in investigating phonetic changes.[3] An accurate instru-

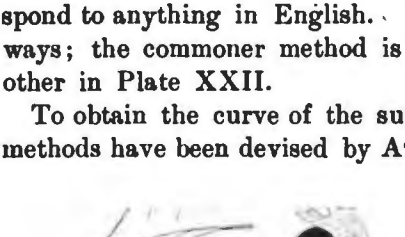

FIG. 241.

[1] ROUSSELOT, Principes de phonétique expérimentale, 278, Paris, 1897; LACLOTTE, Αἰτόλος-Βουκόλος, La Parole, 1899 I 349.

[2] MEUNIER, *Emploi de la méthode graphique pour l'éducation des sourds-muets*, La Parole, 1900 II 65.

[3] LACLOTTE, as before.

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nent[1] for obtaining the position of a point on the surface of he tongue is shown in Figs. 242, 243. A fine wire *C* slides n a tube *A*, its other end being caught in the coil *D* through slot in *A* extending from *E* to *F*. When *D* is at *F* the vire *C* is completely within *A*; when *D* is at *E*, it projects

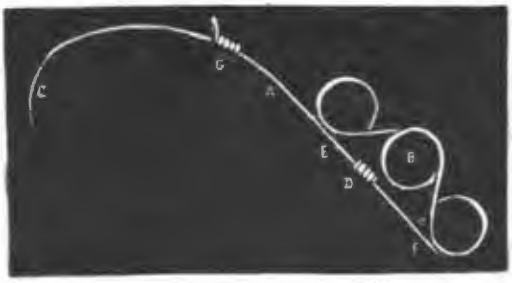

FIG. 242.

4.5mm. The tooth-stop *G* slides freely on *A* when its projecting end is down, but is fixed when its end is up as shown in the figure. The index, middle and ring fingers are placed in the handle *B*; the thumb is used to move *D*. The tooth-stop *G* is placed in the depression between the two front teeth.

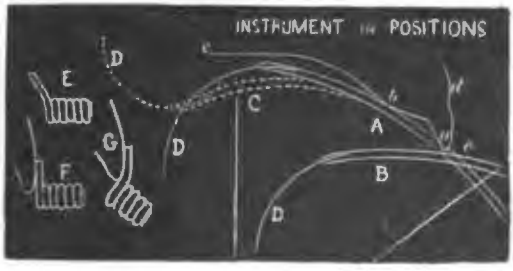

FIG. 243.

The tube *A* is rested against the edge of the teeth (Fig. 243, *a*) and the hard palate (Fig. 243, *b*). The wire is pushed out until it touches the tongue, which is held in the desired position. The instrument is then applied to a plaster mold

[1] ATKINSON, *Methods of mouth-mapping*, Neuere Sprachen, 1899 VI 494.

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of the mouth cut in half sagittally, and the position of th point of *C* is marked on the diagram. The position of th tooth-stop shown at *G* in Fig. 243 slightly lowers the dire tion of the tube in the mouth; that at *F* in Fig. 243 directs as shown at *DB* so as to measure the front cavities in bac vowels. The dotted outline *C* in Fig. 243 shows a modific tion for measuring the position of the velum. A series sagittal diagrams of the sung vowels obtained with this instr ment is shown in Fig. 244. Th

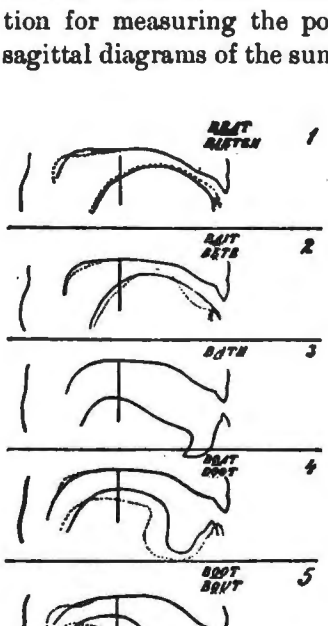

FIG. 244.

diagrams indicate the tongue pos tions for the following vowels 1. ī as in **bīt** 'beat' (——— and an attempt at ī as in Germa **bītn** 'bieten' (. . . . .); 2. ē a in **bēit** 'bait' (———) and a attempt at ē as in French **bē** 'bête' (. . . . .); 3. ā as in **bā** 'bath'; 4. ō as **bōut** 'boat (———) and an attempt at ō a in German **bōt** 'bot' (. . . . .) 5. ū as in **būt** 'boot' (——— and an attempt at ū as in Frenc **bū** 'bout.' A comparison of thes diagrams with those of Plate XVIII to XXVI shows in gen eral a closer resemblance of thes British positions to HOCH DÖRFER'S German positions tha to GRANDGENT'S American ones

Little hollow rubber bulbs of any desired form[1] (Fig. 245 can be introduced into the mouth to record by air transmissio (p. 195) the pressure or tenseness of the tongue at a give point. They may be called 'exploratory bulbs.'

In Italian the relations of pressure of the tongue below th rear part of the palate were found[2] for one person to b

[1] ROUSSELOT, Principes de la phonétique expérimentale, 86, Paris, 1897.

[2] JOSSELYN, *Étude sur la phonét. ital.*, 40, 91, Thèse, Paris, 1900; also in La Parole, 1901 III 41.

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p > b > m; also postpalatal, t > d > n > l; mediopalatal, the same; alveolar, n > t > d. For another they were: postpalatal, t > n > l = d; mediopalatal, d > n > t > l; alveolar, t > d > l > n; postpalatal, k > g; mediopalatal, č slightly > ǰ; postpalatal, š > ž; labial, v > f; postpalatal, v > f; mediopalatal, š > z > s; postpalatal, p > b ≷ m; labial, p ≷ m > b. The differences in the position of the tongue and its pressure against the teeth in d and t and their variations in different positions, as shown[1] in Fig. 246 for the words dido, tito, were recorded by a bulb behind the teeth. The records would seem to indicate differences among consonants usually considered the same that are not inferior to those found among the varieties of a vowel. Such

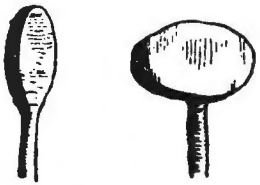

FIG. 245.

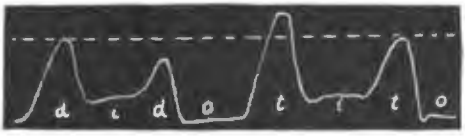

FIG. 246.

records indicate not only differences in pressure but also in the character and extent of the movement.

Records for the Italian vowels[2] of eight subjects showed that the tongue did not rise so high in the middle of the mouth for the first vowel as for the second in ama and similar words, indicating the existence of two forms of a (Fig. 247). Similar records showed that there were three forms of e, two of i, three of o and two of u (Figs. 248 to 250). These vowels are found in a_1ma_2, $kre_1de_2re_3$, i_2ni_1, fi_2ni_1 of one person, fi_1ni_2 of another, $po_1po_2lo_3$ ($o_1 = ɔ$?), $virtu_1$, ru_2more; their palat-



FIG. 247.

[1] JOSSELYN, as before, 35.

[2] JOSSELYN, as before, 13.

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ograms have been given above (Figs. 216 to 220). The elevation of the tongue throughout the word i_2ni_1 is shown in



Fig. 248.

Fig. 251. With an exploratory bulb in the rear of the mouth the word **popolo** gave the tracing shown in Fig. 252. The first **p** hardly appears at all; this is due to the fact that while



Fig. 249.

the articulation for **p** is made at the lips, the tongue has the **o** position. The rise of the tongue during the second **p** appears clearly, and that for **l** strongly. The three **o**'s have

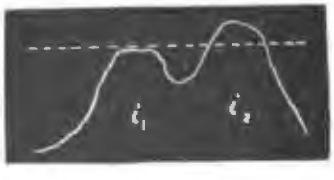

Fig. 250.

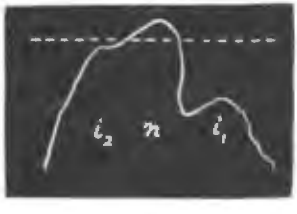

Fig. 251.

successively higher tongue positions. The **o-l** glide shows a considerable rise of the tongue; it is heard as a kind of **u**; the record shows it almost as a distinct sound.

The total elevation of the tongue may be conveniently registered by turning the artificial palate into a tambour *by*

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covering it with a sheet of thin rubber and attaching an outlet tube.[1] It may be called a tongue-tambour.



FIG. 252.

The elevation of the tongue may be indicated by a receiving tambour with a knob attached so that it rests under the soft portion of the chin;[2] the mylohyoid, geniohyoid and digastricus (p. 234) muscles contract to support the tongue in action. The apparatus is shown in Fig. 253. The tambour *M* is held in place by the set of adjustable rods and clamps *P S K* attached to the band *I* at *J* and by the set *A B* attached at *C*. The knob *T* is moved by the contraction of the geniohyoid and transmits the motion in the usual way by a lever with the fulcrum *F* to the rubber top *L*. The screw *O* affords finer adjustment. This apparatus does not interfere with the resonance of the mouth as the exploratory bulb (Fig. 245) does.



FIG. 253.

For the French vowels spoken by ROUSSELOT[3] the relative degrees of elevation of the tongue as indicated by the tongue-tambour are given in Figs. 254, 255, 256, and those by the geniohyoid tambour in Figs. 257, 258, 259.

[1] ROUSSELOT, *Les modifications phonétiques du langage*, 11, Rev. pat. gallo-rom. 1891 IV, V; also separate.

[2] ROUSSELOT, *Les mod.*, as before, 11; Principes de la phonétique expérimentale, 95, Paris, 1897.

[3] ROUSSELOT, *Les mod.*, as before, 29.

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A series of records of Dutch sounds showed [1] for a almos
no increase of tension in the mouth floor, for u a strong
increase, for o somewhat less, for i a very great increase, fo

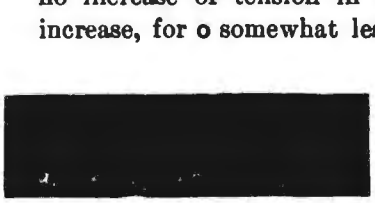

FIG. 254.

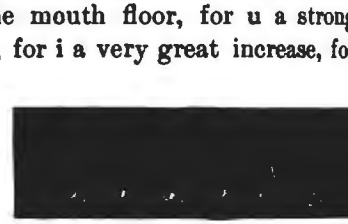

FIG. 255.

e somewhat less — the order of increase being thus a, o
u, e, i; for t, d, n strong increase; for velar sounds
relaxation.

The flapping of the tongue in producing a rolled r inter



FIG. 256.



FIG. 257.

rupts the breath as it passes through to the mouth. A closely
fitting mouth-piece connected with a tambour (p. 219) may
be used to record the rolls or pseudobeats (pp. 19, 44).
The German r was found in one case [2] to have usually from



FIG. 258.



FIG. 259.

20 to 35 beats a second; in initial positions usually 3 (4 or 5
in especially distinct speech); medially 2 after a long vowel
3 after a short one; before a consonant or as a final sound

[1] GALLÉE UND ZWAARDEMAKER, *Ueber Graphik d. Sprachlaute*, Neuer
Sprachen, 1900 VIII 17.

[2] VIETOR, Elemente d. Phonetik, 4. Aufl., 208, Leipzig, 1898.

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ıly 1. Tambour records by HERMANN[1] showed that the equency of the rolls varied greatly. The uvula r had often higher frequency than the tongue r. WENDELER[2] found his speech curves that for his German tongue r the itch of the cord note during the r had no influence on ıe frequency of the roll unless the note was made loud, ıd that loud cord notes raised the frequency of the roll. WAARDEMAKER'S tambour records[3] led him to conclude ıat for his Dutch r the period of the roll was regularly a ıultiple of the period of the cord tone. Such a harmonic elation points to an almost inconceivable preference of the ar for a simple relation between the period of the beat, vhich is distinctly heard, and the period of the physical tone-ibrations, which are not heard separately but as a simple ensation of tone. We cannot, however, always trust the ambour records of the cord tone.

The tongue in action may be observed by means of the RÖNTGEN rays.[4]

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For studies of tongue action: see REFERENCES to the preceding chapters.

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[2] WENDELER, *Ein Versuch, d. Schallbewegung einiger Konsonanten u. anderer Geräusche mit d. Hensen'schen Sprachzeichner graphisch darzustellen*, Diss., Kiel, 1886; also in Zt. f. Biol, 1887 XXIII 303.

[3] ZWAARDEMAKER, *Le registre de l'R*, Archives néerlandaises des sci. exactes et nat., 1899, (2) II 257.

[4] SCHEIER, *Die Verwerthung d. Röntgenstrahlen f. d. Physiol. d. Sprache u. Stimme*, Arch. f. Laryngol., 1898 VII 116; *Ueber d. Bedeutung d. Röntgenstrahlen f. d. Physiol. d. Sprache u. Stimme*, Neuere Sprachen, 1898 V Phonet. Stud. 40.

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CHAPTER XXV

PHARYNX, NOSE, VELUM, LIPS AND JAW

THE *pharynx* (*CC'*, Fig. 93) acts as a resonating cavity in communication with the oral and nasal cavities. Its main period of free vibration (p. 2) depends on its capacity and on the sizes and shapes of its laryngeal, oral and nasal apertures (p. 281). The condition of the pharyngeal walls influences the factor of friction (p. 5) and thus produces changes of auditory timbre (p. 96). Owing to its irregular shape the main free vibration may be accompanied by accessory ones their relations in period and intensity to the main vibration also produce effects of timbre. Changes in shape without change in capacity may thus affect the timbre. Observations on the changes in timbre in song and speech brought about by diseases of the pharnyx have been frequently made; the results have always been stated in vague terms; the attempts at explanation have been unsuccessful; no experimental data have been collected.

The separation of the upper (nasal) from the lower (oral) portion of the pharynx is a complicated act, requiring accurate muscular adjustment. The contraction of the superior constrictor (*1*, Fig. 101) forms a ridge; the velum rises through contraction of the elevators of the velum (*b*, Fig. 97). The pharyngopalatine (*3*, Fig. 97) and the glossopalatine (*H*) muscles act as antagonists to the elevators and serve to give an angular form to the velum during speech, whereby the front part is more nearly horizontal and the rear part more nearly vertical; they pull the velum down on relaxation of the elevators, and the pharyngopalatines pull it forward. Con

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raction of the pharyngopalatines raises the larynx and the harynx wall and also narrows the pharyngopalatine arch. The regulation of the action of these muscles in song and peech is mainly, or wholly, auditory, that is, by the sound roduced.

The *nasal cavity* on each side (*A*, Fig. 93) communicates vith the upper part of the pharynx by an opening of fixed ize called the *nasopharyngeal meatus* or *choana* (just in front f *9* in Fig. 93). The nasal cavity on each side is to a large xtent filled with three *turbinal bodies* (*2*, *3*, *4*, Fig. 93) of ery irregular form; it opens in front at the *nostril* (*n*, Fig. 3). The entire cavity is lined with mucous membrane. Several *accessory nasal sinuses* (two of them shown at *a* and in Fig. 93) have small openings into the nasal cavity.

The bone and cartilage walls of the nasal cavities adapt hem well to act as resonators in connection with the pharynx. Since the capacity and the apertures are practically fixed at ny moment, the effect on the vocal sounds is a constant actor that enters into the adjustments.

Typical groups of sounds are produced by changing the connections of the pharynx with the nasal and oral cavities, nd by altering their apertures.

With the lips open and all cavities connected, the nasal vowels (such as a^n, o^n, $œ^n$, e^n in French) are produced.

With the upper part of the pharynx and the nasal cavity ut off by closure of the velum across the pharynx and with he lips open the pure vowels (such as a, e, i, o, u, ə, ɔ) are ormed in the oropharyngeal cavity.

When the oral cavity is cut off from the pharynx by the velum or tongue, the nose acts with the pharynx as a complex cavity. This is the case in the groups of sounds characterized by n, ñ, and ŋ. The sound ñ is a regular one in French and Italian (Ch. XXIII). As it is usually lacking in in English and German it will be omitted in the following discussion. In respect to articulation it can be considered as intermediate between n and ŋ.

With the lips closed, the oropharyngeal cavity open, and

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pharyngonasal cavity free, the sounds produced belong to the **m** group.

When one nostril is closed during the pronunciation of **m, n, ŋ**, hardly any difference is noticed in **m**, more in **n** and most in **ŋ** without loss of distinctive character. When both nostrils are closed, these sounds come to an end owing to the stoppage of breath, but without becoming **b, d, g** (for which the velum cuts off the upper pharyngeal and nasal cavities). When the entire nasal cavity is filled with cotton[1] or when one of the choanæ is closed (no observations yet reported on both) by a membranous growth[2] the **m, n, ŋ** characteristics are still retained.

When the oropharyngeal cavity is closed by the lips or tongue and by the velum across the pharynx, the sounds of the **b, d, g** class are produced. They come to an end owing to the lack of an opening for the escape of the breath, whereby the blast that operates the vocal cords is gradually reduced to zero.

With large adenoid growths in the nose the speech changes greatly; the result is known as the 'dead voice' of the adenoid patients;[3] **m, n, ŋ** approach but do not merge into **b, d, g**. The filling of the nasal cavities in 'colds' changes **m, n, ŋ** toward **b, d, g**. On the other hand the removal of a large single nasal polyp which leaves a cavity behind gives to the voice for a time a hollow, or 'amphoric,' character. When the accessory nasal sinuses become filled, the voice acquires a 'dead' character.

With a tube inserted through the corner of the mouth and passed behind the place of closure, **m** and **n** are produced instead of **b** and **d** when the velum is closed across the pharynx.[4]

[1] SÄNGER, *Akustische Wirkung der Nasenhöhlen*, Arch. f. d. ges. Physiol. (Pflüger), 1896 LXIII 301.

[2] ZWAARDEMAKER, *Sur les sons dominants des resonnantes, avec quelques observations sur la voix morte des adénoïdiens*, Archives néerland. des sci. exactes et nat., 1899 (2) II 253.

[3] MEYER, *Ueber adenoide Vegetationen in d. Nasenrachenhöhle*, Arch. f. Ohrenheilk., 1873 VII 241, 1874 VIII 129.

[4] SÄNGER, as before.

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The following view of the action of the nasal cavity in vocal sounds seemed justified by the foregoing observations.

The lower resonance tones of m, n, ŋ depend on the size of oropharyngeal cavity and on its apertures. On account of the decreasing size of the cavity behind the closure we should expect the lowest tone for m (labial closure), a somewhat higher one for n (alveolar or palatal closure) and a still higher one for ŋ (velar closure). KŒNIG'S flames (p. 27) and HERMANN'S curves (p. 44) give the same tone for m and n; no data are at hand for ŋ. For the lowest tone we may suppose the nasal cavities to act as two necks of fixed size, shape and conductivity to the pharyngeal resonator. The size and shape can probably be taken as those at the choanæ; the conductivity depends mainly on the amount of free space in the nasal cavities. The differences between the lower cavity tone in m, n, ŋ and that in b, d, g cannot yet be definitely explained. The addition of the upper portion of the pharyngeal cavity in the former case would give a lower tone, the addition of the nasal necks a higher one; the final effect is probably a higher tone. Increasing stoppage of the nasal cavities would lower the tone of m, n, ŋ; with complete stoppage it would be lower than that of b, d, g unless other adjustments were made.

The higher resonance tones of m, n, ŋ are influenced by the various cavities into which the turbinals divide the nasal passages, by the condition of the mucous membrane, by additional cavities present in the accessory sinuses and by the character of the walls. These higher tones are markedly characteristic of different voices and different conditions, but experimental data concerning them are entirely lacking.

Similar considerations are probably valid for the nasal vowels.

The rise and fall of the velum affects the character of the vocal sound.

Observations with RÖNTGEN rays[1] showed that the velum

[1] SCHEIER, *Die Verwerthung d. Röntgenstrahlen f. d. Physiol. d. Sprache u. Stimme*, Arch. f. Laryngol., 1897 VII 125; *Ueber d. Bedeutung d. Röntgenstrahlen f. d. Physiol. d. Sprache u. Stimme*, Neure Sprachen, 1898 V Phonet. Stud. 40.

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rises for the vowels in the order a, e, o, u, i, that for a it does not rise to the line of the hard palate, and that for u and i it forms an arch up into the nasal cavity. For consonants, except the liquids, it rises higher than for i. For occlusives like b and k it flies up and falls at once. For fricatives like f and v it does not rise as high as for the occlusives. For m, n and ŋ, it rises only a little from the position of rest. For nasal vowels there is little or no movement. Rise in pitch or increase in intensity of the cord tone is accompanied by rise of the velum.

The tightness of the closure between the velum and the pharynx wall can be tested by putting water into the nose; this is best done by inserting a thin elastic rubber tube far into the nose and, the head being bent back, injecting water at the moment of producing a vowel. According to SCHUH[1] the closure is complete for i but not for a. CZERMAK[2] found that in speaking a the water ran down into the throat, that in speaking i the water collected and was easily retained for a considerable time, and that u and o resembled i in this respect, but e less so. The difference in tightness is presumably due to the difference in the angle which the palate makes with the pharynx wall.

In order to determine if air issues from the nose in speaking a sound, a cold polished surface — a mirror or knife blade — may be placed at the proper moment under the nose; the faintest trace of breath is indicated by moisture on the surface.[3] In the production of the pure vowels no air issues from the nose; any trace of a nasal tone is accompanied by emission of air.

To detect any passage of the air through the nose it can be

[1] SCHUH, *Die Bewegung d. weichen Gaumens b. Sprechen u. Schlucken*, Wiener med. Wochenschr., 1858 VIII 33.

[2] CZERMAK, *Ueber das Verhalten des weichen Gaumens beim Hervorbringen der reinen Vokale*, Sitzb. d. k. Akad. d. Wiss. Wien, math.-naturwiss. Kl., 1857; also in CZERMAK's Gesammelte Schriften, I 425, Leipzig, 1879.

[3] CZERMAK, *Ueber reine u. nasalirte Vokale*, Sitzber. d. k. Akad. d. Wiss. Wien, math.-naturwiss. Kl., 1858 XXVIII 575; also in CZERMAK's Gesammelte Schriften, I 464, Leipzig, 1879.

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made to act upon a small flame[1] by inserting into the nostril a nipple connected to a rubber tube ending in a glass tube with a small opening.[2] The slightest trace of air produces a fluttering of the flame.

A person with the velum grown to the pharynx wall so that no air could pass through the nose was able to produce the pure vowels but not the nasal ones.[3] The sounds m, n and ŋ could not be pronounced, but were replaced by somewhat similar sounds produced by keeping the cords in vibration while using mouth movements similar to those for b, d and g, but with the least possible noise in the closure and opening.

GENTZEN'S[4] direct observations through a cavity agreed essentially with those of CZERMAK. A really considerable pressure with a rod was required to press down the velum from above during speech. A stylus resting on the velum was made to record on a smoked plate.

According to records by GUTZMANN[5] in a case where the top of the velum was accessible, owing to removal of the upper jaw, etc., the velum was pressed more or less firmly, but always tightly, against the rear wall of the pharynx in all vowels and consonants except m, n and ŋ, while a cross ridge was plainly apparent just above the closure; the rise of the velum was least for a, greater for ɔ and o, still greater for e and u, greatest for i; for consonants the velum was raised at least as high as for i and generally higher, except for m, n and ŋ, for which it remained quiet; high or loud tones were accompanied by greater rise. The natural action

[1] BRÜCKE, Grundzüge d. Physiol. u. Systematik d. Sprachlaute, 2. Aufl., 37, Wien, 1876.

[2] SIEVERS, Grundzüge d. Phonetik, 5. Aufl., 53, Leipzig, 1901.

[3] CZERMAK, *Einige Beobachtungen ü. d. Sprache bei vollständiger Verwachsung d. Gaumensegels mit der hinteren Schlundwand*, Sitzber. d. k. Akad. d. Wiss. Wien, math.-naturwiss. Kl., 1858; also in CZERMAK'S Gesammelte Schriften, I 468, Leipzig, 1879.

[4] GENTZEN, *Beobachtungen am weichen Gaumen nach Entfernung einer Geschwulst in der Augenhöhle*, Diss., Königsberg, 1876.

[5] GUTZMANN, *Die geschichtl. Entwick. d. Lehre v. d. Gaumensegelbewegung beim Sprechen u. s. w.*, Monatsschr. f. d. ges. Sprachheilk., 1893 III 217.

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may have been somewhat disturbed owing to the extensive surgical operation.

The rise and fall of the velum can be indicated by its action on a lever inserted through the nose.[1] A straight iron wire about 200^{mm} in length and 1.8^{mm} in diameter has a loop of 12^{mm} formed on the side at one end and covered with wax. A piece of 40^{mm} in length at the other end of the wire is bent at right angles to the staff but in the plane of the loop. The wire is inserted through the nose so that the edge of the loop rests upon the rear edge of the velum. Any rise of the velum raises the edge and turns the wire; the amount of turning can be seen in the movement of the projecting arm in front. With this indicator CZERMAK showed that the velum occupied a different position for each vowel; the rise of the velum (from higher articulation with the back of the pharynx or else from greater curving) was greatest for i, somewhat less for u, considerably less for o, much less for e and nothing or almost nothing for a. With the consonants the rise was the greatest for the surd occlusives (p, t, k), the velum evidently being raised passively by the air pressure. With sonant occlusives (b, d, g) the rise was a trifle less, the pressure being evidently not so great. With the surd and sonant fricatives (f, s, š, ç, χ; v, z, ž, j, γ) the velum acted in the same way as for the stops, the rise, however, being in all cases less than for the corresponding occlusives. For the l-sounds the rise was less than for the fricatives, a distinct movement being observable, for example, in passing from l to s. For tongue r the rise was greater than for uvula r.

A simple light rod inserted through the nose and pivoted by a thread from a band on the forehead may be made to record directly on a smoked drum the rise and fall of the velum.[2]

[1] CZERMAK, *Ueber das Verhalten des weichen Gaumes beim Hervorbringen der reinen Vocale*, Sitzber. d. k. Akad. d. Wiss. Wien, math.-naturwiss. Kl., 1857; also in CZERMAK's Gesammelte Schriften, I 423, Leipzig, 1879.

[2] ALLEN, *On a new method of recording the motions of the soft palate*, Trans. Coll. Phys. Philadelphia, 1884 (3) III; summarized in Internat. Zt. f. allg. Spr., 1885 II 287.

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A small plaster knob on a light wire from a MAREY tambour attached to the forehead may be inserted into the mouth and attached to the velum.[1] A record of the rise of the velum during the word 'contabulate' spoken with three degrees of rapidity is given in Fig. 260. It shows the sudden rise for **k**, the partial relaxation during **a**, the fall for **n**, the rise for **t**, the slight relaxation for **æ**, and the rise maintained during **bjulet**. Fig. 261 shows a record for 'con — tra — vene — contra — contravene;' the fall during **a** is nearly as great as that for **n**, indicating a decidedly nasal **a**. Fig. 262 shows a record for 'pant — banana — blanch — branch — can't.' In 'pant' the velum makes two distinct movements. In 'banana' the last two vowels involve only a slight rise above the position for **n**; they are strongly nasal. In 'blanch' and 'branch' the relaxation for **n** is complete. The accented vowel in these five words was **æ**. Fig. 263 shows 'hand' spoken with extreme slowness; the rise for **h** and that for **d** are clear; the semiclosure between them indicates as much nasalization for **æ** as for **n**. Fig. 264 shows the phrase 'into Mount Ætna' whispered and then spoken; the action of the palate is practically the same in both cases. Fig. 265 gives the record for the French $œ^n$ 'un' spoken three times by a native and then for a^n 'an' likewise three times;



FIG. 260.



FIG. 261.



FIG. 262.



FIG. 263.



FIG. 264.



FIG. 265.



FIG. 266.

[1] WEEKS, *A method of recording the soft palate movements in speech*, Studies and Notes in Philol. and Lit., Harvard, 1893 II 213.

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Fig. 266 gives similar records for o^n 'on' and e^n 'in'; in all cases there was a movement of the palate *forward* from its place of rest.

The relaxation of velar closure across the pharynx allows the upper pharyngeal and the nasal cavities to influence the sound. This gives the sound an auditory characteristic called — not quite accurately [1] — 'nasalization.' This characteristic consists in changes in the cavity tones of the speech sounds. For a given position of the vocal organs the opening of the upper pharyngeal cavity will add tones due to the size of the cavity and the nature of the apertures; it will also necessarily modify some of the tones of the mouth on account of the additional aperture and the reciprocal action of connected cavities. Thus, a^n will differ from a formed by the same positions of the tongue, lips, etc., not only in having additional cavity tones, but also in changing the mouth tones. To retain the mouth tones unchanged to the ear, the tongue, lips, etc., must make readjustments; this is perhaps the explanation of the fact that for the sound heard as o^n ROUSSELOT finds the tongue position varying from o_1 (p. 315) to o_3 (p. 320).

The action of the velum may be conveniently studied by comparing the record of the breath curve from the nose with that from the mouth. A nasal olive of convenient size (Fig. 88) is connected with a small tambour, and a mouth trumpet (p. 219) with another one; the two tambour points are synchronically registered. When the velum is closed completely across the nasal passage, the recording point is at its position of rest and usually no vibrations appear in the line it draws. As the velum falls, air passes through the nose, the recording point rises and, if delicately adjusted, registers the vibrations from the larynx that may be present; the extent to which the point rises depends on the amount of air issuing from the nose, that is, on the size of the opening between the velum and the pharynx-wall. When vibrations do

[1] SÄNGER, *Ueber d. Entstehung d. Näselns*, Arch. f. d. ges. Physiol. (Pflüger), 1897 LXVI 467.

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appear in the nasal tracing without any rise of the line to indicate exit of air, they are often due, I believe, to the fact that the vibrations in the mouth set the velum itself (and consequently the air above it) in vibration without any relaxation of the closure.

In interpreting the records, it must ever be borne in mind that the inertia of the recording levers distorts them; thus a *constant* emission of air from the nose during n will show itself as a somewhat *gradual* rise of the lever, while a sudden strong one from the mouth, as in p, will give a sudden rise. It must never be forgotten that the scale of rise is not proportional, but that a considerable rise of the lever from rest indicates only a small emission, while a small increase in rise beyond this indicates a great increase in emission.



FIG. 267.

Ordinarily the vocal cords cease to sound when the vowel position is relaxed before a pause; the surplus air is then expelled noiselessly (p. 224). In some dialects the cords are still sounding when the position is relaxed; the opening of the nasal cavity then gives a nasal twang to the sound.[1] Records showing this fact have been made by ROUSSELOT.

Investigations by the above method [2] have been made on Italian sounds. In Figs. 267 to 273 the upper record is from the nose, the lower one from the mouth. In ma and na the nasalization includes not only the liquid but, to a less degree, the entire vowel, especially its close (Fig. 267). The vibrations in the tracing indicate that the velar move-

[1] ROUSSELOT, Principes de phonétique expérimentale, 240, Paris, 1897.
[2] JOSSELYN, *De la nasalité en italien*, La Parole, 1899 I 602.

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ment finished before the cord action did, thus giving a special nasal twang to the end of the vowel. This relaxation of the velar action before that of the cord action is analogous to that of the tongue action in English long vowels whereby they frequently acquire a 'diphthongal' character.

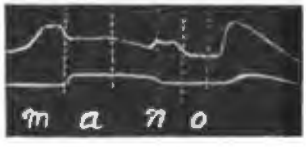

Fig. 268.

The record for **mano** (Fig. 268) shows the nasal current of air during **m**, the mouth current and the smaller nasal one during **a**, the increased nasal current during **n**, the cessation of this current during **o**, and the expulsion of surd air from both nose and mouth after the laryngeal vibrations have ceased.

The explosion of **t** in **ta** (Fig. 269) seems to have been accompanied by a fall of the velum in JOSSELYN'S records; this does not, I believe, indicate any nasalization, as JOSSELYN asserts, but only a sudden relaxation of the tense curvature produced by the pressure of air and a rebound of the recording lever; the bend in the line at this point in JOSSELYN'S figure is just what would be expected from such action. For **p** in **pa** a considerable emission of air is indicated at the moment of the explosion of **p**; this is due, I believe, to the fact that the vowel **a** (which is somewhat nasalized) begins ap-

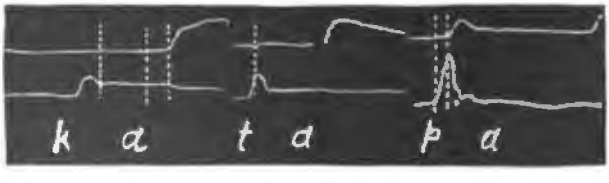

Fig. 269.

parently during the rush of air in the explosion of **p** (p. 45). The **k** of **ka** shows no disturbance in the velar record. During **l**, **r**, **g**, **d**, **b**, **z** of **la**, **ra**, **ga**, **da**, **ba**, **za** the nasal line shows vibrations without any deflection from the point of rest; as stated above, these vibrations indicate, I believe,

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the transmission of vibratory movements and the roll of the r to the velum and thus to the nasal cavity, but no relaxation of velar closure; JOSSELYN's deduction of nasalization for these sounds is, I believe, incorrect. During f of fa a small rise was noted in the nasal line, indicating a slight escape of air through the velar closure.



FIG. 270.

In the record for 'nessuno' (Fig. 271) the full opening of the nasal cavity is seen for n; the e is considerably nasalized throughout, but most strongly near the end; the glide from e to s closes the nasal cavity entirely and the mouth somewhat; the glide from s to u is marked by a slight explosive puff from the mouth and then an almost complete closure; the u shows a steadily increasing stream from the mouth and the glide from u to the n a steadily decreasing one; the u is without nasalization; the u-n glide is strongly nasalized; the n is nasal as before; the o is slightly nasalized. Records of

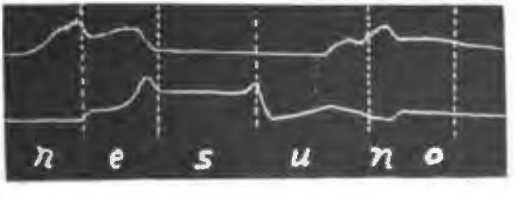

FIG. 271.

'menare,' 'mentire' and 'mandare' are given in Fig. 272. The m is of nearly constant length. The first n is very short, the second more than 3 times, and the last about 3 times as long; similar results show a long n in 'infante,' 'imperare,' 'inni,' 'mente,' and a short n in 'onore,' 'nes-

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suno,' 'mano,' 'tenere.' The results show that n at the end of a syllable is stronger and longer, while at the beginning and after an open syllable it is feebler and shorter. Rejecting the usual view of the nature of a word as made up of series of separate pieces called 'syllables,' I would give the explanation that in the flow of speech the n forms part of the vowel material that with the consonant movement goes to make up the content between centroids of stress, and that for intervals of equal stress-effect its length is varied just as those of the vowels to produce equal amounts of auditory and motor work. The tendency of Italian to velar relaxa-

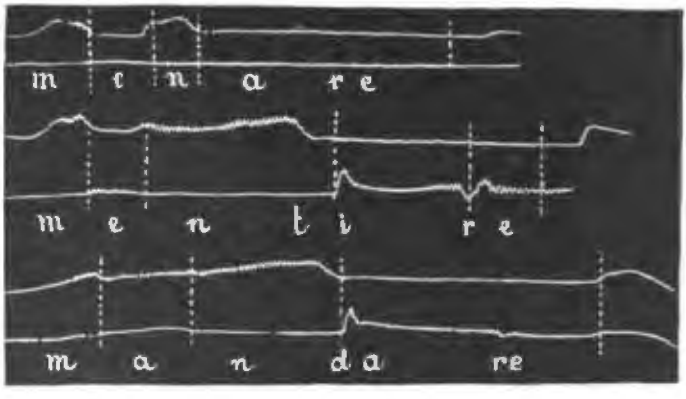

FIG. 272.

tion, that is, to nasality, has been conclusively proved by JOSSELYN, whose records show many nasalized vowels, occlusives and fricatives.

JOSSELYN found[1] that in Italian the nasalization required for a 'nasal' regularly extended to the neighboring sounds and sometimes to the entire word, and that after a vowel the m and n might take a form intermediate between the vowel and the usual m or n.

An interesting and not uncommon pronunciation[2] is indi-

[1] JOSSELYN, *Étude sur la phonétique italienne*, 139, Thèse, Paris, 1900; also in La Parole, 1900 II 179.

[2] JOSSELYN, *Étude*, as before, 139.

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cated in Fig. 273. Here the first n has disappeared, as is proved by the fact that there is no oral occlusion, the vowel being strongly nasalized and merging immediately into the f. This is an approach to the character of a French nasal vowel.

As already pointed out (p. 346), ' nasality ' is an auditory term indicating the presence of tones from the nasal cavity. These tones regularly arise when the rear nasal passage is more or less open.

In a nasal breath record any such opening indicates itself by a rise in the course of the curve. Just how great an effect on the speech sound may arise from the transmission of laryngeal vibrations through the velum when entirely closed across the nasal passage, it is impossible to say. It may per-

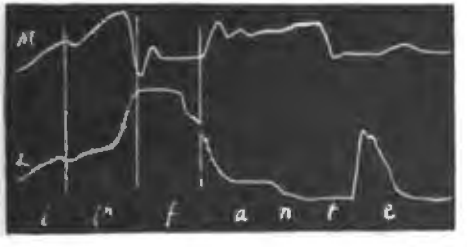

FIG. 273.

haps be tested by stopping the front nasal opening while a vowel is sung, and by having other persons listen for the presence of any change. In an absolutely unnasalized vowel I am unable to observe any difference.

The vibrations in the nasal line indicate vibrations of the air due to the cord action; their appearance indicates either transmission through the velum (p. 347), while still closed against the pharynx wall, or transmission through a velar-nasal opening. In the former case they might perhaps give rise to a faint nasal tone, although this is doubtful. In the latter there is a velar-nasal opening whose size would bear some relation — but no simple one — to the amplitude of the registered vibrations. The auditory effect would be ' nasalization,' properly so termed. In a tight tambour system, how-

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ever, any such nasalization must be accompanied by a rise in the nasal line; the presence of vibrations without such a rise indicates either the transmission of vibrations through the velum without opening (as indicated above), or a leak in the apparatus.

The absence of vibrations from the nasal tracing does not indicate absence of nasal cavity tones; no cavity tones of any kind ever appear in tambour tracings. As long as the cords vibrate, any opening of the velar-nasal passage will be accompanied by nasal resonance.

When there is no cord tone, the opening of the nasal passage is accompanied only by the noise of the escaping breath, which at most can make only a soft h-like sound during speech and cannot ordinarily be heard. The relative weak-

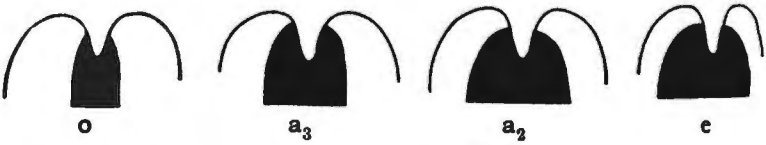

FIG. 274. FIG. 275. FIG. 276. FIG. 277.

ness of such a nasal explosion may be made apparent by pronouncing 'cat' and 'cap' first with the regular mouth explosion and then with a nasal explosion, the mouth being kept closed. An explosion by dropping the velum cannot be made strong enough to be heard when the mouth passage is already opened, as in vowels. This 'surd nasality' occurs as a nasal modification of explosives and fricatives.

The positions of the pillars of the velum (glossopalatine and glossopharyngeal arches) have been carefully observed and drawn by THUDICHUM[1] for his Swiss-French vowels: o as in '*o*r, f*o*rt, s*o*tte, f*o*rte' (Fig. 274); a_3 (close) as in '*p*âte, t*a*sse, c*a*s' (Fig. 275); a_2 (medium) as in '*p*age, p*a*rt, p*a*pa' (Fig. 276); and e as in 'p*è*re, t*ê*te, p*e*rte, n*e*tte' (Fig. 277).

The positions and movements of the lips can be observed

[1] THUDICHUM, *La prononciation de l'a français*, Neuere Sprachen, 1897 IV Phonet. Stud. 22.

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directly and drawn; or they may be photographed by making an exposure at the proper moment. Lip-positions for various American and German sounds are given in GRANDGENT'S Plates XVII to XXVI at the end of this volume; they are freehand drawings of rather schematic character, often showing angles instead of curves.

The activity of the lips is frequently overlooked, although important results depend on the various degrees of lengthening the mouth-opening by retraction of the corners; of rounding by closing the lips except for an opening in the middle, or by pulling the corners toward the middle; and of projection with rounding, or without rounding. These variations in the opening and neck of the vocal resonator change the sounds greatly (p. 281). One special character of English sounds as compared with the corresponding German and French ones arises largely from the small movements of the lips.

The movements of the lips have been recorded by DEMENY, in a series of photographs taken with a kinetocamera;[1] one set of his views for 'Je vous aime' is reproduced by JESPERSEN.[2]

The kinetographic method has not yet been systematically applied to the study of lip movements in speech although it will presumably replace all others, because it leaves the speaker unhindered by apparatus attachments, and because it can be made with any required accuracy. A good registering kinetograph (or cinematographe) is focused on the lips of the speaker and the pictures are made at the rate of 40 or more a second. Before ending the experiment a millimeter scale is laid on the lips and also recorded. The film is developed by means of a special equipment, or is sent to a photographic company. The measurements may be made directly on the negative film, or on a blue print. A positive film may be made for projection. For finer measurements or

[1] DEMENY, *Analyse des mouvements de la parole par la chronophotographie*, C. r. de l'Acad. des Sci. Paris, 1891 CXIII 216; Journal de physique, 1893 328.

[2] JESPERSEN, Fonetik, Tavle I, Köbenhavn, 1897-99.

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for demonstration on a large scale the pictures can be greatly enlarged. In demonstrating the movements by projection the details can be studied by running the film slowly, after the manner employed for explaining surgical operations in medical schools.

The movements of the lips may be registered by a pair of light arms inserted into the mouth and attached to a MAREY tambour;[1] an open tube may be placed before the lips to register the breath pressure. Each lever may be made to register separately.[2] A complete instrument[3] is shown in

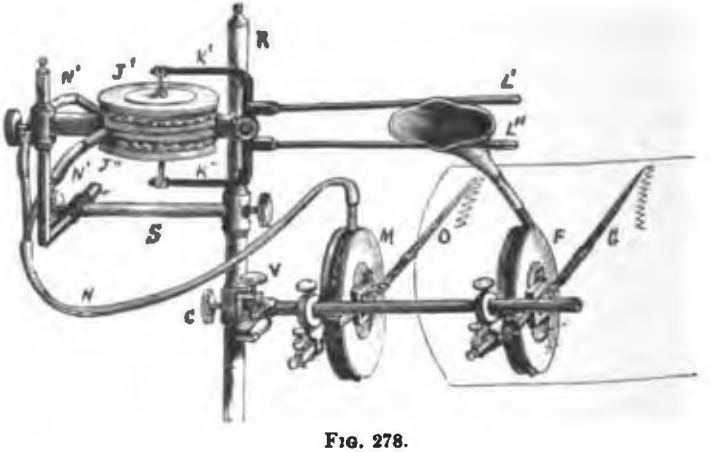

FIG. 278.

Fig. 278. The lips rest on the arms at L' L''. Any compression pulls out the tops of the tambours J' J'' by the arms K' K''; the movement may be transmitted to two separate registering tambours by the tubes N' N'' or to one tambour M by the joint tube N. The breath current is caught in the mouth-piece E and registered by the tambour F. The receiving apparatus is held on the rod R by the adjustable arm

[1] ROSAPELLY, *Inscriptions des mouvements phonétiques*, Travaux du laboratoire de M. Marey, 1876 II 119.

[2] ROUSSELOT, *Les modifications phonétiques du langage*, Rev. pat. gallo-rom., 1891 IV, V; also separate.

[3] ROUSSELOT, Principes de phonétique expérimentale, 92, Paris, 1897.

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S. The recording tambours *M* and *F* are placed on the MAREY support *V*, by which the contact of the recording points may be adjusted. This is likewise fastened to the rod *R* by the screw *C*. The two recording levers are adjusted to register synchronously on the drum.

The pressure of the lips may also be measured by a small rubber bulb (Fig. 245) between them. In Italian the relations of lip pressure have been found[1] to be **p** > **m** > **b** or **m** > **p** > **b**.

To register the lip projection a small tambour or an exploratory bulb may be rested lightly against the upper or the lower lip; any contraction of the muscle of the lip presses the air from the tambour.[2] As indicated by such a tambour, the lips in ROUSSELOT's labials are less completely and firmly closed for **v** than for **f**, and less firmly closed for **b** than for **p**, while for **m** the closure is like that for **b**. A bulb against the lips indicates[3] a greater projection for **u** than for **w** in Italian, as in the words **duo** 'duo' and **dwomo** 'duomo.' A cylindrical tambour or three small rubber balls may be used.[4]

The movements of the lower jaw may be registered by a small rubber bulb placed in the ear and attached to a tambour in the usual way. The arrangement is very convenient and fairly accurate, though not sensitive to very small movements.[5]

To register the movements of the jaw GALLÉE and ZWAARDEMAKER[6] used a movable arc connected to the lower jaw and supported on a framework attached to the head. The movements of the arc were recorded by air transmission with tambours.

In ventriloquism the movements of the lips and lower jaw are made as small as possible. The lower lip is slightly

[1] JOSSELYN, *Étude sur la phonet. ital.*, 91, Thèse, Paris, 1900; also in La Parole, 1901 III 41.

[2] ROUSSELOT, Principes de phonétique expérimentale, 93, Paris, 1897.

[3] JOSSELYN, as before, 115.

[4] GALLÉE UND ZWAARDEMAKER, *Ueber Graphik d. Sprachlaute*, Neuere Sprachen, 1900 VIII 16.

[5] GALLÉE UND ZWAARDEMAKER, as before, 11.

[6] GALLÉE UND ZWAARDEMAKER, as before, 17.

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drawn back and rested against the upper teeth. The tongue articulations are greatly altered.[1]

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For graphic apparatus for phonetics: Verdin, Paris. For tambours and manometers: Albrecht, Tübingen; Petzold, Leipzig; Zimmermann, Leipzig. For cinematographe camera: Lumière et ses Fils, Lyon-Montplaisir.

[1] Flatau und Gutzmann, Die Bauchredner-Kunst, Leipzig, 1894.

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CHAPTER XXVI

SIMULTANEOUS AND SUCCESSIVE SPEECH MOVEMENTS

By records of the breath curve from the mouth (p. 219) and the vibration of the larynx (p. 267) Rousselot[1] has shown that in the German pronunciation of pa and ba the larynx does not begin to vibrate till much later than in the French pronunciation. This is evident in the record shown in Fig. 279; the two upper lines are French pronunciations, the two

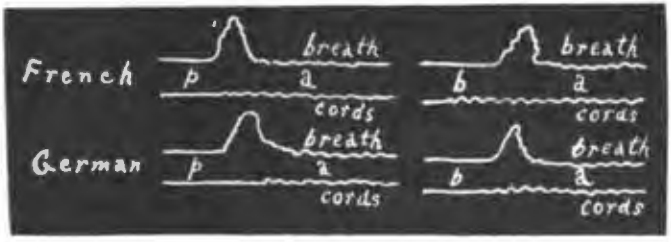

Fig. 279.

lower ones German. In French the p is surd with a sonant explosion; in German the explosion is also surd. In French the b is sonant during its last portion and during the explosion; in German only the explosion is sonant.

Similar records have been made[2] on an American. An example is given in Fig. 280. The breath line of pæt shows the explosion of p at *2*, a rush of surd air from *2* to *3* constituting the surd explosion of p, the vibrations of æ, and the

[1] Rousselot, *Applications pratiques de la phonétique expérimentale*, La Parole, 1899 I 401.

[2] Rousselot, *L'Enseignement de la prononciation par la vue*, La Parole, 1901 III 577.

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occlusion for t; the cord line shows quiescence during the occlusion of p, the advance of the thyroid cartilage from *2* to *3*, the beginning of the cord vibrations of æ at *3*, and their cessation for t. The p thus ends with an aspiration consisting in a rush of surd breath. The record for bæd shows sonancy

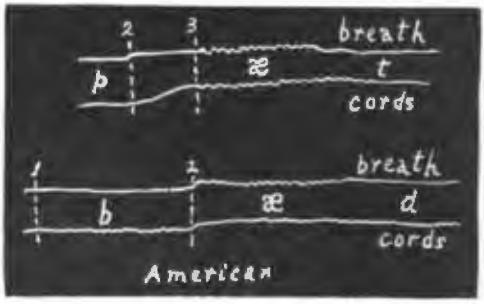


FIG. 280.

throughout the occlusion of b from *1* to *2*, a sonant explosion at *2*, followed by the curves for æ and d. The explosive rush of air is probably much weaker than for p. This set of records showed that p and t were regularly aspirated, but k not, and that b and d were sonant throughout their occlusions while g was either wholly or partially sonant.



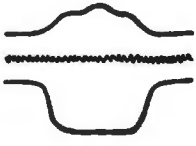
apa

FIG. 281.



aba

FIG. 282.



ama

FIG. 283.

ROSAPELLY registered simultaneously the lip closure with the apparatus mentioned on page 354, the cord vibrations by an electrical vibrating apparatus on the larynx, and the passage of the air through the nose by a tube inserted into it (Fig. 88). Records of French apa, aba and ama are given in Figs. 281 to 283 (upper line, nose; middle line, larynx; bottom line, lips).

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Using simultaneous registration for the larynx by ROSAPELLY'S electrical vibrator, for the nose by a tambour (p. 219) and for the lips by levers connected to a tambour (Fig. 278, without the mouthpiece), ROUSSELOT[1] obtained diagrams like that shown in Fig. 284. The curve from the nose indicates the issue of the air through velar relaxation (p. 346); upward movement in the larynx registration can be taken to show vibration of the cords, the single vibrations seldom appearing; in the lip curve *upward* movement shows *increase* in lip pressure.



FIG. 284.

Among the results obtained by ROUSSELOT for his own dialect of French — without consciousness of the peculiarities — the following may be noted (I have not specified the varieties of the vowels, a_1, a_2, a_3, etc., or their lengths); I have ventured to add physiological and psychological explanations for some of the phenomena.

The nasalization of a nasal vowel varies with the nature of the preceding sound, being complete for the initial position (as $a^n ta^n$) and after s, š and probably all the continuants (as in so^n, se^n, $ša^n trie$) but lacking in the first portions after p, b, t, d, k, g (as in $pa^n s$, po^n, ta^n, ka^n). In the case of the occlusives mentioned, the velum is closed. The explo-

[1] ROUSSELOT, *Les modifications phonétiques du langage*, Rev. des pat. gallo-rom., 1891 IV, V; also separate.

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sion usually occurs through the mouth; if the velum is opened instead of the mouth, the explosion is nasal; if both are opened, it is orinasal. If the cords do not sound during the explosion, there is a surd breath explosion. To produce a surd oral explosion the velum cannot open till the explosion is over; if it then opens before the cords begin to vibrate for the following vowel, a silent interval occurs. If the cords begin to vibrate during the oral explosion and before the velum opens, the result is a glide of the character of an unnasalized vowel. In the case of the sonant explosives the cords are already vibrating during the explosion and the occlusion must be followed by a non-nasal vowel glide unless the explosion is to be nasal. In the cases of s, š, etc. the vowel glide may be very short.

The consonants ž and z are nearly always surd in the middle though sonant at both ends (as in **eⁿžur** 'un jour;' **aza**, an artificial group), while v is nearly always completely sonant (as in **sivəvforsave** 'si vous vous forciez'). This may possibly be due to the elimination of the breath pressure in the larynx due to the obstruction in the mouth; the palatograms for z and ž (Figs. 206, 207) indicate rather considerable closure, but d and g have still more closure and are yet sonant. The cause is not to be sought in some association between articulation and lung pressure, as the lung action is not jerky.

Final sonants often become surd before they end, on account of the long pause for which the larynx prepares; thus in **eⁿžurkoɟaviynomeynfœm** 'un jour ça[=il]y avait un homme et une femme' the first m is entirely sonant while the second one, occurring just before a short pause, is half surd.

Surds between vowels may become sonants (as in **toⁿ-p•oⁿpoⁿ** 'ton pompon,' **ləp•yžen** 'le plus jeune,' **sap•ɔlav** 's'appelait'). This is due to the greater ease in maintaining the glottal position as compared with the double act of relaxing and then tensing the cords. This gain is mental; it saves two changes of volition with the necessity of auditorily verifying the results.

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Simultaneous sonation and nasalization of a surd were found in ' diable ton happeur,' which appeared in the records as ' **djabʌtuna^{n}p^{n}ur** ' (Fig. 285), the **p** actually becoming a nasalized sonant labial somewhat resembling **m**. The phenomenon is probably due in the first place to the avoidance of glottal readjustments, for the reason just stated, and in the second place to the greater ease of gradually closing the velum through **p^{n}** to **u** rather than very suddenly after **a^{n}**. The difficulty of the rapid velar action may lie not only in the movement itself but also in the dissolution of its association with cord action through the preceding sounds. In the following examples the ^{n} attached to the letter for an occlusive indicates velar explosion.



FIG. 285.

In groups of occlusives (**p**, **b**, **t**, **d**, **k**, **g**) with fricatives (**f**, **v**, **s**, **z**, **š**, **ž**) an initial surd remains such but an initial sonant often becomes surd (as in **kvuty** ' que veux-tu ? ' but **d$_{\circ}$fyra** ' refuser '). In the latter case there is a partial loss of cord action. In such groups between vowels there is most often an assimilation of the first consonant to the second in respect to sonancy, very rarely of the second to the first; sometimes

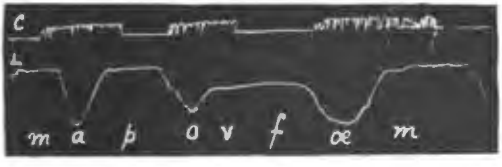

FIG. 286.

the two retain their values. Examples were found in: **ab$_{\circ}$ka** for **abka**, **pip$_{\circ}$zi** ' pipes-y,' **upik$_{\circ}$bəbje^{n}** ' il pique bien bien,' **kopus$_{\circ}$b$_{\circ}$je^{n}** ' ça pousse bien,' **puš$_{\circ}$bje^{n}** ' pouche [tousse] bien ! ,' **eb$_{\circ}$kvuty** ' eh bien ! que veux-tu ? ,' **fob$_{\circ}$$_{\circ}$pra^{n}dr** ' il faut bien prendre,' **pad$_{\circ}$kitpa^{n}** ' pas de quitte pain,' **e^{n}-led$_{\circ}$$_{\circ}$pyl** ' un lait de poule,' **žyg$_{\circ}$$_{\circ}$pəti** ' joue, petit,' **mo^{n}-**

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pov$_{o}$pəti 'mon pauvre petit!,' mapov$_{o}$fœm$_{o}$ 'ma pauvre femme!' as in Fig. 286, kœkinəbuz$_{o}$paso^{n}so 'celui-ci ne bouse pas son sol,' kunpuž$_{o}$pa 'qu'il ne puisse pas.' The surd forms of the sonants retain their mouth action and do not become the same as the corresponding surds, and conversely; thus b$_{o}$ remains distinct from p, p$_{o}$ from b, k$_{o}$ from g, etc. (pp. 304, 317).

When a surd is followed by l or m it *sometimes* becomes sonant. In many cases of tr and pr the t and p are sonant (as in up$_{o}$rətəna^{n}, 'ils prétendent').

In liquids the presence or absence of the cord tone during the whole or part of the sound varies from case to case.

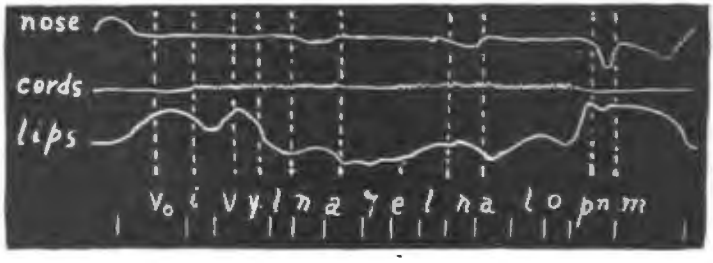

FIG. 287.

In general, initial or final liquids remain sonant or become half surd. Between a vowel and a surd the nasals m and n and also l, ʎ, r and ȷ are always sonant. Between a surd and a vowel they are almost always sonant, though ȷ has a marked tendency and r, l and ʎ a less tendency to become surd during part of the length.

In an investigation by ROUSSELOT [1] tracings of lip pressure (p. 354), larynx action (electrical vibrator, p. 267) and nasal breath (p. 219) were made on a native of Bonn, a native of Bütow (Further Pomerania) and a native of Hamburg.

Fig. 287 gives a record of the Pomeranian dialect for 'wir wollen nach Eldena laufen.' The dotted lines aid in com-

[1] ROUSSELOT, *Recherches de phonétique expérimentale sur la marche des évolutions phonétiques d'après quelques dialectes bas-allemands*, La Parole, 1899 I 769.

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paring corresponding points of the records. The approximate boundaries between the sounds I have tried to indicate by the vertical lines at the bottom. For v the beginning is indicated by the closing of the lips (rise in the lower line) and of the velum (fall in the upper line); the lack of vibrations in the middle line indicates that it is surd or that the cord vibrations are very weak; it is a very long sound. The lips open for i and the cords vibrate. The lips again close for v, which is this time sonant. The lips separate vertically again for y, still more for l, slightly less for n and most for a. The middle line indicates that y, l, n and the first part of a are sonant, the latter part of a being surd. The top line indicates complete closure of the velum during v_o, i, v, y and the first part o, l, and nasalization of the parts of l and a adjacent to the fully nasalized n. A pause with slight lip movement occurs between a and e. The lips come gradually nearer throughout e, l and the first part of n, open during a, close during l, open again during o, close suddenly for the implosion of p, relax slightly but do not open for the explosion of p, and remain closed during the last sound, which is thus m and not n as written. The nose line shows that the portions of l and a adjacent to n are slightly nasalized, and that the explosion of the p occurs entirely through the nose. The p is thus not the ordinary sound but the nasal explosive p^n. The cord line indicates sonancy up to the implosion of p. The p is surd. In spite of the lack of vibrations in the cord line their presence in the nose line shows that the m is sonant. The m is a long sound like v; all the others are short ones of about the same duration. The phrase may be expressed by $v_o$ivylna^n-elnalop^{n}m. The record makes it very clear that each part of the phrase is a synthesis of continuous movements and any separation into distinct sounds or into sounds and glides must be a rather arbitrary one. Other records of the same phrase showed like results.

Records of the Bonn pronunciation of 'ich ging meines Ganges und dachte' showed that 'ging' occurred twice (in

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slightly slower speech) as **giŋk** and five times (in slightly faster speech) as **giŋ**, the **k** being lost between **ŋ** and **m**, although the speaker supposed it always present. In pronouncing 'Ganges' the speaker supposed himself to have always said **gaŋs** but the records often indicated **ganks**. The **i** and **a** were often nasalized, producing **giⁿŋ**, **miⁿnəs**, **gaⁿŋks** etc.

The supposedly lost **k** of **juŋ** 'jung' in the Pomeranian dialect often appeared in the records (though not heard) of 'dat jung Pirt' which was spoken as **dat juŋk pirt**. In the Bonn dialect **a** supposedly lost final **n** of 'vekofe' was found to reappear (though not noticed) in one record in three of 'de al Hemde vekofe' 'die alten Hemden verkaufen,' the record on this one occasion indicating **fəkofəⁿ** and on the other two **fəkofə**. Such appearances of sounds supposed to have been lost in the history of the dialect seem to indicate the transmission of unperceived elements of a language.

Records of the Pomeranian **pint** and **bint** showed the intonation of the larynx starting after the explosion in **p** and near the beginning of the explosion in **b**. The difference between German **p** and **b** often seems small; a difference in articulation is probably always present (p. 304). Medial **b** between vowels was found to be sonant throughout in Pomeranian but often surd in the Bonn dialect. Not only **b** but also **g**, **v** and **d** were often found to be surd in the Bonn dialect.

A labial may labialize the following sound, **lopn** → **lopm** in the Pomeranian (above) and Hamburg dialects; a vowel between two nasals or followed by a nasal may become nasalized in the Bonn dialect, **miŋe** → **miⁿŋe**, **man** → **maⁿn**; a consonant may be exploded nasally on account of a preceding nasal (Bonn), **endə** → **endⁿə**, **embdə** → **embⁿdⁿə**; a surd may become a sonant when followed by a sonant, but not necessarily, **lopm** may → **lop̬m**; a surd may or may not be changed to a sonant between two vowels in the Bonn dialect, **hatyrənoχ** may → **hat̬yrənoχ**, **opemol** → **op̬emol**. There may exist, totally unsuspected by the ear, a tendency

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to change occlusives to fricatives. In one case of the Bonn dialect the lip pressure for **p** was found to be less firm than that for **m** in **lopm**; in one of the Pomeranian dialects it was found to be no stronger than that for **v**. In both dialects there appeared a tendency to nasalize the vowels; in records of the Hamburg dialect this tendency was very strong.

ROUSSELOT[1] considers it to be proven that phonetic transformations are accomplished by degrees and that if they are extended over considerable territory they leave traces of their various stages; that they are to be considered as the products of physiological tendencies which can be detected even before they are noticed in speech; that they show survivals of past forms which are unnoticed by the speaker or the hearer.

Records of the Italian pronunciations[2] of several natives showed variations of the moment at which the cord tone begins in combinations of surds with sonant consonants and vowels. In the following typical records the upper line is that of cord vibrations registered by an external capsule (Fig. 124), the lower line that from a mouthpiece connected to a tambour (p. 219). In making comparisons it should be remembered that the tambour Y axis is curved (p. 197). The tambour curve should be referred to its X axis by a curved line. The vertical lines indicate corresponding points of the two X axes.

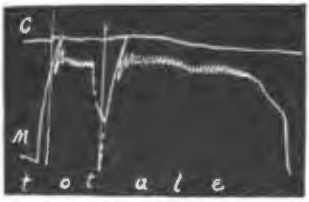

FIG. 288.

In the record for **totale** (Fig. 288) the vibrations for **o** do not begin till a moment after the **t** has exploded, indicating a rush of 'surd air' between the **t** closure and the **o**. The vibrations for **a**, however, begin at the moment of the explosion of the **t**. The record shows that the recording lever began

[1] ROUSSELOT, as before, La Parole, 1899 I 790.

[2] JOSSELYN, *Étude sur la phonétique italienne*, Thèse, Paris, 1900; also in La Parole, 1899 I; 1900 II.

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its fall at the end of o but, owing to its friction and inertia, did not have time to descend completely before the explosion occurred; the moment of explosion can be found by completing the curve as indicated by the dotted line. These two forms of t are of frequent occurrence in Italian. The difference between a t with a surd explosion and one with a sonant explosion must have its effect on the ear. That the sonant explosion may or may not possess the cavity tones — and therefore the mouth configuration — of the following vowel has been shown by HERMANN (p. 45).

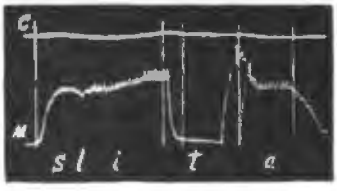

FIG. 289.

The record for slita 'slitta' (Fig. 289) shows an almost entirely sonant s (or s_o), a very long t closure, a long surd explosion and the vowel a. A synchronic dotted curve shows where the intonation of a occurs on the mouth line. The curve along which the recording point falls when the breath ceases to act is shown at the end of the i where the breath is cut off by the t closure; at the end of the t the point does not fall in this way but sinks gradually, indicating a more gradual cessation of the breath, that is, simply the

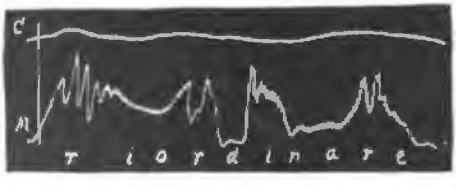

FIG. 290.

fading away of the explosion of the t. All records of Italian 'double consonants' show, just as in this case, that they are never double movements, but single consonants lengthened and intensified.

In the record of riordinare (Fig. 290) the cord tone started before the tongue began the roll for the first r. The first r

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showed four flaps, the second r apparently one somewhat complicated one, the last r one flap.

In the record of atjene 'attiene' (Fig. 291) a long t appears as in slita. Its explosion does not die away like most explosions but passes into a surd breath involved in the 'consonant i'.

The records also showed that in the occlusives the distinctions of sonancy between surd p, t and sonant b, d differ in each individual; that in a true sonant the cord tone begins during the occlusion ('*d*ozzina'); that in some initial and double consonants (as in 'a*dd*entro'), where the muscular wall of the cavity is more firmly contracted, the sonancy ceases before the explosion owing to the equalization of the air pressure above and below the glottis, in one case ceasing at the end of the glide-movement from a to J in 'aggetivo;' that in one form of surd (aspirated surd) the vibrations of the following vowel begin after the explosion is finished (as in '*c*aino' 'sli*tt*a'); that in surds the vibrations of the vowel may begin before or during the explosion (as in 'avvoca*t*o'); that even in such a surd the larynx vibrations may begin during the explosion but nevertheless may be marked by a rush of air later in the explosion (as in '*t*otale'). Similar conditions seem to occur in German according to the curves published by HERMANN.[1]

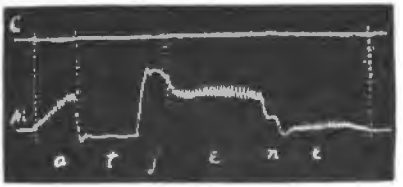

FIG. 291.

The character of 'consonant i and u' in Italian has been investigated by JOSSELYN.[2] A tambour recording the breath current (p. 219) and another recording from the exterior of the larynx (p. 267) gave tracings similar to those just discussed. In 'piena' the laryngeal vibrations begin some time

[1] HERMANN, *Fortgesetzte Untersuchungen über d. Konsonanten*, Arch. f. d. ges. Physiol. (Pflüger), 1900 LXXXIII 1; also above, Fig. 33.

[2] JOSSELYN, *Note sur* i *et* u *consonnes*, c[e] *et* g[e] *en italien*, La Parole, 1899 I 833; *Étude sur la phonétique italienne*, 104, Thèse, Paris, 1900; also in La Parole, 1901 III 85.

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after the p has exploded while in 'pena' they begin almost at the same time as the explosion. There is thus a current of surd breath between the p and the e of 'piena' while there is no such current in 'pena.' That the sound is not simply a surd i is shown by the different palatograms for 'pi' of 'pieno' and 'pi' of 'pia.' The word is thus phonetically pjeno. Similar results were obtained in comparing fjaŋko 'fianco' with fiʎo 'figlio,' kjama 'chiama' with kilo 'chilo,' tjene 'tiene' with tenero 'tenero,' kjaro 'chiaro' with karo 'caro.' The j was surd throughout its length, or became sonant at its end under influence of the following vowel. When a sonant consonant was followed by j as in bjeko 'bieco,' vjeto 'vieto,' djetro 'dietro,' gjačo 'ghiaccio,' the explosion of the consonant was weak; the j was sonant in these cases. It was evident throughout that 'unsyllabic i' preceded by a consonant and followed by a vowel was a palatal consonant j which tended to unite with the preceding consonant and modify its articulation. The union of j with, and the modification of, the consonant were greater as the places of articulation were more nearly alike; the labials p and b showed little influence from j; t and d showed more; for k the change was marked, the explosive in kjaro 'chiaro' losing much of its force and its breath record resembling rather that of the fricative in fjaŋko 'fianco,' while the g in gjačo 'ghiaccio' gave a breath record scarcely differing from and even weaker than that of v. A palatogram showed a consonant with a prepalatal articulation between t and k to exist in 'c' of 'cece.' This articulation coincides closely with that of j. The union of the consonant and j was probably made with a single movement of the tongue that caused an occlusion and then a gradual opening. This sound may be indicated by č, its sonant by J. A similar result was found in the records of 'cielo.' These words would thus be phonetically čeče and čelo. Likewise 'gente' appeared as Jente. This hinders us from considering Italian č, J as the consonant diphthongs tš, dz (p. 321). A palatogram of the first sound in 'ieri' showed

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that it was the consonant j, the word being jeri. It is worth noting that in general 'i' has a vowel character where it corresponds to Latin vowels ('pia, via') and becomes j where it replaces a consonant ('clarum-chiaro,' 'flammam-fiamma') and where it arises from diphthongization ('tenet-tiene').

In a similar manner it was shown that in 'puoi, fuoco, quinto' there was a wholly or partly surd **w** after the initial consonant. The words were thus phonetically **pwoi, fwoko, kwinto.** This consonant **w** was often very weak or lacking in some pronunciations; 'puoi,' for example, being the same as 'poi.' The distinction in labial action was clearly shown between **w** and **u** in records of the projection of the lips (p. 355). This consonant **w** is a common Italian development from a Latin labial vowel (*o* → **uo** → **wo**) or consonant (*qu* → **kw**).

Simultaneous records of the air issuing from the mouth and of the vibrations of the larynx (by an external capsule) have been used for the study of the dialects derived from the ancient Armenian.[1] In the popular speech of Constantinople there are three ways of pronouncing the sonants **b, g, d, dz, dž,** namely: 1. with the beginning of larynx tone preceding the explosion by about 0.08^s; 2. with the tone beginning at the moment of explosion; 3. with the tone beginning slightly after the explosion, by 0.01^s or 0.02^s. There are thus in fact three kinds of sonant explosives; the first, corresponding exactly to the French sonants, is employed in cases of emphasis; the second, corresponding to the German sonants, may be called the standard sonants, since the great majority belong to this class; the third class, appearing only occasionally, resembles the corresponding surds but differs in having less force and in having the larynx tone earlier in the explosion. In the literary language of Constantinople and in the dialect of Aslanbeg these sonants are regularly pronounced like the aspirated surds (see below) but have less force; sometimes, however, they are pronounced as in the popular speech. In the dialects of Nouxa and Choucha

[1] ADJARIAN, *Les explosives de l'ancien arménien*, La Parole, 1899 I 119.

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these sounds are fully sonant; the larynx vibrations begin before the explosion, sometimes even as long as 0.10^s before. In the dialects of Mouch and Sivas they have formed two distinct classes; the first is like the pronunciation at Nouxa and Choucha; in the second the consonant is pronounced with more force than in the first class and the mass of air emitted is larger; in both classes the vibrations generally begin 0.02^s to 0.03^s after the explosion. The unaspirated surds p, k, t, ts, tš are considered in both the popular and the literary speech of Constantinople to be the same as the sonants and are, as the records showed, pronounced in exactly the same ways. At Aslanbeg and Sivas they have also become sonants, the vibrations beginning at 0.015^s to 0.08^s before the explosion. In the dialects of Nouxa, Mouch and Choucha they have remained surd and are perfectly distinct from the sonants and the aspirated surds. The aspirated surds p^h, k^h, t^h, ts^h, $tš^h$ fall into three classes in both the popular and literary speech of Constantinople; in the first the vibrations begin at 0.01^s after the explosion; in the second they begin just as the explosion begins; in the third they begin after explosive emission of air is completed (or nearly so) — the first and third classes being rare. At Mouch the pronunciation is like that of the second class (standard) at Constantinople. In the dialects of Nouxa, Choucha, Sivas and Aslanbeg these consonants are completely surd. The bearings of these facts on the phonetic development of Armenian have been discussed;[1] the resemblance of some of the Armenian sounds to the aspirates of the Sanskrit grammarians had already been noticed.[2]

Simultaneous registrations of the movements of the jaws and lips and of the tension of mouth-floor (p. 355) have been made by GALLÉE and ZWAARDEMAKER.[3] Some of their

[1] ROUSSELOT-MEILLET, *Note sur les évolutions phonétiques*, La Parole, 1899 I 127.

[2] SIEVERS, Grundzüge d. Phonetik, 5. Aufl., 171, Leipzig, 1901.

[3] GALLÉE UND ZWAARDEMAKER, *Ueber Graphik d. Sprachlaute namentlich der explosivae*, Neuere Sprachen, 1900 VIII 8.

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records are given in Figs. 292 and 293. Each wave in the time line at the bottom indicates $\frac{1}{25}$ of a second. The vertical checks on the curves indicate synchronous positions of the recording levers. The upper line in each case shows the jaw movement; depression indicates lowering of the jaw. The upward curves in the second line indicate tension of the upper lip. The rise in the third line indicates increase of tension of the floor of the mouth cavity.

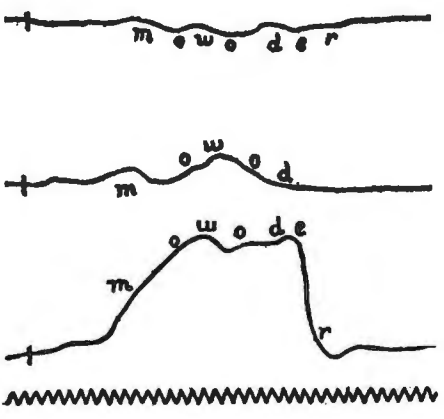

Fig. 292.

The curves in Fig. 292 for **mowoder** 'moeder' spoken in the Deventer dialect show lowering of jaw for **o** and **e** and tension of the lip for **m** and **w**. The tensing of the mouth-floor begins during **m**, increases strongly during the rise of the tongue for **o**, relaxes somewhat during **w**, increases again for **o**, maintains itself during the energetic tongue articulation of **d**, increases during the raising of the tongue for **e** and falls for **r**.

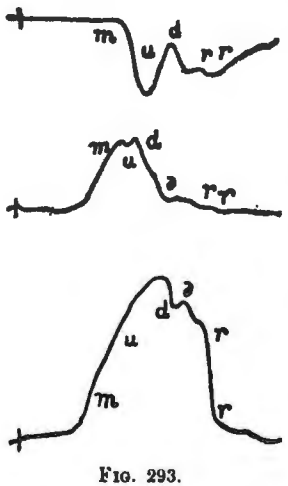

Fig. 293.

For **mudər** 'moeder' in the North Holland dialect the records are given in Fig. 293. The jaw movements are analogous but much more energetic; the lip is tensed with much more energy for **m**; the mouth-floor follows in general the same course as before.

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That a vowel may have an influence not only on the preceding consonant but also on the vowel before this consonant has been shown by LACLOTTE.[1] An exploratory bulb (p. 333) was placed between the tongue and the palate and a breath receiver (p. 219) placed before the mouth; they were attached to two tambours. The records showed that the tongue position during the consonant is lower in **ba** than in **bi**, in **za** than in **zi**, in **ža** than in **ži**. LACLOTTE considers the records to show that the tongue takes, for the beginning of the work of articulation of the syllable, the position necessary for the vowel and maintains it throughout the consonant and its explosion. In **da** the d-articulation is frontal, in **di** it is rather dorsal. Records of **ela** and **eli** showed that the articulations differed for **e**, the tongue being higher and nearer to the i position in **eli**. Similar results were found for **eba** and **ebi**, **venta** and **venti**. The influence of a vowel on the articulation of the vowel of the preceding syllable shows itself in the tendency to vowel harmony and renders it possible to explain why 'illi' → French 'il' but 'illa' → French 'elle,' 'viginti' → 'vingt' but 'triginta' → 'trente,' and similar cases. The auditory factor in vowel harmony and the tendency to similarity in movements have been considered above (p. 121).

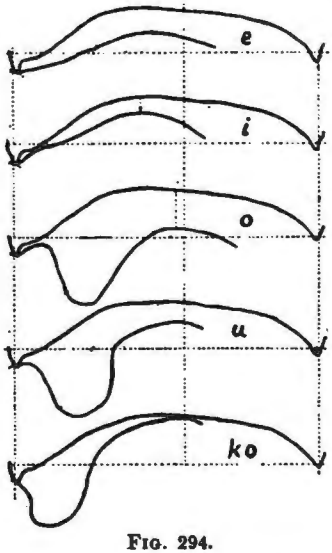

FIG. 294.

The method of attacking historical problems by experimental methods may be effectively illustrated by an investigation by LACLOTTE.[1] The words *αἰπόλος* (goat-herd) and *βουκόλος* (ox-herd) are evidently composed of two portions;

[1] LACLOTTE, *L'Harmonie vocalique*, La Parole, 1899 I 177.

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the first designates the animal, *αἴξ* (goat) and *βοῦς* (ox); the second is related to the Indo-European root *qel* which is found in Latin as **quēl*, whence *inquīlīnus*, *cōlō*, etc. In the occidental European languages the evolution of *q* into **k** or **p** has been independent of the neighboring vowels, whereas in Greek it became regularly *τ* before *ι* or *ε*; *κ* before *ο* and after *ου* or *υ*; and *π* before *ο* and after *ε*, *ι*, etc. Why should the labialization that occurs after the other vowels, not occur after *ου*?

Using the vulcanite strip (p. 330) LACLOTTE recorded the tongue positions for his pronunciations of **e**, **i**, **o**, **u** and **ko**; the typical sagittal diagrams are given in Fig. 294. For **u** the tongue is drawn back, raised and held at 5^{mm} from the palate, touching the edges with the point of articulation at the last molar. The action for **ko** is very similar to that for **u**. For **e** and **i** the action is quite different. It is evident that it is much easier to pass from the **u** than from the **e** or **i** to the **ko** position. In the case of a general tendency to change **ko** to **po** this tendency would be favored after **e** and **i** but resisted after **u**; the **p** would afford opportunity for the tongue adjustments after **e** and **i** while **k** is easiest between **u** and **o**.

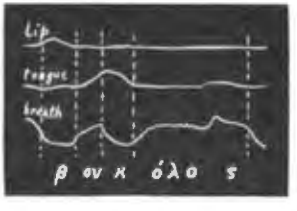

FIG. 295.

With an exploratory bulb (p. 333) between the lips, another at the point of articulation of **k** and a breath mouthpiece (p. 219) pierced to allow the lip tube to pass, LACLOTTE obtained the records shown in Figs. 295 to 297. For **bukolos** (Fig. 295) the lip line shows the closure for **b**; the tongue line shows the small posterior rise for **b**, the larger one for **u**, and the still larger one for **k**, followed by the very small (posterior) one for **s**; the breath line shows the explosion for **b**, the air current for **u**, the closure and explosion for **k** and the air current for the following sounds. The set of movements in **uk** is continuous with easy transitions. For **bupolos** (Fig. 296) the lip line shows the two closures for **b** and

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p; the tongue line shows the posterior action for u with less posterior action for p and none for o (but with some anterior action for o, Fig. 294); the breath curve shows the closure for p. There is more than double the amount of lip work and more tongue work owing to the changes between different articulations. The form *βουπόλος would be more difficult than βουκόλος. In aipolos (Fig. 297) the lip line shows the pressure for p, the posterior tongue action is small, the breath curve is marked; the tongue at i is far from its position for k but is readily relaxed to the p position. The tendency of *q* to p is thus favored in *αἰπόλος*.

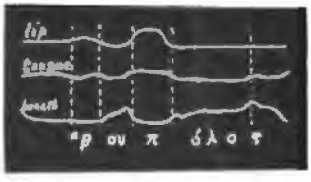

FIG. 296.

Simultaneous records may be made of the curve of speech by the methods described in Part I, and of any of the muscular activities by the methods described in this Part.

ROUSSELOT[1] has made simultaneous records of the curve of speech and of a muscular movement by using a phonautograph (Ch. II) and an exploratory bulb (Fig. 245), and also of the curve of speech and the breath pressure by attaching the phonautograph to one arm of a Y-tube, a tambour to the other and a mouthpiece to the stem. Some of his results will be briefly mentioned. Characteristic records are given in Figs. 298 and 299; they were taken on different occasions and do not refer to identical sounds. Fig. 298 shows the records of lip pressure and voice vibrations in the middle portion of apa. The gradual closing and opening of the lips is seen in the upper line; the closure begins before the cords cease to vibrate; the a-p glide is thus sonant. The opening, p-a glide, is likewise sonant. Fig. 299 shows the curve of breath pressure from the mouth and the speech curve. The a-p glide is sonant; the explosion of the p is likewise sonant. Tracings of the tongue pressure against the

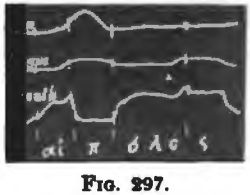

FIG. 297.

[1] ROUSSELOT, Principes de phonétique expérimentale, 353, Paris, 1901.

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rear part of the palate, and of the speech curve during the vowel **a**, showed the following formation. From its position of rest against the palate the tongue descended to a minimum position; the tongue then gradually rose to a position of maximum articu-

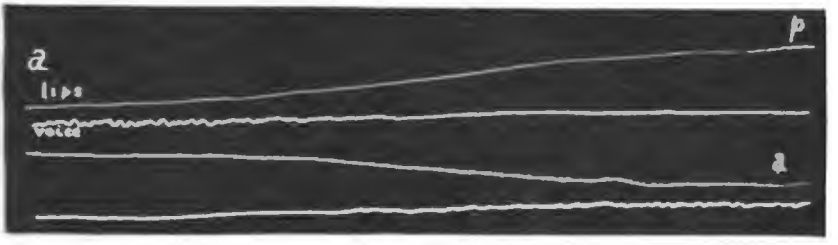

FIG. 298.

lation and gradually fell again to a position lower than the first minimum. This movement was probably compounded of a gradual fall of the jaw and a fall-rise-fall of the tongue. The voice-tone began during the fall to the first minimum; its intensity rapidly rose to a fairly maintained maximum and fell with the relaxation of articulation at the close; its pitch followed about the same course. Analogous results were found for other vowels. Records of the speech curve and the breath pressure at the mouth for **aja** and **aia** showed for **i** little diminution in the intensity of either during **i** as com-

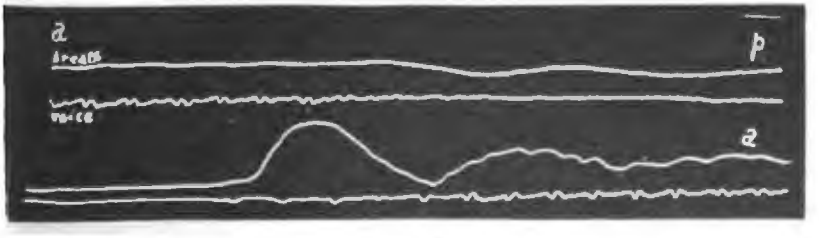

FIG. 299.

pared with **a**, but for **j** a gradual diminution of both during the first and last portions [on- and off-glides] and practical loss of the vibrations during the middle portion. In the combination **aça** — a surd between two vowels — the change

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from a to ç [the a-ç glide] and from ç to a [the ç-a glide] appears in the records to be a sonant ç, which must be nearly identical with ɟ. Some resemblance was found between the speech curve during l or r and that during the neighboring vowels. One example of lingual r showed about 32 flaps a second, a cord tone of about 140 frequency, and a lower resonance tone of about 450. In **asa** the changes from a to s and from s to a were gradual; similar results were found for **afa, aza,** and **ava.** In **aba, ama, ata, ada, aka, aga** the speech vibrations recorded from the mouth quickly lost their amplitude as the occlusion was made and did not regain them until it was almost completely over. The passage from the vowel to the occlusion seemed to be more sudden in French than in German. In **apa, ata, aka** two types of explosion were found. In one the speech vibrations appeared with the first portion of air at the explosion; in the other there was a considerable interval between the beginning of the explosion and the beginning of the vibrations. The latter type occurred in German and in emphatic French, the former in ordinary French. In **aba, ada, aga** the speech vibrations appeared at the first moment of the explosion, as would be expected from the continued vibration of the cords during the occlusion.

In concluding this chapter I may point out 1. that the intention to perform two movements simultaneously is never perfectly executed; 2. that the character of any movement depends on other movements occurring at the same time; 3. that it depends on the immediately preceding movements; 4. that simultaneous movements become associated with a single intention; 5. that a course of movement is to be considered as a fluctuation in muscular action rather than as a succession of sharply defined separate movements.

The adjustments of large groups of simultaneous and successive movements in the flow of speech depend on auditory and motor habits.

The speech experiences of an individual under given circumstances associate themselves together and with the cir-

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cumstances. Two or more different sets of habits are formed, and these may be associated with different circumstances. Cases are frequent of children with a foreign nurse speaking the foreign tongue whenever addressed by the nurse, even though she may use the native tongue.

In the same speaker the somewhat different, though corresponding, sounds of two languages will usually be associated readily in each language singly but less readily from one language to another. German words are spoken with more difficulty when cited in the middle of an English sentence than when used alone. This is not due to any physiological difficulty, but to interruption in the natural associations of voluntary movements (p. 158). The so-called 'basis of articulation' (p. 113) is a system of habits of simultaneous and successive motor impulses. The mental habits are best formed by confining the instruction exclusively to the sounds of the language being taught; alternate reading and translation of a foreign tongue makes the acquirement more difficult (p. 151).

The importance of early training in pronouncing various languages correctly is deducible from the general law that habits formed in childhood are the most permanent ones. In spite of later correction the old habits may often appear in cases of fatigue [1] or of excitement. VIETOR relates [2] an observation of an actress who in emotional scenes used her native γ, j in various German words instead of the g required by the rules of the stage. I have heard a German 'Gymnasiallehrer' drop back into his native South German dialect in the process of relating an exciting experience.

In forming habits of speech the movements should be made as correctly as possible from the start. Every incorrect or imperfect movement tends to create a habit of its own, which must be overcome (p. 158) if improvement is to be made. In the formation of a habit the immediately noticeable result

[1] HÖPFNER, *Ueber d. geistige Ermüdung d. Schulkinder*, Zt. f. Psych. u. Physiol. d Sinn, 1893 VI 191

[2] VIETOR, Elemente d. Phonetik, 4. Aufl., 169, Leipzig, 1898.

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does not always bear a fixed relation to the amount of practice. It has been established by experiments on practice and habit that the strength[1] and precision of control,[2] after increasing slowly for the initial stage, then show a stage of rapid gain after which the increase is very slow. The highly important law[3] that 'it is intense effort which educates' has been established for the telegraphic language; it is probably valid for all habits.

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[1] Fechner, *Ueber d. Gang d. Muskelübung*, Ber. d. k. sächs. Ges. d. Wiss., math.-phys. Kl., 1857, IX 113.

[2] Bryan and Harter, *Studies in the physiol. and psychol. of the telegraphic language*, Psychol. Rev. 1897, IV 27; Johnson, *Researches in practice and habit*, Stud. Yale Psych. Lab., 1898 VI 51.

[3] Bryan and Harter, as before, 50.

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CHAPTER XXVII

VOCAL CONTROL

THE degree of contraction of a muscle is governed by the amount of stimulation from its nerve (p. 191). When a contraction of a definite nature has to be performed, the amount of this stimulation must be regulated by reference to the condition of the muscle at each moment of its action. When several muscles act together, the subordinate centers for separate muscles are controlled by higher centers for group-action (p. 192).

The combined action of groups of muscles requires the coordination of several centers of regulation by a higher center. Thus, the production of a tone of constant character requires regulation not only of the thyroarytenoid, cricoarytenoid and other laryngeal muscles, but also of the breathing muscles. The production of any concrete sound requires regulation not only of these muscles but also of the cavity muscles and — for expression, gesture, posture, etc. — of most of the other muscles of the body.

Vocal movements are controlled by systems of centers. The center for the control of each single muscle lies in the spinal cord or in the basal portion of the brain. Centers for automatic control of separate activities, as of breathing, laryngeal action, etc., lie at higher levels, namely, in the bulb (p.193). Centers for voluntary control of the separate activities are found in the cortex of the cerebrum in the anterior and posterior central convolutions (for the head muscles of the right side in the region between 'Arm' and 'Speech' in Fig. 57, for the trunk muscles in the region above 'Arm.') The centers

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for voluntary control of combined activities are also in the cortex (for vocal movements at 'Motor words' in Fig. 57.) They are all subordinated to the centers for ideas of speech (in front of 'Motor words' in Fig. 57) and these in turn to the centers of thought supposed to be located in portions of the frontal, parietal and temporal lobes (*F*, *P*, *T*, association centers of FLECHSIG [1]). The scheme of subordination is partly shown in Fig. 58.

Any center may act to a great degree independently but its intimate connection with the others makes it highly probable that even such independent action is influenced by their condition. For example, we may safely say that although the contraction of the thyroarytenoid muscle is brought about directly by its special center it is nevertheless influenced at each instant not only by the activities of the centers for the other laryngeal muscles, of those for the pharynx, tongue, lip, thorax, etc., and of the higher ones for song and speech, but also by the activities of the still higher centers of mental life. The intimate connection of all parts of the nervous system leads us to suppose that the action of such a single center is influenced to a greater or less degree by the activities of every nerve center and that thus it stands in connection with every part of the body. Experiments on the nervous and mental reactions of the vaso-motor system, of the heart, of the muscles of the sweat glands, bladder, anus, etc., make it probably safe to say that the production of any vocal sound is accompanied by nerve impulses to and from every organ of the body. Vocal sounds of a certain character, such as a clear, smooth, energetic phrase in song, become associated with the regulation not only of the vocal muscles but also of those of the arms and hands, and, in fact, the entire body. The disturbance of any of these by restraint or unnatural posture interferes — to a greater or less degree, depending on the individual and on circumstances — with the vocal action. To produce the proper modulation the singer or

[1] FLECHSIG, Gehirn und Seele, Leipzig, 1896; Die Lokalisation d. geist. Vorgänge, Leipzig, 1896.

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speaker should put his entire body into the appropriate condition.

On the psychological side we can draw analogous conclusions.

In first attempting to make a new sound or in attempting to notice the details of a speech movement, we are specially 'conscious' of the movement or group of movements. As the movement is repeated, it occurs with less and less attention until it is made with no distinct knowledge of the performance ('automatically' in one sense). In the last case it is said to be quite 'unconscious,' although when reminded of it we may often remember a conscious fact that passed unnoticed at the time. Even movements of which we can obtain no definite consciousness, such as those of the muscles of the diaphragm or the larynx, are probably represented in consciousness by faint elements, for their influence on other elements can be proved. With a pathological degree of attention they may come distinctly into consciousness, as in hypochondria. If the term 'consciousness' is not limited to what is distinctly present in mind, it is not too much, I believe, to assert that all muscular movements are accompanied by some degree of consciousness.

If objection is made to the use of the word 'consciousness' in such a broad sense, we may say that all centrally originated movements represent mental phenomena, of some of which we are distinctly conscious, of others less conscious, and of still others 'unconscious' in the usual meaning of the word. 'Conscious' might be used as a term representing a phenomenon varying between a maximum and zero; ordinarily it is used to represent it between a maximum and an undefined lower limit, beyond which the phenomenon is said to be 'unconscious.' To conform to ordinary usage I shall use 'conscious' in the meaning of fully conscious, and shall speak of 'semi-conscious' and 'unconscious' as usual. 'Mental' refers to any phenomenon that can be proved to affect any element that may be 'conscious.' The whole motor production of speech is thus to be treated not only as a physiological mechanism but also as a psychological process.

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The differences in the degree of consciousness of the sensations of movement are evident in the case of the vocal organs. We are, under ordinary conditions, clearly conscious of the positions and movements of the lips, much less so of those of the tongue, and completely unconscious of those of the velum and interior of the larynx. Moreover, we cannot in any way acquire consciousness of some of them. No one can feel the contact between the velum and the rear wall of the pharynx or gain even the remotest notion of the action of the muscles within the larynx. As already pointed out (p. 247), even the simplest facts of laryngeal action were learned only by aid of the laryngoscope, and our uncertainty to-day concerning the interaction of the laryngeal muscles is defined by the limits of clinical and experimental methods. I know of only one case in which the internal action of the larynx was supposed to be observable in consciousness; the result was the supposition of a tone produced by the anatomically impossible contraction of the larynx below the glottis. The notion of many phonetists that any very definite knowledge can be gained of tongue action by attending to its sensations is a delusion of a kind familiar to psychologists.

Several factors of vocal control are now to be considered: 1. reflex-tonus; 2. force of movement; 3. accuracy of movement; 4. precision of movement; 5. accuracy of co-ordination; 6. quickness of response; 7. quickness of movement; 8. forms of sensory-motor control; 9. ideo-motor control; 10. general voluntary control. Another important topic, the adjustment of simultaneous and successive movements, has been considered in detail in the preceding chapter.

Even the muscles apparently at rest in the body are contracted to some extent. The utmost voluntary relaxation of the hand hung over the edge of a table is not complete; during sleep it relaxes still more. The muscles of the face relax in fatigue and sleep. This condition of faint continual contraction has been named *tonus;* it is due to continuous mild nerve stimulations sent from the spinal cord and brain in response to sensations from the skin and elsewhere (Brond-

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GEEST reflex). The view that it is due to centrally originated nerve action is erroneous; it has been clearly proved that there is no tonal action of the central nervous system.

The effect of the degree of tonus on song and speech has not been experimentally investigated. It may be suggested that flabby muscles in the resonance cavities would diminish the duration of the free vibrations on account of the loss of energy at the soft walls; this may be expressed as an increase of the factor of friction k in the formula on p. 5. The effect on the ear would be a change in the 'color' of the vocal sound in a way still undefined and yet readily recognizable in the depressing voices of weak or sick persons in comparison with a stimulating healthy voice. Such changes in color appear as the result of fatigue, ill-health, and other devitalizing conditions; in smaller degrees they result from any disturbance — mental or bodily, such as grief, disappointment, colds, the missing of a meal, etc. — that diminishes the vitality of the nerve centers.

The attempt is instinctively made by the speaker or singer to correct such a fault by voluntary innervation of the muscles; this cannot succeed perfectly because an increase of innervation brings about contractions of associated and antagonist muscles with the result of changed conditions and changed sounds. Such extra muscular effort is, moreover, very fatiguing.

The lacking tonus can often be temporarily replaced by drugs that act upon the nervous system; among them are tea, coffee, strychnine and other tonics. There is evidence to show that it can be temporarily or permanently improved by influence — success, encouragement — that stimulates mental activity.

The amount of tonus can often be measured by a tonal dynamometer (or 'tonometer') consisting essentially of a spring that registers the amount of pressure required to impress the muscle.

The *force of the movement* depends on the amount of stimulus sent to the muscle. The muscles contracted to perform a

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movement include not only those directly involved but also their antagonists. This requires an excess of effort over what might be expected, but when the innervations are properly coordinated this excess is not necessarily large. In learning a new movement the contraction of both favoring and antagonist muscles is unnecessarily large and fatiguing. The presence of some contraction in all the muscles connected with a group of movements is highly favorable to quick and accurate control of the movement and its variations. This principle is involved in the contraction of the entire abdominal wall or part of it during inspiration in order to accurately control the expiration in singing.[1] In singing the scale the chest and the abdomen often make movements of expansion in opposition to the general expiratory contraction. This may be due to an attempt to adjust the thorax to resonate to the cord tone,[2] or, perhaps, to adjustments giving more control over the expiration.

Changes of the force of movement in the organs of articulation show themselves in various ways. The properties of song and speech that depend on the energy of action have not yet been determined. Whatever they may be, they are instinctively felt by the hearer and affect his general mental attitude strongly. An energetic (not necessarily loud) voice in oratory or in song commands attention and approval — other things being equal — by appeal to some of the fundamental instincts of the hearer. The first words of a born leader are often sufficient to move an assembly. That this ability need not be connected with a high grade of intellect has often been shown. The results arise, I believe, from differences in motor energy, but their details must be left to a future experimental analysis of speech curves, muscular activity and mental impressiveness.

The distinction of ' tense ' and ' lax ' action, as in the for-

[1] MACKENZIE, Hygiene of the Vocal Organs, London, 1888; CURTIS, Voice Building and Tone Placing, 68, New York, 1896.

[2] SEWALL AND POLLARD, *On the relations of diaphragmatic and costal respiration, with particular reference to phonation*, Jour. Physiol., 1890 XI 159.

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mation of vowels, has to do with the energy of muscular movement, which is associated with the degree of contraction, and has nothing to do with the reflex tonus. Most of the philological speculations in respect to tense and lax sounds are probably erroneous as they do not agree with what is known concerning muscular action; experimental data are, however, lacking.

The force of effort may be measured by dynamometers of various forms. The most usual measurement is that of the pressure required to compress a spring or to raise a column of mercury or water. Special dynamometers have been devised for the lips, tongue and respiration muscles. A convenient dynamometer for the mouth can be made by attaching an exploratory bulb (Fig. 245) to a water or mercury manometer (p. 225).

The *accuracy of movement* may show itself in various ways. The curve of movement described by a given point of the moving body may not be the same as that intended. Thus, a certain speech sound requires an elevation of the point of the tongue along a certain definite line till it strikes the prepalatal region; any change from this line will produce a change in the speech sound. With the other appropriate speech adjustments this speech sound may be made the implosion of a frontal-prepalatal t; any inaccuracy of movement will produce a different implosion.

The inaccuracy of movement is a fundamental source of inaccurate and wrong sounds.

The inaccuracy of the action of the cricothyroid muscle produces inaccuracies in the cord tone (p. 269) which the singer may be able to hear but powerless to correct. A tone may be out of pitch, or may fluctuate in pitch instead of being constant; a succession of notes may be united by glides instead of sudden jumps.

Inaccuracy in the various laryngeal muscles may produce harsh tones instead of the smooth ones intended. Inaccuracy in the breathing muscles may produce the fluctuations heard in one form of tremolo, or a too rapid expenditure of

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breath which makes it impossible to sing properly, etc. Inaccuracy of velar action produces nasality, modifications of vowels, etc. Inaccuracies of tongue and lip action modify speech essentially.

The methods of studying the accuracy of various vocal movements have been described in the preceding chapters. The movements can frequently be registered on a smoked drum; the defects are studied by the eye at leisure and the improvement followed in the successive records. This method has proved highly effective in correcting the defects of singers and speakers.[1]

The *precision of movement* refers to the regularity and evenness with which it is executed. It depends mainly or entirely on the nervous control.

Accuracy and precision of coordination represent the nervous control over simultaneous muscular adjustments. The defects of one form of stammering arise from defective coordination. A typical case, due to altered nerve activity, may be found in the 'thickened' speech of alcoholic intoxication. The typical form of defect due to excessive nerve activity may be seen in the incorrect adjustments that arise during excitement.

The accuracy and delicacy of the coordination of the regulative centers vary greatly with individuals. Just as in the case of painting or violin-playing the coordination and regulation are naturally good in some persons and poor in others; the degree to which they can be improved by training is also variable.

The *quickness of response* in a movement depends mainly on the rapidity of the action in the nervous centers and on the number of centers involved in the reaction to the sensation. When full consciousness is involved, as in the reactions discussed in Ch. XV, the time required is considerable. As the reactions become less conscious (more 'automatic') the

[1] NATIER ET ROUSSELOT, Les applications de la phonétique expérimentale à la médecine, Paris (in press).

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time is reduced. One object of vocal training should be to render song or speech as automatic as possible.

The *quickness of movement* depends on both muscular and nervous quickness. They must be properly balanced. Unusual slowness of nervous (mental) action renders speech apparently labored and pedantic; unusual quickness slurs it.

Hurried movements readily become inaccurate. The difficult rolled r often becomes unrolled. The effect of hurry shows itself in careless utterances, like gmoin for 'guten Morgen' or sple for 's'il vous plait.' A defective relation between the speed of thought and the control of the vocal organs results in inaccuracy in the exact formation of sounds. The effect of extreme nervous haste can be seen in the defect of speech known as 'Poltern' in German.[1] In German cases i often sounds like e, u like o, oi like ai; f and v often appear as p and b, s and z as t and d; p, t, k are often hardly distinguishable from b, d, g. Only rarely does a large change of articulation take place; in a few cases k, g → t, d or t, d → k, g; somewhat more often m → n, n → m, l → r, r → l. The errors are not constant as in stammering.

Quickness of movement can be studied by the graphic methods described in the preceding chapters; the necessary allowance must be made for the friction and inertia of the apparatus.

Rapid, precise speech seems to have a stimulating effect on the hearer. Its physiological and psychological characteristics are still uninvestigated. The ability to speak rapidly and clearly is associated with great activity of the nervous system and of the train of thought. Owing to this association such speech has a stimulating effect on the hearer and is used by skilful speakers for this purpose.

The *sensory-motor control* is generally muscular and auditory.

The action of the vocal muscles occurs under guidance of the sensations of movement obtained from them (p. 191).

[1] LIEBMANN, *Poltern* (*Paraphrasia praeceps*), Vorlesungen üb. Sprachstörungen, 4. Heft, Berlin, 1900.

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The association of the correct movement-sensation ordinarily occurs with the aid of hearing the sounds produced. In the deaf it occurs without this aid; the usual teaching of vocal articulations to the deaf is done through touch and sight; special teaching of the muscle sensations directly has been shown to be of use.

The character of the direct control of single muscles without the aid of control through other senses may be tested in various ways. Labial, lingual and velar action may be studied by graphic methods while sound movements are silently made, the results being compared with those obtained in the usual way; I am not aware of any experimental work along this line.

Some factors of auditory-motor control have already been discussed: the uncertainty and indefiniteness of auditory sensations in Ch. VIII; the inaccuracy and lack of precision of muscular movement in Ch. XV. In addition to these the inaccuracy of the connection between sensation and movement is of importance.

The amount of stimulation sent to the muscles at each movement is governed by the sensations. Too much stimulus at one instant produces too much contraction, and consequently a change in the complex of sensations; this is followed by a reduction in the amount of nerve impulse. The reduction is generally too great; the sensations then vary in the reverse direction; and renewed correction is attempted. For a contraction intended to be constant, as of the cricothyroid in singing a tone of constant pitch, the continually fluctuating and erroneously changing motor impulses produce changes in the sensations from the tendons and in the pitch of the tone heard (this last is not a factor of control in the deaf). The intention to keep a constant pitch results in an adjustment of the vocal centers to receive constant sensations and to impart motor impulses standing in definite relations to them. The fluctuating sensations actually received are used to regulate the impulses. An analogy may be drawn to an engine with its governor; too great speed causes the governor

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to reduce the steam supply, and conversely; without a fly-wheel to make the changes slow the engine would require rapid readjustments by the governor. The vocal mechanism is light and delicate; its small inertia renders its action very fluctuating (p. 269); it thus requires continual regulative action. When a rising tone is desired, the governing center is adjusted so that each degree of intensity of the sensations is answered by an increased motor impulse. Falling tones are regulated by the opposite relation. A rise or fall that seems steady to the ear requires a complicated — probably not proportional, perhaps logarithmic (p. 109) — relation.

The learning of speech sounds consists largely in forming connections between the motor sensations and the auditory ones. When such associations already exist, new sounds are liable to confusion with familiar ones. The sounds of a foreign language may be heard to resemble familiar ones and the motor associations of the familiar ones become attached to the new ones. The incorrectness of the association is discovered to some extent by the speaker's hearing of his own sounds, but remains also to some extent undetected.

The formation of *ideo-motor associations* has received little attention from phonetists.

Sounds occurring simultaneously with sights, touches, tastes, smells, emotions, acts of will, etc., tend to be connected with them so that when any one of a complex group occurs again the others are revived more or less clearly in consciousness. It is in this way that speech movements become associated with printed letters. The introduction of new letters requires the formation of new associations; the use of letters to represent sounds in an unfamiliar manner is resisted by the associations already formed. The neglect of these evident facts is one reason why the phonetic alphabets hitherto devised have all failed to find general acceptance.

The close interconnection of all the nerve centers indicates that the action of any one may influence all others. Among others the intellectual and emotional centers influence the

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vocal centers and consequently the vocal mechanism. Experimental data are still entirely lacking except in regard to internal speech in its effect on nasal whispering (p. 132) and on the action of the larynx (p. 112). Yet from what is known of other activities it can be safely asserted that the character of the vocal movements in song and speech depends most intimately on the mental condition. From this we can readily deduce a conclusion used in musical and oratorical instruction that the singer or speaker must feel what is to be said if he wishes to say it properly.

The ideo-motor associations affect the contractions of the various vocal muscles and consequently the character of the air-vibration produced. At present the most promising method of investigation seems to lie in analyzing speech curves (Part I) obtained in connection with various modes of thought (conversation, declamation, etc.) and emotion (excitement, anger, etc.). The effect of the mental condition consists exclusively in modifications of the factors of vocal control just considered. That the 'mind' can affect the air-vibrations of the singer or speaker, or directly communicate with the 'mind' of the hearer is a superstition born of ignorance and credulity.

The yet-uninvestigated minute auditory variations in the sounds of speech and song have great effects on the mind of the hearer. Although no one can say in what the vocal difference consists, there is an intimate connection between the mental attitude of the hearer and the voice-character of the speaker. This relation is well known to speakers and singers; fatigue, worry or embarrassment often seriously affects the voice.

A highly important problem — still hardly investigated experimentally — lies in the relation of vocal control to the emotions. Every change in the emotional condition results in changes not only of the action of the involuntary muscles (heart, blood vessels) but also in changes in breathing and vocal action. The resulting changes in the voice have powerful emotional effects on the hearer. These emotional changes

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in vocal action cannot be perfectly reproduced by the speaker voluntarily in the absence of the emotion. It is a familiar principle with orators and singers that to produce the full vocal effect they must first arouse the emotion itself and then allow it to find its natural expression.

For singers and speakers we may safely say that vocal training should include not only a development of the various other factors of control but also a thorough practice in voluntarily bringing up the typical mental conditions and in properly expressing them.

To phonetists we may point out that the object of speech is the attainment of a certain result, that this may often be done by very different muscular adjustments, and that muscular adjustments do not by any means go all the way in elucidating phonetics. 'It is well to remember that ridiculous old paradox quoted by GALEN from the Stoics: "It is evident the voice cometh from the mind; it is evident also it cometh from the larynx; hence the mind is not in the brain." GALEN splutters over this a good deal, and fails entirely to see its bearing; but GALEN had very little *esprit*. If he had seen and heard what can be done without a larynx at all, he would not have considered without reservation the larynx as the "principalissimum organum vocis," as the Medievals put it in their Hog-Latin. No two larynxes are alike, and doubtless if we could get down to very fine points it would be found that more or less identical results are reached by very different dynamics and neural discharges.' (WRIGHT.)

It is now the place to consider the dependence of vocal control on the *general voluntary control*, as in changes of nutrition, fatigue, emotion, and general habits.

The laws governing the amount of energy used in action, its rate and accuracy of expenditure, its curve of fatigue, its dependence on emotions and motives, etc., have been studied with great success in the case of arm and finger movements with results which — on the principle of similarity in all actions of an individual — are directly applicable to vocal movements. Experimental records have not yet been made directly

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on the vocal organs, but we can assume that each individual has his own peculiar forms of vocal movement; that he expends his vocal energy in a fashion peculiar to himself; that the forms of vocal movement and of vocal expenditure change in their details with every mental condition; that they are directly expressive of conditions of thought, emotion and motive; that they cannot be completely changed from one expression to another except by changes in the mental conditions.

When the nervous system is well nourished, its elements accumulate quantities of highly complicated substances. These represent potential energy which may be turned into kinetic energy by the breaking down of the more highly compounded substances into simpler ones. This kinetic energy shows itself in the forms of mental and muscular work. The discharged energy can be replaced by re-formation of the complex substances through nutrition.

A large store of potential energy shows itself mentally — other things being equal — in a feeling of good nourishment. Whether this feeling arises directly from the nervous system or indirectly from the nature of the reflex-tonus and action of the internal organs and muscles, may be left undecided. A small store of potential energy is accompanied by a feeling of weakness.

The condition of good nourishment shows itself in 1. increased energy of the reflex-tonus; 2. increased force, quickness and precision of movement; 3. increased accuracy of coordination and association.

These are the fundamental factors in the production of good vocal sounds. Flabby muscles, that is, with poor tonus, do not have the firm configurations necessary for forming cavities with firm walls. Weak muscles cannot hold out against the work required of them. Slow muscles cannot perform to perfection the rapidly changing adjustments. Inaccurate control produces inaccurate results. Poor coordination produces defective results. The typical forms of these results have just been considered; their variations in conditions of poor nourishment have not been experimentally investigated.

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The defective results are often perceived by the speaker or singer; he instinctively tries to correct them by extra muscular exertion. The over-exertion of some muscles requires over-exertion of their antagonists in order to obtain the proper positions. This brings about an abnormal condition of the vocal organs and difficulty in movement and control. The larynx tone, for example, becomes a strained and fatiguing falsetto with little flexibility instead of a readily modulated chest tone; there is often huskiness of the voice owing to lack of precision in the vocal muscles; the weakened breath action has to be strengthened by a special effort.

The effects of fatigue are analogous to those of poor nourishment. The activity of a day's work or of direct electrical stimulation has been shown (HODGE) to result in a decrease in the active elements of the nerve cells. Fatigue, from this point of view, might be said to be the exhaustion of nourishment. Another element in a condition of fatigue arises from the presence of toxic products in the blood resulting from organic activity.[1]

The vocal effects of fatigue are marked; fatigue can appear in the voice even before it does in the face. The effects resemble those of poor nutrition but are not quite the same. Just what their elements are has not been experimentally determined; they probably appear, as in all voluntary action, in lack of steadiness, precision, quickness, endurance, etc.[2]

The voice in singing depends not only on the structure of the vocal organs and the ear but also on all the factors of vocal control that we have considered. These should be taken into account at the outset of special vocal instruction in order to avoid a mistaken career, and also for the possibilities of improvement. The troubles of singers arise not merely from laryngeal and aural defects but largely from those of control.

[1] Mosso, *Ueber d. Gesetze d. Ermüdung*, Arch. f. Anat. u. Physiol. (Physiol. Abth.), 1890 Supplem.-Bd. 89.

[2] SCRIPTURE, New Psychology, Ch. XVI, London, 1897.

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Laryngoscopic and otoscopic examinations should be supplemented by accurate tests of vocal action and auditory perception, by examination of their association, by various tests of control, and by as thorough a study of mental and bodily peculiarities as may be practicable.

We have now to consider some typical methods of altering the vocal control in defective speech; no general treatment of the subject will be attempted.

Defects of articulation often arise from lack of sensitiveness in regard to the motor organs, combined probably with a lack of acoustic sensitiveness which is usually developed

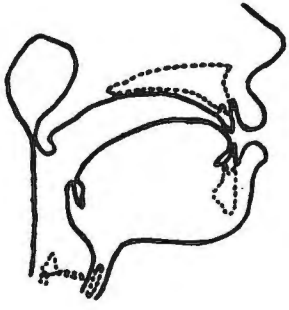

FIG. 300.

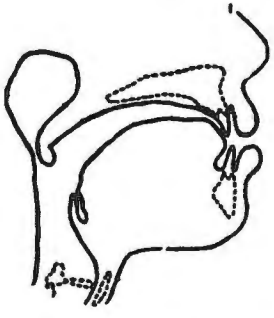

FIG. 301.

only in connection with correct articulation. They can often be corrected by special methods and devices. Two methods may be employed, education of the sensations of the motor organs directly, and education by appeal to another sense.

The direct education of the motor organs may be illustrated by the following cases. In producing s the tongue is usually slightly curved over the lower alveolæ,[1] the anterior dorsal portion being raised toward the upper incisor teeth and the palate without touching them, while the sides are pressed strongly against the molars and the upper lateral alveolæ. In this way a small narrow channel is formed through which the air rushes (Fig. 300). This may be called the ' interior

[1] ZÜND-BURGUET, *De la prononciation de l's et du š*, La Parole, 1899 I 281.

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lingual-alveolar s.' The s may also be formed by placing the point of the tongue behind the superior incisors so that it does not touch either the teeth or the alveolæ (Fig. 301). The rush of air then occurs between the point of the tongue and the palate. This may be called the 'anterior linguo-palatal s.' It is frequent in the speech of Roumanians. It is never so intense or clear as the other s; it readily becomes a kind of soft š if the point of the tongue is slightly pushed backward, or a lisped š if it is advanced a trifle too much toward the teeth. To transform the lisped s into the normal s ZÜND-BURGUET uses a little wire loop (Fig. 302) that catches the point of the tongue and directs it to the proper

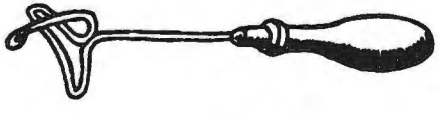

FIG. 302.

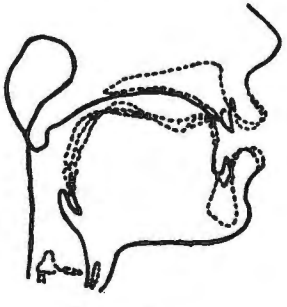

FIG. 303.

position. Great numbers of lispers have been cured with this. In producing š the sides of the tongue usually rest along the alveolæ and the superior molars (see preceding Chapters); the point of the tongue lies quite free between the anterior part of the jaw and the palate; the medio-dorsal portion rises toward the palate and forms with the point a little depression whose depth varies (Fig. 303). This little medio-lingual cavity forms a sort of resonance chamber that is of great importance for the sound. A second cavity is formed between the teeth and the lips by projecting the latter. The most frequent fault arises from touching the point or the dorsum of the tongue to the palate, whereby the sides of the tongue leave the teeth, and the air finds issue at one or both sides instead of through the medio-lingual cavity; this

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fault has been called 'chlintement' by ROUSSELOT on account of the resemblance of the sound to a kind of mixed š and l. The defect is readily cured by practice with a wire that directs the tongue down.[1] It is to be noted that this description of the formation of š differs considerably from those given by most other investigators, who do not specify the existence of any such medio-lingual cavity.

The auditory-motor associations may often be advantageously replaced by visual-motor ones.

The appeal to the eye is regularly made in teaching the deaf to speak. It is also used to advantage in the cases of persons whose defective movements cannot be corrected by auditory teaching. The manner of doing this for improving a foreigner's pronunciation has been illustrated by ROUSSELOT.[2]

In the case of a child of 11 years who used t for **k**, s and š, d for g, and l for ž, without yielding to any auditory correction and without evidence of any auditory or vocal defect, ROUSSELOT succeeded in producing the correct articulation by an appeal to the eye. He placed an exploratory bulb (Fig. 245) in his own mouth at the point of articulation for the t and pronounced successively **ta** and **ka**; the long lever of a tambour (p. 195) connected to the bulb made large movements for **ta** and none for **ka**. The child understood the difference, and after practice with a bulb in his own mouth was able to produce the sounds correctly. For **s**, **z**, š and ž the lever was arranged to pass over a paper with the proper position for each sound marked on it. Two lessons were enough to correct the fault in this case.

In teaching the distinctions of articulation among the palatal consonants, MEUNIER[3] has used two thin rubber chambers attached to an artificial palate (Fig. 304), each attached to a tambour (Fig. 305); as the correct articulations

[1] ZÜND-BURGUET, as before, 285.

[2] ROUSSELOT, *Applications pratiques de la phonétique expérimentale*, La Parole, 1899 I 401.

[3] MEUNIER, *Emploi de la méthode graphique pour l'éducation des sourds-muets* La Parole, 1900 II 82.

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are made, the lever of one of the tambours attached to the chambers will point to the proper letter on the cardboard diagram.

A similar method is of use[1] in teaching the proper pressure to be used in a certain articulation; a small bulb is used in teaching the precise place of articulation, a medium bulb in teaching the lip-pressure and a large bulb in teaching certain vowels. A mouth-piece inclosing a large bulb is useful in teaching the proper lip action, as, for example, in the French y (*u*). A bulb applied beneath the chin indicates the proper degree of

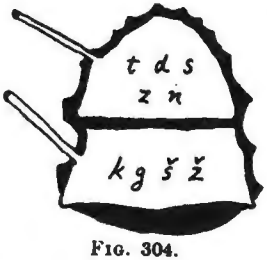

FIG. 304.

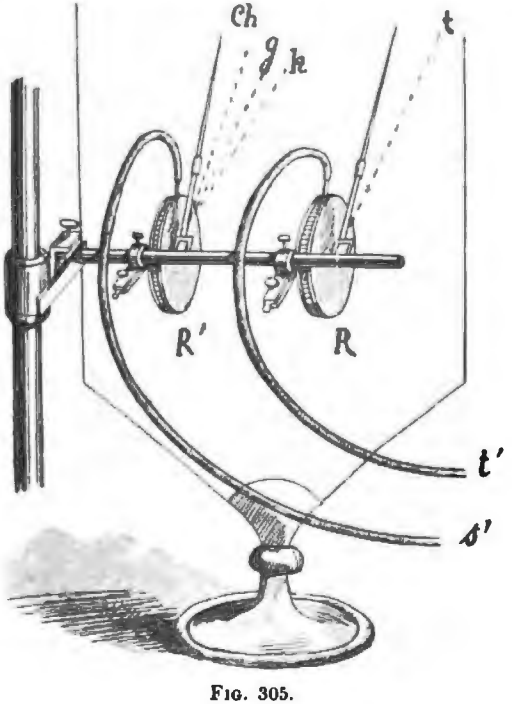

FIG. 305.

[1] ZÜND-BURGUET, *Applications pratiques de la phonétique expérimentale*, La Parole, 1899 I 18, 45, 149.

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tongue retraction for vowels like a, o, u. A bell-like alarm placed over the larynx serves to indicate sonancy. ZÜND-BURGUET uses an indicating alarm tambour to impress on the eye and ear the results obtained by air-transmission; the movement of the arm can be seen; an adjustable bell, placed at the point which should be reached by the movement, indicates to the ear the success of the articulation. The points to be reached in pronouncing various vowels may be indicated on a scale above the pointer; the movements necessary to produce the differences between closely related vowels can thus be taught. The indicator may likewise be used with a lip-bulb to teach such differences as those between e, i and y. Attached to a breath mouthpiece, the indicator shows impressively the difference between the greater expense of breath in English or German p, t, k and the smaller expense in French p, t, k, in which the glottis is closed during the explosion (Figs. 279, 280). Numerous other uses can be made of the ZÜND-BURGUET apparatus.

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PART IV

FACTORS OF SPEECH

CHAPTER XXVIII

VOWELS

THE necessity of a study of the physical nature of the vowels was emphasized by WILLIS. 'The mouth and its apparatus were constructed for other purposes besides the production of vowels, which appears to be merely an incidental use of it, every part of its structure being adapted to further the first great want of the creature, his nourishment. Besides, the vowels are mere affections of sound, which are not at all beyond the reach of human imitation in many ways, and not inseparably connected with the human organs, although they are most perfectly produced by them; just so, musical notes are formed in the larynx in the highest possible purity and perfection, and our best musical instruments offer mere humble imitations of them; but who ever dreamed of seeking from the larynx an explanation of the laws by which musical notes are governed? These considerations induced me, upon entering on this investigation, to lay down a different plan of operation; namely, neglecting entirely the organs of speech, to determine, if possible, by experiments upon the usual acoustical instruments, what forms of cavities or other conditions are essential to the production of these sounds, after which, by comparing these with the various positions of the human organs, it might be possible, not only to deduce the explanation and reason of their various positions, but to separate those parts and motions which are destined

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for the performance of their other functions, from those which are immediately peculiar to speech (if such exist).'[1] WILLIS's idea of studying the physical characteristics of the vowels has been developed by a series of later observers, finding its full expression in the study of curves of speech by the investigators referred to in Part I. In its perfection the 'physical definition of a vowel' will consist of a mathematical expression for the course of the molecular vibration which it involves.

The nature of the vibrations in spoken vowels can perhaps be made clear by a study of the records in Plate II.

The curves[2] shown in the Plate are from a record containing the nursery rhyme of *Cock Robin*, spoken by an American. The words in the Plate occur in the following phrases: 'I' in 'I, said the beetle,' 'my' in 'With my bow and arrow,' 'parson' in 'I'll be the parson,' 'saw him' in 'I saw him die,' 'caught' in 'Who caught his blood?' and 'said' in 'I, said the rook.' The record was traced off as described in Ch. IV. The equation beneath the Plate indicates the relation between length and time.

The curve for 'I' shows a series of vibrations in which each group resembles the neighboring one, while there is a gradual change in character from a typical form for the a in the first part to a typical form for the i in the second part of the diphthong ai of which the pronoun 'I' is composed. In the first portion there appears a succession of strong vibrations, each followed by a series of weaker ones. These strong vibrations recur at periods of steadily decreasing length.

If we consider separately each group of vibrations beginning with a strong one, we find that it is, aside from minor details, the typical curve (Fig. 4) of a vibration initiated by a blow and dying away by friction, for which the equation is

$$y = a \,.\, e^{-kt} \,.\, \sin 2\pi \frac{t}{T},$$

[1] WILLIS, *On vowel sounds, and on reed-organ pipes*, Trans. Camb. Phil. Soc., 1830 III 231; also in Ann. d. Phys. u. Chem., 1832 XXIV 397.

[2] SCRIPTURE, *On the nature of vowels*, Amer. Jour. Sci., 1901 XI 302.

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where y is the elongation at the moment t, a the amplitude, e the basis of the natural series of logarithms, k a factor representing friction and T the periodic time (p. 6).

The succeeding groups of vibrations following the first group are of the same form but of steadily increasing amplitude. They recur at steadily decreasing intervals. The formula for each group is approximately the same except for the difference in amplitude. The vibrations are evidently aroused by a series of blows (p. 11) of steadily increasing strength at steadily decreasing intervals.

It seems clear that these vibrations represent the free vibrations of the air in the mouth cavity aroused by a series of sudden blows and that these sudden blows are due to explosive openings of the vocal cords (p. 260).

The tone from the cords results from the succession of groups of vibrations; it is a tone of intermittence (p. 94). The period of the tone from the cords is represented by the distance from the strong vibration at the beginning of each group to the strong one at the beginning of the following group (p. 65).

The method of studying the details of such curves has been given in Ch. V.

The complexities of the small vibrations indicate the presence of several partial tones. These complexities change steadily from the beginning of the vowel onward as the pitch rises, in a way to indicate the presence of at least the following partials: 1. the fundamental cord tone consisting of a series of explosions rising from a period of 0.0170^s (frequency, 59) to one of 0.0052^s (frequency, 192); 2. a constant cavity tone of 0.0034^s period (frequency, 294); 3. a constant cavity tone of 0.0013^s period (frequency, 769) and 4. higher cavity tones undergoing change.

The minor complexities in the vibrations disappear at about one-quarter of the distance from the left on the second line in the figure. At the same time the amplitude is strongly increased. Shortly afterward the amplitude decreases and finally reaches zero. Throughout the whole

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latter portion the curve has an entirely different character from that of the first half; we are probably quite safe in considering it the curve of i in the diphthong ai. Throughout the i the groups consist of two vibrations, one slightly stronger than the other. The period for the group 0.0052" (frequency, 192) remains constant till near the end, where it lengthens to about 0.0122" (frequency, 82). The cavity vibration forming half of each group remains constant at 0.0026" (frequency, 384) through nearly all of the i. Toward the close it still apparently remains at the same period, producing phenomena of interference as the group period is lengthened.

From the curve for i it seems justifiable to conclude that the vocal cords emit explosions instead of sinusoid puffs of air here as well as in the a. The explosion produces a strong free vibration in the mouth cavity which is followed by another of diminished amplitude. This would be followed by a third of still less amplitude, just as in a, but a new explosion from the cords occurs at just that moment. The coincidence of double the period of the cavity tone with the period of the cord explosions explains the rapid gain in amplitude when the cord tone rises sufficiently to produce the coincidence (p. 13). The maximum is followed by a relaxation in the force of breath, but the two tones maintain the same relation for a considerable time. As the sound finally dies away, the cords also relax, both breath and pitch falling together. The explosions from the cords seem much less sharp in i than in a.

In ' my ' the m vibrations are too faint for accurate measurement. The a resembles somewhat, but not closely, the a of ' I.' The period of the cord explosions remains constant at 0.0074" (frequency, 135) instead of decreasing. The lower resonance tone has a period in the neighborhood of 0.0022" (frequency, 455); it apparently undergoes a slow change from the beginning of the a to the i.

The last third of the curve somewhat resembles the i portion of ' I.' There is, however, only a faint rise in ampli-

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tude, and the i portion is very brief. The vibrations in this portion are in groups of three; the groups have a period of 0.0074^s (frequency, 135) constant to the end. The vibrations within the group have a period one-third that of the group itself, indicating a constant cavity tone of 0.0025^s (frequency, 400).

In the a of ' parson ' the cord tone rises from a period of 0.0090^s (frequency, 111) to one of 0.0072^s (frequency, 139) and falls again to the pitch from which it started. There are indications of a constant cavity tone of 0.0022^s (frequency, 455) and of higher tones with changing periods. In respect to the pitch of the lowest cavity tone there is close agreement of this a with that of ' my,' yet the form of the curve resembles that of a in ' I ' more closely than that in ' my.' The peculiarity of ' my ' seems to lie chiefly in the suddenness with which the vibrations within a group fall in amplitude after the initial strong vibration. In both ' parson ' and ' I ' the cavity vibrations within each group during a die away less quickly. Such differences may perhaps find their explanation either in the greater friction in the free vibratory movement in the mouth (less rigidity of the walls?) or in the sharper character of the cord explosions in the case of ' my.'

The curve for ɔ in ' saw him ' indicates a quite different vocal action from that present in a. Instead of a strong initial vibration followed by decreasing ones the earlier portion of the vowel shows groups that contain at least two strong vibrations. It is presumably the case that the cord explosions are of a more gradual character or else that the action of friction is much less. Even later in the vowel where there is apparently only one very strong vibration in a group, this probably occurs because the lower portion of the second one is cut off by interference with another partial tone.

The cord tone, starting with a period of 0.0072^s (frequency, 139), remains at this pitch for a time and then falls to 0.0080^s in period (frequency, 125). A lower cavity tone with a period of 0.0026^s (frequency, 385) is apparently present.

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The last part of the line shows the vibrations for i, resembling those for i in ai of 'I' and 'my.' The middle portion, where there is a weakening in amplitude, belongs to the sonant h (p. 277). The m is just begun where the record is cut off. The grouping in the i is by threes. The cord tone of i starts with a period of 0.0083^s (frequency, 121) and steadily rises to one of 0.0072^s (frequency, 139) in the m. The lower cavity tone has a period of about 0.0025^s (frequency, 400).

Another example of 'saw him' from the same record was partially discussed in Ch. V and on page 277.

The curve for the ɔ of 'caught' exhibits a decided difference from that for the ɔ of 'saw,' although both vowels are generally considered to be the same. The ɔ of 'caught' shows a quick and strong increase in amplitude followed by a rather sudden decrease. Its pitch is approximately constant. The initial strong vibration of a group is followed by very much weaker vibrations; the vocal action resembles that in a rather than in the ɔ of 'saw.' In the last few groups there is a marked change as the ɔ alters to t.

The cord tone rises from a period of 0.0074^s (frequency, 135) to one of 0.0064^s (frequency, 156) but falls again in the last few periods. The lower cavity tone seems to have a period of about 0.0024^s (frequency, 417). Other tones of higher pitch are present.

In the e of 'said' the vocal action is seen to differ essentially from that in a or ɔ, and to resemble somewhat that in i. There is much less indication of the explosive character of the cord tone. There are three cavity vibrations to each group. The pitch of the cord tone is nearly constant at 0.0072^s period (frequency, 139); the lower resonance tone has a period of 0.0024^s (frequency, 417). There are minor fluctuations in the curve that indicate higher cavity tones. The amplitude increases steadily until the vowel is ended rather abruptly by the change to d.

The preceding account gives in general the pitch of only the lower cavity tones in each vowel. A determination for

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the higher tones would require more elaborate methods. It is probable that the higher tones are quite as important for the vowel characters as the lowest ones. The disagreement in the accounts of various investigators in regard to the tones found in the vowels may have arisen partly from finding different ones.

The results seem to justify the conclusion that the movement of the air in the mouth cavity is a free vibration and not a forced one. The curves of spoken vowels given in Plate II all show that the mouth tone is constant even while the cord tone is steadily changing. It follows from these facts that the period of the mouth tone is independent of the period of the cord tone and that there is no necessary relation between the adjustment of the size of the mouth cavity and the tension of the vocal cords. If the period of the mouth vibration is independent, it must be the period of the free or natural vibration.

Two theories have been held concerning the relation between the cord tone and the cavity tone; these may be termed the WILLIS-HERMANN and the HELMHOLTZ theories; the supporters of each have tried to prove them in various ways.

WILLIS[1] fitted a reed to the bottom of a funnel-shaped cavity and obtained sounds resembling vowels by modifying the opening of the cavity. He then tried closed cylindrical tubes of different lengths and found that different vowel-like sounds were produced by different lengths of the tube (p. 290). His experiments led him to the conclusion that the vowel-like sounds are produced by the repetition of one musical note in such rapid succession as to produce another. 'It has long been established, however, that any noise whatever, repeated in such rapid succession at equidistant intervals as to make its individual impulses insensible, will produce a musical note. For instance, let the musical note of the pipe be g^2 and that of the reed c^1, which is 256 beats a second, then their

[1] WILLIS, *On vowel sounds, and on reed-organ pipes*, Trans. Camb. Phil. Soc., 1830 III 231; also in Ann. d. Phys. u. Chem., 1832 XXIV 397.

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combined effect is $g^2 \cdot \cdot \cdot g^2 \cdot \cdot \cdot g^2 \cdot \cdot \cdot g^2 \cdot \cdot \cdot$ (256 in a second) in such rapid equidistant succession as to produce c^1, g^2 in this case producing the same effect as any other noise, so that we might expect *à priori*, that one idea suggested by this compound sound would be the musical note c^1.

'Experiment shows us that the series of effects produced are characterized and distinguished from each other by that quality we call the vowel, and it shows us more, it shows us not only that the pitch of the sound produced is always that of the reed or the primary impulse, but that the vowel produced is always identical for the same value of s [the length of the pipe]. Thus in the example just adduced, g^2 is peculiar to the vowel ɔ [as in 'all']: when this is repeated 256 times in a second the pitch of the sound is c^1, and the vowel is ɔ: if by means of another reed applied to the same pipe it were repeated 171 times in a second, the pitch would be f^0, but the vowel still ɔ. Hence it would appear that the ear in losing consciousness of the pitch of s [the length of the pipe] is yet able to identify it by this vowel quality. But this vowel quality may be detected to a certain degree in simple musical sounds; the high squeaking notes of the organ or violin speak plainly i, the deep bass notes u, and in running rapidly backwards and forwards through the intermediate notes, we seem to hear the series u, o, a, e, i, i, e, a, o, u, etc., so that it would appear as if in simple sounds, that each vowel was inseparable from a peculiar pitch, and that in the compound system of pulses, although its pitch be lost, its vowel quality is strengthened. . . . Having shown the probability that a given vowel is merely the rapid repetition of its peculiar note, it should follow that if we can produce this rapid repetition in any other way, we may expect to hear vowels. ROBINSON and others had shown that a quill held against a toothed wheel would produce a musical note by the rapid equidistant repetition of the snaps of the quill upon the teeth. For the quill I substituted a piece of watch-spring pressed lightly against the teeth of the wheel, so that each snap became the musical note of the

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spring, the spring being at the same time grasped in a pair of pincers, so as to admit of any alteration in length of the vibrating portion. This system evidently produces a compound sound similar to that of the pipe and the reed, and an alteration in the length of the spring ought therefore to produce the same effect as that of the pipe. In effect the sound produced retains the same pitch as long as the wheel revolves uniformly, but puts on in succession all the vowel qualities as the effective length of the spring is altered, and that with considerable distinctness, when due allowance is made for the harsh and disagreeable quality of the sound itself.'

Thus WILLIS maintains two theses: 1. that a vowel consists of [at least] two tones, a cord tone and a mouth tone; 2. that the mouth tone is independent of the cord tone in regard to pitch.

The theory of WILLIS was adversely criticised by WHEATSTONE,[1] who supposed that the vowels arose from the vibrations of the vocal cords through the strengthening of certain overtones by the resonance of the mouth. WHEATSTONE'S view was expounded as a general hypothesis by GRASSMANN[2] and developed into a theory by HELMHOLTZ.[3]

'We may well suppose that in tones of the human larynx, as in those of other reed instruments, the overtones would continuously diminish in intensity as their pitch is higher, if we could observe them without the resonance of the mouth. In fact they correspond to this assumption fairly well in those vowels that are spoken with widely-opened, funnel-like mouth-cavities, as in sharp a or e. This relation is, however, very materially changed by the resonance in the mouth. The more the mouth-cavity is narrowed by the lips, teeth, or

[1] WHEATSTONE, London and Westminster Review, 1837, p. 27.

[2] GRASSMANN, *Leitfaden d. Akustik*, Program d. Stettiner Gymnasiums, 1854; *Ueber d. physik. Natur d. Sprachlaute*, Ann. d. Phys. u. Chem., 1877 I 606.

[3] HELMHOLTZ, *Ueber d. Vokale*, Arch. f. d. holl. Beitr. z. Natur- u. Heilk., 1857 I 354; *Ueber d. Klangfarbe d. Vokale*, Gel. Anz. d. k. bayr. Akad. d. Wiss., 1859 537; also in Ann. d. Phys. u. Chem., 1859 CVIII 280, and in Ges. wiss. Abhandl., I 395, 397, Leipzig, 1882; Die Lehre v. d. Tonempfindungen, 5. Aufl., 168, Braunschweig, 1896.

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tongue, the more prominently its resonance appears for tones of very definite pitch, and by just so much more it thus strengthens those overtones in the tone of the vocal cords which approximate the favored degrees of pitch; and by just so much more the others are weakened.' [1]

'The pitch of the strongest resonance of the mouth depends only on the vowel for whose production it has been arranged, and changes essentially even for small changes in the character of the vowel, as, for example, in various dialects of the same language. On the other hand, the resonances of the mouth are almost independent of age and sex. I have found in general the same resonances for men, women, and children. What is lacking to the childish and female mouth in capacity can be easily replaced by narrower closure of the opening, so that the resonance can still be as deep as in the larger male mouth.' [2]

According to HELMHOLTZ, 'the vowel sounds are different from the sounds of most musical instruments, essentially in the fact that the strength of their overtones depends not only on the ordinal number of the overtone but above all on its actual pitch. For example, when I sing the vowel a on the note $e^{-1\flat}$, the reinforced tone is $\flat^1$, or the 12th partial, and when I sing the same vowel on the note $\flat^2$ it is the second one.' [3]

The theory of HELMHOLTZ necessitates the assumption of an accommodation of the resonance tone to the voice tone within quite a range; thus as the voice tone rises or falls the mouth must also change its tone or be able to extend its resonance to a considerable degree. This assumption was made by HELMHOLTZ, the range of accommodation being supposed to extend over as much as an interval of a fifth in music each way from the tone of best resonance. This view has been called the 'accommodation theory.' According to this theory the mouth must accommodate itself to one overtone of the cord tone, and when this rises or falls to a considerable degree

[1] HELMHOLTZ, Die Lehre v. d. Tonempfindungen, 5. Aufl., 170, Braunschweig, 1896.

[2] HELMHOLTZ, as before, 171.

[3] HELMHOLTZ, as before, 191.

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it must readjust itself to some other one in order to keep the resonance tone within a limited range.

The difference between the theories of WILLIS and HELMHOLTZ lies chiefly in the relation between the mouth tone and the cord tone; for the former there is no relation, for the latter the resonance tone is one of the overtones of the cord tone.

HELMHOLTZ devised an apparatus of electric tuning forks and with some success produced vowel-*like* sounds by combining different sets of tones (p. 291).

'WILLIS'S description of the acoustic movement in the vowels doubtless coincides closely with the truth; but it gives only the manner in which the motion occurs in the air, and not the corresponding reaction of the ear to this motion. That even such a motion is analyzed by the ear according to the laws of resonance into a series of overtones is shown by the agreement in the analysis of the vocal sound when it is executed and by the resonators.' [1]

HELMHOLTZ was greatly influenced in his theory by his views of the action of the ear.

The hypothesis that all regular vibratory movements reaching the ear are analyzed by it into a series of harmonics of the fundamental period is an assumption that seems to lead naturally to the HELMHOLTZ theory. This assumption, however, we must disregard at the present time; the problem concerns the nature of the vibratory movement characterizing a vowel and the solution must be found in an unbiased analysis of the vowel curve; the question of how the ear acts is a separate one.

The HELMHOLTZ theory was for a long time accepted in the main by later writers. It was made the basis of PIPPING'S first analysis of vowel curves.

PIPPING'S [2] work with HENSEN'S instrument (p. 20) led him to the following conclusions.

[1] HELMHOLTZ, as before, 191.

[2] PIPPING, *Zur Klangfarbe der gesungenen Vokale*, Zt. f. Biologie, 1890 XXVII 77.

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'In agreement with HELMHOLTZ I have found that each vowel is distinguished by one or more regions of reinforcement of constant pitch. The intensity of its partial tone is, *caeteris paribus*, greater as it coincides more accurately with the range of reinforcement.

'In regard to the range of the reinforcement I cannot agree with HELMHOLTZ. HELMHOLTZ does indeed state that the range can be different according to the opening of the mouth, the firmness of walls of the oral cavity, etc. But he lays so little weight on this difference that he does not attempt to use it in the characterization of the different vowels. To judge from page 183 of the "Lehre von den Tonempfindungen," HELMHOLTZ thinks that the range of reinforcement must extend in general at least a musical fifth above and below, and this is certainly not the case.

'Sung vowels contain only harmonic partial tones.' That is, a vowel produced by singing consists of a series of tones whose vibrations stand in the relations of 1 : 2 : 3 : 4 : etc.

'The intensities of the various partial tones do not depend to any essential degree on their ordinal numbers.' That is, in distinction from most musical instruments it is not a fact that the first partial is much the stronger and that the higher partials are in general weaker.

'The various vowels differ from each other in ranges of reinforcement which are of different numbers, width, and position in the scale of pitch.' That is, one vowel may have two ranges of reinforcement, another three, etc., and these ranges may differ.

On a later occasion[1] PIPPING believes that the range of accommodation may exceed even the limits allowed by HELMHOLTZ.

The first point at issue between the two theories may be thus stated: is a cavity tone found in a vowel necessarily an overtone of the cord tone?

Among the results that support the view of WILLIS we

[1] PIPPING, *Zur Lehre von den Vokalklängen*, Zt. f. Biologie, 1895 XXXI 573, 583.

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may notice those obtained by DONDERS with the SCOTT phonautograph (p. 17).

'Each of the fourteen vowels when sung on a constant tone produces a constant curve. . . . For each vowel the form of the curve changes with the pitch. This result is connected with the peculiarity of the vowels, that their timbre is determined not by overtones with a certain relation to the fundamental, but rather by overtones of a nearly constant pitch.'[1]

This last statement rests on the fact that if the tones of the mouth are overtones of the cord tone bearing a definite relation to it, such as 1st, 2d, etc., the curve will remain the same in form no matter what the pitch, just as the curve of vibration for a violin string has a typical form which persists in spite of changes in the pitch of the string. On the other hand, if the tone of the mouth is a constant one, as WILLIS assumes, the combined vibration produced by the cord tone and the cavity tone will change for any change in the pitch of the cord tone. DONDERS'S conclusion seems indisputable.

HERMANN'S investigations were carried out by transcribing the curves of song from the phonograph (p. 39). He finds that the essential fact in a vowel is the intermittent or oscillatory blowing of the cavity tone by the cords. Under such circumstances it makes no difference whether the cavity period coincides with any fraction of the cord period or not.[2] HERMANN thus supports the theory of WILLIS in asserting that the cavity tone is completely independent of the cord tone.

HERMANN has objected to the overtone theory of the cavity tone that in many voices it is so high above the cord tone that it cannot be supposed that an overtone of that pitch can possibly be present. Thus with the cord tone g^{-1} the vowel i has a strong cavity tone that would correspond to the 28th

[1] DONDERS, *Zur Klangfarbe der Vokale*, Ann. d. Physik u. Chemie, 1864 CXXXIII 528.

[2] HERMANN, *Phonophotographische Untersuchungen*, Arch. f. d. ges. Physiol. (Pflüger), 1890 LXXIV 380, 381.

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or 29th partial of the cord tone, whereas such a high partial, if present at all, would be too weak to be heard.[1]

In his latest investigations PIPPING[2] finds that the cavity tones are independent of the cord tone and abandons the HELMHOLTZ theory.

Similar independence of the cavity tone in some of the vowels when sung appears in the work of MERRITT (p. 27), NICHOLS and MERRITT (p. 28), BEVIER (p. 49), and others. In the analysis[3] of the curves of many cases of the diphthong **ai** (App. II) in words spoken in the chest register by a male voice, I find that the cavity tone in **a** is quite independent of the cord tone in pitch. The cavity vibration can be seen to remain of constant period while the cord tone rises through a distance of several octaves ***within a single vowel.***

HERMANN'S researches[4] on the modifications of tones by the telephone show that the partial tones of a complex are weakened by the transmission according to a definite rule: the amplitudes are transmitted in relative amounts directly proportional to the frequencies.[5] Thus, the three partials 100, 200, and 300 with the original amplitudes *a*, *b*, *c* would have after transmission the relative amplitudes $\frac{a}{3}$, $\frac{b}{2}$, $\frac{c}{1}$. The lower the original tone the weaker is the result. Bass music is greatly weakened in comparison with soprano. In spite of this difference between the original and the transmitted sound the vowels retain their specific characters; the relations of intensity between the tones of a vowel are therefore not essential characteristics of the vowel. Thus, the mouth tone in a certain vowel may differ greatly in intensity while that of the cord tone remains constant and yet the vowel will be heard as the same one.

[1] HERMANN, *Phonophotographische Untersuchungen*, Arch. f. d. ges. Physiol. (Pflüger), 1894 LVIII 274.

[2] PIPPING, *Zur Phonetik d. finnischen Sprache*, Mém. de la Société finno-ougrienne, XIV, Helsingfors, 1899.

[3] SCRIPTURE, *Researches in experimental phonetics (first series)*, Stud. Yale Psych. Lab., 1899 VII 1; *On the nature of vowels*, Am. Jour. Sci., 1901 XI 302.

[4] HERMANN, *Die Uebertragung der Vokale durch das Telephon und das Mikrophon*, Arch. f. d. ges. Physiol. (Pflüger), 1891 XLVIII 543.

[5] HERMANN, as before, 561.

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In the same research HERMANN also shows that the relations of phase have no influence on the character of the musical sound heard.[1]

These results of HERMANN'S appear irreconcilable with any vowel theory that regards the mouth as a resonator strengthening one or more of the partial tones of the cord tone.[2]

The failure to produce vowel curves by adding harmonics (p. 69) and to produce vowel sounds by compounding tones (p. 291) have already been mentioned. To these may be added the failure of wave discs representing sums of harmonics to give vowel sounds when used with a slit blast in a siren (p. 89). Curves for the wave siren produced by summing harmonic sinusoids according to the data given by AUERBACH for the vowels gave no satisfactory results.[3] Similar curves according to a FOURIER analysis (p. 71) of the vowels made by LAHR[4] gave[5] a and e well, o and u poorly, i not at all, and u for y.

In the face of such conclusive evidence it is hard to see any point in which a decision in favor of the theory proposed by WILLIS and developed by HERMANN can possibly be attacked. It is natural to assume that a theory found to be valid for one vowel will be valid for all; it is, of course, possible that other laws may hold good in other vowels, but until this possibility is proven we can treat all vowels on the independent-tone theory; at any rate, the cavity tone is not necessarily an overtone of the cord tone.

Several problems concerning the physical nature of vowels still remain: 1. the nature of the cord tone; 2. its method of arousing the cavity tones; 3. the nature of the cavity tones. These will now be considered.

WILLIS supposed the cord tone to be produced like a reed

[1] HERMANN, as before, 560.

[2] HERMANN, as before, 566.

[3] KŒNIG, *Bemerkungen üb. d. Klangfarbe*, Ann. d. Phys. u. Chem., 1881 XIV 369; also in *Quelques expériences*, 234, Paris, 1882.

[4] LAHR, *Die Grassmann'sche Vokaltheorie im Lichte des Experimentes*, Ann. d. Phys. u. Chem., 1886 XXVII 94.

[5] EICHHORN, *Die Vokalsirene*, Ann. d. Phys. u. Chem., 1890 XXXIX 148.

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tone, namely, by a series of explosive puffs. That this may be the case has been shown by the curves of HERMANN (p. 39); he says that an explosive puff followed by an interval of 'cord silence' (if I may use the term) is one of the essential characteristics of a vowel. Such a series would be similar to that emitted by a siren with holes passing before an air jet (p. 89).

This view is also supported by the following facts. A vibratory body, whatever its natural period, when acted upon by a force varying harmonically, must itself vibrate with the period of the impressed force. If the variations of the acting force are of the nature of a sum of harmonics, the period impressed will be that of one of them. If the cords acted like most musical instruments, their vibrations could be properly treated as the sum of a series of harmonics and the mouth tone would necessarily be one of them. The *forced* vibrations of the mouth cavity can include only harmonic partials of the larynx note.[1]

It has been shown above that the mouth tone is inharmonic to the cord tone and that it is a *free* vibration. It follows that the cord vibrations are not of the nature of the sum of a series of harmonics. HERMANN draws the conclusion that the vibrations of the cords must be of an explosive nature, to which a harmonic analysis is not applicable. To this it has been answered that when the cavity tone is high in relation to the cord tone, the treatment by analysis into a series of harmonics may not be applicable and that this may not disturb the usual views of resonance, but that, when the natural period of the vocal cavity is not distant from the cord period, the cavity must vibrate with a period that is harmonic to the cord period.[2] RAYLEIGH apparently does not regard the deductions of HERMANN as conclusive. The issue seems clearly presented in the curves of the nature of those in Plates I and II. In the first part of the vowel a in 'I' the cord tone rises steadily till it is only about a duodecime below

[1] RAYLEIGH, Theory of Sound, 2d ed., II § 397, London, 1896.
[2] RAYLEIGH, as before, § 397.

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the cavity tone, and yet the latter remains constant with no tendency to become one of the harmonics of the cord tone. Continuing along the curve, we find that beyond the middle the period of the cavity vibration is somewhat lengthened while that of the cord vibration continues to become shorter. In the latter third of the curve the vibrations are clearly in groups of twos, alternate ones being stronger. As the change from the a portion to the i portion is continuous without anything like a break that might indicate a sudden readjustment of the cords, each pair of waves in the i portion must belong to one cord vibration and each single wave must represent a cavity vibration. The cavity period is slightly less than half the cord period. Thus, even when the two tones used in forming the vowel i are nearly in the relation of a simple musical interval, there is no accommodation of one to the other in respect to period. It is to be noticed that the first vibration of each pair in the i is stronger than the second, just as in the a portion the first vibration is stronger than the following ones. It is worthy of remark that the relative strengths are not the same in the two cases, and that the character of the explosion from the cords must differ to some extent in the two halves of ai. Similar conditions are found in the other vowels.

Such relations between the cord vibrations and the cavity vibrations are incompatible with the theoretical requirements of the supposition of the sinusoidal nature of the cord vibration. The conclusion seems quite justifiable that the cords emit a series of puffs, or explosions of air, instead of vibrating regularly back and forth. The same conclusion was reached above (p. 260) from a study of cord action.

The sharpness of explosion is, I believe, a matter of degree. HERMANN seems to consider all explosions as very sharp; the intermittence — or period of cord silence — he has even asserted to be an essential of the vowel character. That the intermittence is not necessary can be seen in HERMANN'S curves for i, 1, etc. (p. 39). In my curves I find vowels with all degrees of sharpness of explosion.

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I would amend the WILLIS-HERMANN view by saying that the cords emit a series of puffs whose nature may vary from the sharpest of explosions to a perfectly smooth sinusoid. I would also add, as already stated (p. 94), that the character of the sound emitted by the cords depends essentially on the nature of the puff.

The manner in which the cord tone arouses the cavity tones can now be definitely stated.

WILLIS considered the mouth and cords to be analogous to a reed pipe. Each vibration of the reed sends a wave of condensation and rarefaction along the pipe. When the pipe is of such a length that this wave is reflected back in such a way as to reinforce the vibration of the reed, the cavity tone is a loud one. Thus, when a properly adjusted resonator is placed behind a vibrating fork the tone of the fork is strongly reinforced (p. 14). The reinforcement is also strong when the resonator period coincides with a sub-multiple of the reed period.

Such a coincidence between the periods of the cavity tone and the reed tone is not necessary. Each impulse from the reed may be considered as striking the pipe with something of the nature of a blow, whereby the proper tone of the cavity itself may be aroused for an instant (p. 285). The pipe may thus have its own pitch and be heard, no matter what relation there may be between it and the pitch of the reed. When the blow from the reed is rapidly repeated, both the reed tone and the pipe tone will be heard (p. 94).

Such a method of producing cavity tones has been declared to be impossible by HENSEN,[1] who remarks that air from a reed pipe cannot arouse a resonance tone. The experiment on which he bases this statement consisted in placing a resonator at the end of a reed pipe. At a certain pressure of air the pipe sounded its own tone, at a different pressure it was silent. The resonator sounded only when the pipe was silent. Nevertheless there were occasions when both the pipe tone and the resonance tone appeared together.

[1] HENSEN, *Die Harmonie in den Vokalen*, Zt. f. Biol., 1891 XXVIII 39.

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To these experiments and deductions HERMANN replied that a labial pipe can be used to sound a reed pipe, and some experiments were made to demonstrate the fact.[1]

I have attempted in another way to show that a series of puffs of air of any periodicity may be used to sound a labial pipe of any pitch.

A disc with its edge cut into waves forming approximately a sine-curve (Fig. 2) was rotated by an electric motor at any desired speed. Its edges passed between the ends of two pieces of rubber tubing so arranged that the air blown into one of them passed directly into the other one if the waves of the disc permitted; the position was so chosen that the waves of the disc regularly interrupted the air current completely. The farther end of the rubber tubing was flattened and placed so as to blow against the edge of a piece of brass pipe stopped at the other end. In this manner a series of puffs from the disc was used as the blast of a pipe. The experiment began with the disc at rest and the air passage free. A current of air was blown through the tubing; the pipe gave forth a tone. The disc was then set in rotation; the tone of the pipe was regularly intermitted. As the disc moved faster, this intermittence became more rapid. Finally, the intermittence itself was heard as a tone in addition to the pipe tone (p. 94). Thus an intermittent air current, such as is employed for producing tones directly (p. 89), can be used to produce a pipe tone in addition. The development of this apparatus into a vowel producer has been mentioned on p. 293.

I have succeeded in arousing the tone of a closed tube by blowing through a membrane pipe (p. 258). The pipe was made by binding a piece of thin soft rubber around the end of a glass tube. Two opposite points of the thin-walled rubber tube thus made were each caught between the thumb and finger; the membrane was then stretched till the sides came together. A blast of air through the tube set these edges in vibration and produced a tone. By placing

[1] HERMANN, *Weitere Untersuchungen ü. d. Wesen d. Vokale*, Arch. f. d. ges. Physiol. (Pflüger), 1895 LXI 195.

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the edges at the right spot over the mouth of a bottle or a test-tube or a key (Fig. 74) the tone of the latter could be distinctly heard in addition to that of the pipe. The pitch of the membrane tone could be altered at will. It was not so easy to arouse a tube of low pitch, such as a bottle, because the volume of air passing through the pipe was not large.

It can thus be regarded as definitely settled that the current of air from a reed can be used to arouse a tone in a cavity properly adjusted to receive the air. To this statement we may add that the reed tone and the cavity tone may vary independently of each other, but that the cavity tone is loudest when its pitch is higher than that of the reed tone.

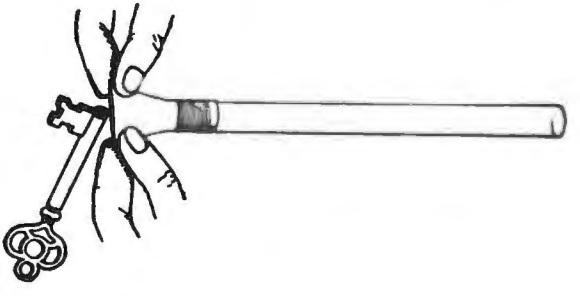

Fig. 306.

Willis's view of the way in which the cavity tone was superimposed on the reed tone is very explicit. 'According to Euler,[1] if a single pulsation be excited at the bottom of a tube closed at one end, it will travel to the mouth of this tube with the velocity of sound. Here an echo of the pulsation will be formed which will run back again, be reflected from the bottom of the tube, and again present itself at the mouth, where a new echo will be produced, and so on in succession till the motion is destroyed by friction and imperfect reflection.

[1] Euler, *Conjectura physica circa propagationem soni*, Opuscula II; and in Tentamen novae theoriae musicae, Petropoli, 1739.

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. . . The effect, therefore, will be a propagation from the mouth of the tube of a succession of equidistant pulsations alternately condensed and rarefied, at intervals corresponding to the time required for the pulse to travel down the tube and back again; that is to say, a short burst of the musical note corresponding to a stopped pipe of the length in question will be produced.'[1]

The true view of the action of the cords in producing a cavity tone seems to be the following one. The sudden puff of air from an explosive opening of the cords may be considered to act as a piston compressing the air before it in the vocal cavity. The air acts as a spring by its resistance to compression and drives the piston back beyond its position of equilibrium; the resistance to dilatation draws it back, and so a vibratory movement is set up. Under these circumstances the air acts merely as a spring; the form of the cavity is immaterial and the period of vibration remains the same, provided the capacity is not varied. The single impulse of the piston thus makes the cavity a source of vibration, whose period remains practically constant but whose amplitude steadily diminishes from loss of energy mainly by communication to the external air (Fig. 4). Such vibrations are seen in the curves for a in Plates I and II. This view is an adaptation of that given by RAYLEIGH for resonators in general (p. 28).

The question still remains as to the nature of the tone thus produced in the cavity.

There are cases in which the HELMHOLTZ view of the action of the vocal cavity might seem to have a possibility of correctness. If we assume (1) that a uniform condition has been attained, (2) that the natural period of the cavity does not differ greatly from that of the cord period, and (3) that the cord vibrations are not of an explosive nature, it follows that the effect of the cavity can only be to modify the intensity and phase of the partials of the cord note. The partial or partials nearest to the natural periods of the mouth

[1] WILLIS, as before, 243.

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cavity will be reinforced, and they can be found from the speech curve by the FOURIER analysis. The cavity tone must thus have a period of one of the overtones in the cord tone.

Under the assumptions made above, the vibration of the cavity is a 'forced' one, and the conclusion concerning the action of the vocal cavity is necessarily correct.[1] The first and second assumptions made above have been explicitly stated by RAYLEIGH, who concludes that both the WILLIS-HERMANN and the HELMHOLTZ ways of treating the action of the cavity are legitimate and not inconsistent. 'When the relative pitch of the mouth tone is low, so that, for example, the partial of the larynx note most reinforced is the second or the third, the analysis by FOURIER'S series is the proper treatment. But when the pitch of the mouth tone is high, and each succession of vibrations occupies only a small fraction of the complete period, we may agree with HERMANN that the resolution by FOURIER'S series is unnatural, and that we may do better to concentrate our attention upon the actual form of the curve by which the complete vibration is expressed.'[2] The two forms of treatment imply that the cavity tone is to be considered in the one case as a free vibration of the air in the cavity, and in the other case as a forced vibration. . Some cases of i in my study[3] of ai may be reconciled with the HELMHOLTZ view, the resonance tone being an overtone of the cord tone and changing with it. All cases of a and most of those of i are decidedly inconsistent with the overtone theory. Possibly the variation from the overtone theory arises from the explosive manner in which the cords open. The general description of their action for ai probably holds good even when the cavity tone is only about an octave above the cord tone; each puff of air is stronger at the start and fades away, setting the air in the vocal cavity into free instead of forced vibration. This general characteristic can be traced in each ai even to the point

[1] RAYLEIGH, Theory of Sound, §§ 48, 66, 322k, 397, London, 1894, 1896.
[2] RAYLEIGH, as before, § 397.
[3] Appendix II.

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where the resonance tone is slightly lower than the octave of the cord tone.

In my opinion the explosive blow theory (free vibration of the vocal cavity) and the overtone theory (forced vibration) express the conditions in the extreme cases. When the puffs have infinitely sharp forms the former is necessarily correct; when they are sinusoidal the latter is also necessarily correct. Puffs of forms between these extremes will modify the waves from the vocal cavity according to their forms. For a very sharp puff the vibration in the speech curve will have the period of the cavity with an initial amplitude depending on the energy of the puff; the vibration will fade away rapidly. For a puff of the same total energy the initial amplitude will be less as the puff becomes less sharp, the period remaining that of the free vibration of the cavity; the vibration will fade away less rapidly. For sinusoid puffs the cavity vibration will have an amplitude depending on the relation between the natural period of the cavity and the period of the puff; for harmonic relations it will be greater, for inharmonic ones smaller; there will be no fading away.

We are thus justified in defining a vowel physically as a vibratory movement, consisting of a series of puffs of more or less explosive form and of one or more free frictional sinusoids (aroused by the action of each puff) whose periods are those of the natural tones of the cavities.

Free vibrations (p. 2) are frictional sinusoids (p. 5) when there is no constant supply of energy (p. 14). Since the soft walls of the mouth cause great damping or loss of energy, the value of the frictional factor k (p. 6) is large and the vibrations die away quickly. The rapidity of decrease may be clearly seen in the resonance vibrations in the first portion of 'I' in Plate II. As the puffs from the cords become stronger, the free vibration lasts longer. As the puffs come at shorter intervals, the last vibration does not have time to die away before the impulse comes from the next puff. The phenomenon of resonance thus appears, as shown in Fig. 14.

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We will now consider the auditory nature of a vowel.

A sung vowel can be heard to include at least one tone, namely, the voice, or cord, tone. Even a spoken vowel has some general pitch character to it. This cord tone is practically lacking in whispered vowels (p. 274). Since the whispered vowels can be distinguished from other sounds and from each other, and since they seem to vary in pitch, it is evident that vowels possess other tones than the cord tone. Since these vary with the adjustments of the vocal cavities, we may call them 'cavity tones.'

It is clear that a sung vowel consists of at least the cord tone and one cavity tone. Does the vowel character depend on the relation between these two tones?

A direct proof that the vowel characteristic cannot lie in such a relation has been obtained by singing vowels into the phonograph going at the usual speed and then reproducing them at quite different speeds.[1] A change in the speed of the record not only changes the pitch of the cord tone but also changes the vowel. In HERMANN'S experiments,[2] with increase of speed e approached the sound of i, u that of o, and finally all vowels approached a sound between e (ä) and œ; with decrease of speed all the vowels approached a bleating sound resembling œ. In running a celluloid phonograph at different speeds I have found that the French a in 'pas' changes to e as the speed is increased, and to ɔ as it is decreased. Experiments of the same kind by ROUSSELOT[3] show that changes in speed produce systematic modifications in the vowels, the amount of change required to reach a given modification being different for different speakers. With decreasing speed the vowels appear to become as indicated in the following list: $a_3 \rightarrow ɔ \rightarrow o_1 \rightarrow œ_1$; a_1

[1] BLAKE AND CROSS, *Helmholtz's vowel theory and the phonograph*, Nature, 1878 XVIII 93; CROSS AND WENDELL, *On some experiments with the phonograph relating to the vowel theory of Helmholtz*, Proc. Amer. Acad., 1892 XXVII 271.

[2] HERMANN, *Ueber das Verhalten der Vokale am neuen Edison'schen Phonographen*, Arch. f. d. ges. Physiol. (Pflüger), 1890 LXXIV 42.

[3] ROUSSELOT, Principes de phonétique expérimentale, 226, Paris, 1897.

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$\rightarrow a_3 \rightarrow o_1 \rightarrow \text{œ}_1$; $e_1 \rightarrow e_3 \rightarrow ɔ \rightarrow \text{œ}_1 \rightarrow \text{œ}_3$; $e_3 \rightarrow i_2 \rightarrow y^1 \rightarrow \text{œ}_1 \rightarrow \text{œ}_3$; $i_2 \rightarrow$ gradually weaker i_2 or $\rightarrow$ y; $\text{œ}_1 \rightarrow$ gradually weaker œ_1, or $\rightarrow \text{œ}_3$; $\text{œ}_3 \rightarrow$ gradually weaker œ_3, or $\rightarrow$ y, or $\rightarrow$ u; y $\rightarrow$ gradually weaker y $= \text{œ}_2$, or $\rightarrow$ gradually weaker y $\rightarrow$ u; $o_3 \rightarrow$ u; $o_1 \rightarrow o_3 \rightarrow$ u; u $\rightarrow$ gradually weaker u. The inferior numerals indicate varieties of a vowel as in Ch. XXIII.

These phonograph experiments show not only that an important essential of the vowel character does not lie in the relation of the cavity tone to the cord tone, but also that it does lie in the presence of a tone of a limited range of pitch.

Similar evidence is furnished by the attempts to manufacture vowels. When a band of metal is carefully cut so that its edge reproduces the curve of a vowel, and is made to pass in front of a narrow slit from which a blast of air issues, the vowel itself is distinctly heard when the frequency with which the waves of the edge pass the slit is the same as that of the original cord vibrations, and therefore when the cavity tone is of the original pitch. At other frequencies the vowel sound appears modified. An essential characteristic of many vowels is thus a fixed cavity tone.[1]

The supposition that a vowel requires a cavity tone of a certain pitch can be tested by removing that tone. This has been done[2] by the use of interference tubes adjusted to kill any tone with its even-numbered overtones or with its odd-numbered overtones. Most vowels (especially a and o) became nasalized by extinction of the cavity tone and its odd overtones, with a greater or less change of the special vowel character. All vowels with high cavity tones (e, i, œ, y, æ,) became a deep indefinite murmur when the chief cavity tone was removed. With the extinction of its higher cavity tone a $\rightarrow o^n$; with extinction of its lower one a $\rightarrow æ^n$

[1] HERMANN, *Ueber die Prüfung von Vokalkurven mittels der König'schen Wellensirene*, Arch. f. d. ges. Physiol. (Pflüger), 1891 XLVIII 574.

[2] SAUBERSCHWARZ, *Interferenz-Versuche mit Vokalklängen*, Arch. f. d. ges. Physiol. (Pflüger), 1895 LXI 1.

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though rather indefinitely. The vowel æ was completely annihilated by loss of its cavity tone. From the agreements and differences in his results SAUBERSCHWARZ concludes that the vowel-characteristic lies in tones of certain relations of pitch, in some vowels a fixed tone being the most prominent element, in others a certain overtone of the cord tone.

The supposition[1] that the essential of vowel character lies solely in the relations of two or more cavity tones to each other and that these tones may be of any pitch is devoid of the slightest foundation (p. 292). A relation between cavity tones of fixed pitches may be suggested[2] as requisite for the vowel character, but this seems hard to reconcile with HERMANN'S telephone experiments (p. 412).

The conclusive proof of the relations of the cavity tones in the vowels is given by exact determinations of the vibrations necessary to produce the proper effect on the ear. The considerations presented in this Chapter have shown that the vowel-character — that is, its distinctiveness to the ear — depends at least partly on fixed cavity tones.

The 'essential characteristic' means that characteristic which is most effective in enabling the ear to distinguish certain groups of sounds that we designate as a, e, i, etc. There are other possible groupings of vowel sounds and other characteristics of them all and singly. One characteristic that varies among them is the character of the cord puff. This seems to differ in the various vowels. It has already been noted (p. 291) that u and o can be approximated by using tones with sinusoidal puffs, while the others cannot.

Generalizing from the individual peculiarities of different speakers, I would say that a sung vowel consists of a voice tone with its various overtones, and of various cavity tones, these tones being in pitch independent of the voice tone.

[1] LLOYD, *Speech sounds; their nature and causation*, Phonetische Studien, 1890 III 275, 278; 1890 IV 39; 1891 V 125; *The genesis of vowels*, Jour. Anat. Phys., 1897 XXXI 233.

[2] M'KENDRICK, *Observations on the theories of vowel sounds*, Proc. Roy. Soc. Edin., 1897-1899 XXII 71, 87.

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The different vowels are distinguished 1. by a fixed region of pitch for each vowel, and 2. by certain relations among the cavity tones. It should be added that these distinctions are not perceivable by the ear directly, but go to make up the characteristics that distinguish unit-sounds from each other.

Turning now to the motor nature of vowels, we may distinguish between whispered, sonant, and surd vowels.

A whispered vowel implies 1. a contracted passage, generally at the glottis (p. 274), to produce a fricative noise; and 2. a cavity or series of cavities in front of this passage through which the fricative noise passes. A slight degree of sonancy often seems to be present (p. 275). The character of the whisper noise varies greatly. The cavities probably resonate (p. 13) to periodic impulses picked out of the irregular fluctuations in the rush of air.

A sonant vowel implies a vibration of the vocal cords and a fairly constant open adjustment of the cavities. In cases of extirpation of the larynx an artificial larynx may sometimes be inserted. A vibrating reed takes the place of the vocal cords.

A surd vowel consists typically of a cavity or series of cavities through which an unobstructed current of air passes. There is none of the glottal friction which is present in the whispered vowels. The cavities are aroused to resonance. Surd vowels are very weak sounds.

We thus have as physiological definitions: whispered vowel = laryngeal friction + faint cavity resonance; sonant vowel = cord vibration + cavity vibration; surd vowel = breath + cavity resonance. These are typical forms; the actual vowels often combine them in succession.

Speech is sometimes possible when the laryngeal passage is entirely closed. The voice of HICKEY[1] in speech and in

[1] COHEN, Trans. Phila. County Med. Soc., 1892 XIII 302; Trans. Coll. Phys. Phila., 3d series, 1893 XV 131; *Ein Fall von gut modulationsfähiger Stimme u. s. w.*, Arch. f. Laryngol. u. Rhinol., 1894 I 276; ALLEN, *Speech without a larynx*, Med. News, 1894 Mar. 17.

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song is audible at a distance of 12 meters; it appears to be a true voice and not a whisper, perhaps due to vibratory movement of some edge within the cavity. Such a vowel consists of edge vibration + cavity resonance.

In such cases where the laryngeal passage is entirely obstructed a peculiar kind of whispered vowel may be produced by gathering air in the mouth or pharyngeal cavities and emitting it. Such a vowel consists of mouth or pharyngeal friction + cavity resonance.

In cases with a closed larynx and an external tracheal aperture a metallic reed may be inserted in the aperture whereby a musical tone may be produced while a vowel is whispered by the mouth. Such an abnormal vowel would be defined as reed vibration + mouth or pharyngeal friction + cavity resonance.

The supposition that spoken and sung vowels consist of whispered vowels + a cord tone is an absurdity. 'The concomitant resonances [mouth tones] which create or constitute vowel quality are animated, primarily and essentially, by the irregular noises which issue, "together" with the vocal tone from a speaking or singing glottis, but "without" it from a whispering one. Some of these are always found capable of affording just the appropriate impulse, and of kindling the resonances of the configuration [mouth cavity].'[1] A whispered vowel produced at the same time with a violin note does not become a sung vowel by the addition. Moreover, the addition of the cord tone necessarily produces a vibration of the resonance cavity far stronger than any obtainable by whispering — one that would utterly overpower a whisper element. Finally, in ordinary speech there is no whisper action added to the cord vibration; even a small whisper action in the cords while vibrating produces a breathy tone (p. 273) readily noticed by the ear as abnormal.

The different vowels have been usually defined according to the relation between the maximum elevation of the tongue

[1] LLOYD, *Speech sounds: their nature and causation*, Phonet. Stud., 1890 III 277.

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and the roof of the mouth + certain types of lip action + the condition of the nasal opening. The place of the maximum elevation of the tongue — its so-called ' articulation ' (p. 325) — is named ' velar ' (' guttural ') or ' palatal,' according as it occurs in the region of the velum or the hard palate. The size of the opening may be typified as ' high, mid, low ' (referring to the degree of elevation of the tongue).[1] In regard to another distinction,[2] the division into ' narrow ' and ' wide ' (or ' primary '), there is much uncertainty and dispute; even the existence of such a difference is denied.[3] The firmness of contraction of the tongue muscles is added in the terms ' tense ' and ' lax.' The lip action is typified as ' neutral,' ' rounded ' or ' spread.' Nasal modification is indicated by ' nasality.'

The motor relationships of the vowels have been indicated in various systems with more or less accuracy. These systems are useful for various purposes, but have led to the misconception of the maximum tongue movement as the essential of the vowel, whereas the whole course of the ever-changing movement must be considered (p. 325).

SWEET'S system[4] of the vowels is given in the following list; his phonetic characters (Romic) are enclosed in quotation marks: UNROUNDED, *back*: high, ' ʌ,' Gaelic l*a*ogh; mid, ' a,' b*u*t, f*a*ther; low, ' ɐ,' French p*a*s; *mixed*: high, ' ɪ,' Welsh *u*n; mid, ' ë,' *e*ye, bett*er*; low, ' ä,' h*o*w, s*ir*; *front*: high, ' i,' b*i*t, s*ee*; mid, ' e,' m*e*n, s*ay*; low ' æ,' c*a*re, m*a*n; ROUNDED, *back*: high, ' u,' p*u*t, t*oo*; mid, ' o,' b*oy*, s*ow*; low, ' ɔ,' n*o*t, l*aw*; *mixed*: high, ' ü,' Norwegian h*us*; mid, ' ö,' fell*ow*; (no example for low); *front*: high, ' y,' Fr. l*une*; mid, ' ə,' Fr. p*eu*; low, ' œ,' Swedish f*ör*. It should be noted that the English key-words refer to the sounds used

[1] SWEET, Primer of Phonetics, § 35, Oxford, 1890.

[2] BELL, Visible Speech, 40, London, 1867; Science of Speech, 14, Washington, 1897; SWEET, Primer of Phonetics, 18, Oxford, 1890.

[3] EVANS, *On the Bell vowel system*, Phonet. Stud., 1889 II 1, 113; SOAMES, Introduction to Phonetics, § 96, London, 1899; references in BREYMANN, Die phonetische Literatur, 41, Leipzig, 1897.

[4] SWEET, as before, 21.

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in the London pronunciation; some of them differ considerably from those commonly heard in America.

VIETOR[1] classifies the chief vowel types on mixed auditory and motor principles: *A.* pure vowels: *a.* guttural vowels, 1. the u sounds, 2. the o (ɔ) sounds, 3. the a sounds; *b.* palatal vowels: I. unrounded, 1. the e (æ) sounds, 2. the i sounds; II. rounded, 1. the œ sounds, 2. the y sounds; *c.* guttural-palatal vowels; *B.* nasal vowels.

The system of the *Association Phonétique Internationale*[2] is the following:

	PALATAL	VELAR
close	i y ɪ ʏ	ɨ ʉ ɯ u ʊ
half-close	e ø	ɘ ɵ ɤ o
medium	ə	
half-open	ɛ œ ɜ ɞ ʌ ɔ	
open	æ ɐ a ɑ	

A further development of this system has been proposed[3] as follows:

MOUTH PASSAGE:	LIPS:	TONGUE ARTICULATION: PALATAL		VELAR
very close	rounded	y	ʉ	u
	unrounded	i	ɨ	ɯ
close	rounded	ʏ		ʊ
	unrounded	ɪ		ɯ̈
half close	rounded	ø	ɵ	o
	unrounded	e	ɘ	ɤ
half open	rounded	ɸ	ɤ̈	ɔ
	unrounded	ɛ	ʌ	ʌ
open		æ		ɐ
very open		a	ɑ	

All the vowel systems 'suffer from the defect that they rest mostly on inaccurate observation and subjective estimates — especially in the case of the forms of articulation. It is to be hoped that . . . experimental phonetics will lead also to

[1] VIETOR, Elemente d. Phonetik, 4. Aufl., Leipzig, 1898.
[2] Used in Le maître phonétique (edited by PASSY) and a number of books.
[3] Ideophonic Texts (edited by PIERCE), New York.

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an exact vowel-system of cultured German, English and French.'[1]

The nasal vowels have been mentioned above (p. 339); they have been discussed at length by ROUSSELOT.[2]

Great differences are found in the 'attack,' or 'on-glide' (I would prefer the term 'entrance') of a vowel. In German an initial vowel regularly begins with the glottal catch (p. 278); the glottis is firmly closed, the cords are stretched to nearly the pitch required for the vowel, and the vibration begins suddenly with considerable amplitude. In American speech an initial vowel begins regularly with small tension of the cords and with small amplitude. This appears clearly in the curves for ai (Plates I and II), a (Plate VIII), ɔn (Plate X, line 5), and in the cases of ai discussed in Appendix II. In general the American initial vowel begins with a low pitch and rises more or less rapidly; in exceptional cases it is constant or falling, as in the interjection of satisfaction a (Plate VIII), and in ai 'eye,' at the end of a phrase (Appendix II). In connected speech an 'initial vowel' means, of course, a vowel at the beginning of a phrase after a pause. French attacks resemble the American ones; Hungarian attacks resemble the German ones; in German Swiss (St. Gall) they seem to vary.[3] The *coup de glotte* of singers is the German attack; for Americans it is an artificial action that must be learned; it sometimes produces nodules on the cords in Americans, probably due to inaccurate and too energetic action.

The exit of final vowels (in a phrase) seems among Americans to consist regularly in a fading of intensity often with a fall in pitch. This is clearly seen in the final o of 'sparrow' (Plate I), i in ai of 'I,' i in ai of 'my' (Plate II), a of 'ha,' e (ɔ^{n}) of 'eh' (Plate VII), a of 'ah' (Plate VIII), a of 'ah' (Plate XI). In French and Hungarian a single record of

[1] VIETOR, Elemente d. Phonetik, 4. Aufl., 64, Leipzig, 1898.

[2] ROUSSELOT, Principes de phonétique expérimentale, 2me partie, 532, 582, Paris, 1901.

[3] ROUSSELOT, as before, 484.

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each [1] seems to indicate a somewhat less gentle exit for the isolated vowel œ.

The term 'vowel' is often used in contrast to 'diphthong.' The supposition that a vowel is of constant character throughout its duration is, however, quite erroneous, many of the vowels being as thoroughly diphthongized as the usually recognized diphthongs. The term 'vowel' is properly used to indicate the class of open sounds. These sounds may be of all degrees of constancy. A perfectly constant vowel may be termed a monophthong, one with two clearly distinguishable parts a diphthong, one with three a triphthong, etc. The diphthongal character of a vowel may be primarily settled by its effect on the ear; it may be due to changes in the pitch of the cord tone or of any of the cavity tones, or to changes in intensity.

'Diphthongization' may be used to indicate a difference between the beginning and the end of a sound. A sound beginning like an a might change till it ended like an i; such a changing vowel might be said to be diphthongized. The change might not be distributed evenly throughout the vowel; it might change at first slowly, then more rapidly, and then again more slowly. A case might occur where the sound beginning like an a did not pass evenly into i, but changed more rapidly in its interior; such a sound might be considered as a + glide + i. This latter case is generally the one in mind in discussions of diphthongs. Again, a vowel might undergo little change during most of its length but a rapid change just as it ended. Thus we might have a + glide. Finally, a rapid change might occur at the start, after this the vowel being as constant as any vowel ever is. Thus we might have glide + a.

These four types represent cases *arbitrarily* selected out of all the possibilities within the extremes of 1. a perfectly constant sound; 2. a sound beginning in one way and ending in another; 3. a sound with continuous change; 4. a sound with an abrupt change.

[1] Rousselot, as before, 485.

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If we add that the beginning may be any one of the infinite number of possible vowels and the ending any other one, and if we consider that the four factors of change are each infinitely variable, it becomes evident that the number of possible 'diphthongs' is limited only by the possibility or practicability of distinguishing among them.

Among the phenomena of diphthongization we may note the following:

Absolutely constant vowels never occur in speech except in the sense that their changes are unnoticed. When the changes become distinctly perceptible, we have the 'on-glide,' the interior change, and the 'off-glide' in a vowel. A development of the 'on-glide' produces the rising diphthong; of the 'off-glide' a falling diphthong; of the interior change a diphthong of two more or less nearly equal elements.

Just what forms of diphthongization actually appear in a language must be settled by experiment. Aside from MARTENS's study (p. 20) of au and ai, and my own work on ai, I know of no experimental study of diphthongs. An account of the latter condensed from a previously published monograph[1] is given in Appendix II.

Curves of various vowels, diphthongs and triphthongs are to be found in the Plates at the end of this volume.

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[1] SCRIPTURE, *Researches in experimental phonetics (first series)*, Stud. Yale Psych. Lab., 1899 VII 1.

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CHAPTER XXIX

LIQUIDS AND CONSONANTS

'CONSONANT' is a term loosely applied to sounds that are not distinctly vowels. The sounds m, n, ŋ, r, l are often classed as 'liquids' or even as 'semi-vowels.'

Vowels, liquids and consonants may be distinguished by the degree of openness of the vocal cavities; thus the three sounds i in biovə 'be over,' ɹ in ɹu 'you' and j in lejn Germ. 'legen' have successively narrower passages above the tongue. The diminution in the opening is accompanied by increased fricative noise. On this principle m, n, ŋ are liquids and ɹ, l may be vowels, liquids or consonants. The three typical degrees of ɹ and l may be denoted by $ɹ_v$, $ɹ_l$, $ɹ_c$, l_v, l_l, l_c.

The unfortunate classification of liquids solely as consonants has led various writers on verse to speak of a syllable containing a vowel followed by a liquid as short, whereas the total vowel quantity is really long. In fact, in speech the specific vowel may be omitted, leaving the liquid as a vowel between two consonants.

The liquids are probably also to be distinguished from related vowels and consonants by the fact that they undergo greater changes.

The vowel i of bit 'bit' undergoes presumably no more change between its beginning and end than the other vowels do; the liquid ɹ of ɹu 'you' undoubtedly passes rapidly through a considerable range of change; the consonant j of lejn (Germ. 'legen') is again of a more constant character than the liquid. The character of the liquid ɹ appears in 'draw your' (Plate I, next to last line); instead of the

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strong vibrations found in all cases of i and in the neighboring vowels ɔ and u, it shows faint ones of a changing character.

The sound w in wil 'will' is the liquid form of u; it is sometimes called 'consonant u.' The final sound of 'bow' in Plate I seems to end rapidly by some articulatory action in the mouth rather than in the usual fashion for vowels (p. 429); it is the consonant w rather than the vowel u; the word is thus phonetically **bow** or **bouw**. This addition of w is due to the fact that a vowel follows; before a consonant the word would presumably be **bou** or **bo**. The development of such a hiatus-filler is a common linguistic phenomenon.

French ɥ ('consonant y') as in 'lui' also seems to be a liquid. Perhaps other vowels have liquid forms.

This view of the liquids as involving more movement than the vowels I had arrived at in my own phonetic work. It is strikingly confirmed by ROUSSELOT'S [1] simultaneous tracings (p. 374) of lip movement, breath record and speech curve for y and ɥ, and of breath pressure and speech curve for i and j, and by tongue and breath curves for ei, ej, ia and ja.

The essential factors in consonants seem to be occlusion, explosion, friction and roll. These are combined in the most varied ways. Occlusion and explosion appear in p, b, t, d, c, ɟ, k, g, '. Occlusion without explosion appears very often when the corresponding sounds occur in certain combinations; if separate letters are needed for these non-explosive occlusives, they can perhaps be obtained by breaking off unessential parts of the type, for example, ᴘ, ᴅ, ᴛ, ɑ, ᴄ, ɟ, ᴋ, ɢ. The occlusives may have nasal explosions [2] instead of oral ones; this may be indicated by *n*-modifiers, thus pⁿ, bⁿ, etc. Friction appears as the most essential factor in ɸ, β, f, v, s, z, š, ž, θ, ð, ç, j, χ, ɣ, h. The roll appears in the various forms of r. Fricative explosions of the occlusives occur in various forms and degrees.

[1] ROUSSELOT, Principes de phonétique expérimentale, 2me partie, 404, 637, Paris, 1901.

[2] ROUSSELOT, as before, 527.

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The attack in consonants differs in different cases. For **pa** and **sa** the attack seems to be more energetic in German than in French;[1] for **ba** it is less energetic in German because the explosion is weakened by the probably complete closure of the glottis during the surd portion of the **b** (Fig. 279).

We have now to consider the phenomenon known as 'mouillure.' Its general character has been outlined by SIEVERS.[2] It is produced by the adaptation of a consonant or a group of consonants to the articulation of a palatal sound (generally i or j), that is, by a rise of the forward part of the dorsum of the tongue. Such a rise is an addition to the articulation of a labial sound; it is difficult for a velar, a postpalatal, or a frontal one, but is easy for a prepalatal, and unavoidable for an alveolar-prepalatal. The degree of rise may vary. In some cases the mouillure appears to the ear throughout the duration of the sound without any addition at the end, as in *ʎ*, *ñ*; in others it appears as a difference only at the end; in others it modifies the sound and appears also in the release, as in *k*-mouillé. A mouillé sound is not the same as the corresponding consonant followed by j; thus *ʎ* is not the same as lj, *ñ* as nj, etc. All the mouillé sounds are characterized by the formation of a narrow passage between the predorsal part of the tongue and the prepalatal region.

The mechanism of the mouillure has been established by the experiments of LENZ (Figs. 307 to 323).[3]

For **aka, eke, iki** LENZ obtained by means of an artificial palate (p. 298) the contacts shown in Figs. 307, 309, 310. They show for **k** successively more anterior contact and the formation of a channel under the influence of the adjacent vowels. For **k** as in Fr. 'qui,' Ital. 'chi,' 'chiesa,' the contact was still more advanced and the channel diminished (Fig.

[1] ROUSSELOT, as before, 487.

[2] SIEVERS, Grundzüge d. Phonetik, 5. Aufl., 185, Leipzig, 1901.

[3] LENZ, *Zur Physiologie u. Geschichte d. Palatalen*, Diss., Bonn, 1887; also in Zt. f. vergl. Sprachf., 1888 XXIX 1.

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k in **aka**

FIG. 307.



k in **aka**

FIG. 308.



k in **eke**

FIG. 309.



k in **iki**

FIG. 310.



c

FIG. 311.



c

FIG. 312.



κ

FIG. 313.



κ

FIG. 314.



σκ

FIG. 315.



τ

FIG. 316.



ξτ

FIG. 317.



τ

FIG. 318.



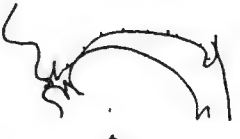
τ

FIG. 319.



t_1

FIG. 320.



t_1

FIG. 321.



$t_s s_s$

FIG. 322.



č

FIG. 323.

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311); the sound may be indicated by c. It is evident that a slight advance of the tongue would close the entire prepalatal region. This occurs in the medio-prepalatal contact shown in Fig. 313; the anterior untouched region is very small. The direction of pressure is, as in the preceding cases, mainly upward. The contact is released by drawing the tongue down and back, that is, by starting with a small groove in the prepalatal region and proceeding backward until the release is complete. The breath presses through with a relatively weak explosion and a following short rush; the slower the movement the weaker the explosion and the stronger the rush. This k is the so-called *k*-mouillé; it may be indicated by ĸ. The fricative portion, when spoken as an independent sound, may have its opening at the front or at the rear of this prepalatal position; in the former case the sound resembles a σ (specifically a backward or dorsal-palatal s), in the latter a ξ (specifically a forward ç). Owing to the fact that the curvature of the tongue is greater than that of the palate at this point, it results that the upward pressure produces the firmest contact not in the middle of the prepalatal region but at its front or rear edge. The release of contact would thus begin either at the rear or at the front of the region of contact; in the one case the fricative addition to the sound would be σ-like, in the other ξ-like. The former seems to be the usual one as described above. When the palatal σ is spoken alone, the region of contact is that bounded by the white lines in Fig. 315; when it is followed by ĸ the contact covers the whole portion shaded in Fig. 315; the region of contact is practically the same as for isolated ĸ (Fig. 313), though slightly greater, owing to the fact that the previous position of the tongue for σ renders only a slight movement necessary to complete the closure. This shows clearly the nature of the release of ĸ.

The alveolar-prepalatal contact (Fig. 316) marks a sudden change from the previous series. The pressure of the tongue is directed forward against the alveolæ. The release of the large contact occurs from the rear by formation of a small

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groove through which the air rushes after the weak explosion; the sound resembles a combination of t and ξ, the t portion being weaker as the opening is slower. The sound is the so-called *t*-mouillé; we may indicate it by τ. On account of the convexity of the alveolar region its closure is firmer than that of κ. For the group ξτ the closure is limited to a small supra-alveolar region (Fig. 317). The sound τ as usually produced has a contact region as shown in Fig. 318; the likeness of Figs. 317 and 318 indicates that the release of τ is like ξ. The sounds of Fig. 316 and Fig. 318 are absolutely identical to the ear. Fig. 318 shows the fricative opening already partly formed. It also shows that a prepalatal closure is not necessary for τ; nevertheless the closure next forward from κ is necessarily τ, as the tongue cannot make the prepalatal closure without the alveolar one.

LENZ'S investigation shows that the passage of the surface of the k contact forward through c and κ produces a change in the character of the explosion, whereby it receives a fricative addition of σ or ξ. Such a change in the pronunciation of a word has usually been erroneously considered as the introduction of a parasitic ȷ (consonant i).

The sounds κ and τ are in respect to movement neither pure k sounds nor pure t sounds, but are somewhere between them. We must now consider: 1. the nature of the differences between the group k, c, κ (indicated by K) and the group t, τ (indicated by T); 2. the difference of κ from k and c, and of τ from t; 3. the mechanism of the fricative addition; 4. the essential characteristics of κ and τ.

The chief difference to the ear between a K and a T cannot lie in the tone of the rear mouth cavity; as LENZ points out, this would produce a change in pitch; a steady fall in pitch is observed in the series k, c, κ without their becoming the same as T. The direction of the expiratory rush of air cannot make the difference, because a T can be formed by the tongue-point against the same portion of the palate as is used in K without sounding the same as K. A frontal-postpalatal T may have the same pitch as a dorsal-postpalatal K, but they

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are quite different in sound; even dorsal-alveolar T does not resemble a K, while dorsal-alveolar and frontal-alveolar T are hardly distinguishable. Physiologically the difference between T and K seems to lie in the use of the front and predorsal portions of the tongue for T and that of the medio- and postdorsal portions for the K, with the result of a different action in the two cases. As LENZ points out, the anterior portion of the tongue is much more movable than the posterior portion. The mediodorsal portion is hindered in its movement, especially along its middle line, by the frenum, while the front portion has (ordinarily) free movement. When the mediodorsal portion is pressed against the palate, the chief pressure is at the sides. In all K-closures the contact is looser in the middle, and the release naturally occurs first along the middle line. The K-explosions have thus all a scratchy character, due to the gradualness of the release and the consequent rush of air over the middle before the tongue is fully away from the palate. When the anterior portion of the tongue is closed against the palate, the contact is firm at all points and the release may occur evenly; when this happens quickly the explosion is sudden and there is no noticeable rush sound. In certain contacts the gradual release is unavoidable, as explained for κ. The gradual release for τ is not a necessity of the contact but is derived from an additional muscular action. Just behind the region of closure the tongue makes contact along the sides, tending to form a channel in the middle; the release is naturally fricative.

The relation between T and K may be illustrated by that between the bilabial explosive p and the labio-dental explosive ρ formed by the lip against the teeth. The sound of p is a clear explosive, owing to the sudden relaxation of the lips, while that of ρ is a scratchy explosive, owing to the slower completion of the explosion due to the irregularities of the teeth.

The difference between the explosions of the K and T sounds lies in their dullness and sharpness. The κ and τ differ from the others in having fricative additions. The

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groove is in both formed in the prepalatal region; this occurs in κ in the chief contact surface, in τ just behind this surface.

The sounds κ and τ are each produced by a single continuous movement of the tongue; they may be said to be simple speech movements. To the ear they may appear as simple as the explosives if the fricative addition is weak. Increase in the fricative addition makes the consonant diphthongs κσ and τξ. Still further development into independent sounds requires change of contact and produces cç or kχ and ts.

By raising the lower jaw and lifting the predorsal portion of the tongue against the alveolar and prepalatal regions (Figs. 320, 321) a t_4 can be produced with a somewhat σ-like fricative addition. (The numerals $_1$, $_2$, $_3$, $_4$ indicate successive degrees of backward contact.) Still further progression of the region of contact may bring about the clear dorsal-alveolar t_3. Thus the progression of the contact surface forward gives k → c ⇒ κ → τ → t. Such a development is relatively seldom in the history of sounds, the most usual occurrence being an independent development of the fricative addition to τ by a more gradual release of the contact; this produces a κ-like movement in place of the τ-movement, whereby the predorsal-alveolar contact is first opened only along the middle line, so that instead of t_3 we have the combination t_3s_3. The region of contact for t_3s_3 is shown in Fig. 322.

Further progress of the closure forward and downward to the teeth occurs by raising the jaw and lowering the apex of the tongue through a supradental t_2 till finally a bidental t_1 is reached. The gradual release of the supradental t_2 produces a s addition, that of t_1 a θ addition; the compound sound becomes t_2s or $t_1\theta$.

The unified sound č, corresponding to the compound sound tš, differs, according to LENZ, from τ in having the mediodorsal portion of the tongue less raised, whence it results that the gradual release of contact covers a larger space, producing a fricative release that passes rapidly from ξ to σ

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and σ̌, with σ̌ usually the most prominent element. A č sound does occur in which the elements ʂ and σ are more prominent than σ̌. It is quite erroneous according to LENZ, to consider č = t + š (or more accurately τ + σ̌) as such an analysis separates the portions artificially. It must be said, however, that the degree of fusion in many vowel diphthongs is just as complete as in č, and that a notation such as ai cannot usually be considered to indicate distinctly separated sounds (p. 430). The contact surface of č is shown in Fig. 323; the white line incloses the surface for σ̌ alone. A comparison of Figs. 318, 320, 323 shows that there is a closer similarity between t_4 and č than between τ and t_3s_3.

As a development of τ the č has an advantage over t_3s_3 in being spoken with nearly the same portion of the tongue, that is, mediodorsal, while t_3s_3 uses the predorsal portion. Whether a dialect develops τ to č or to t_3s_3 depends upon circumstances; only one of the developments occurs at the same time. LENZ suggests that the choice depends on the preference for similarity of the acoustic impressions or for that of the sensations of movement. If the former prevails, $\tau \rightarrow t_3s_3$; if the latter, τ → č.

The so-called 'mouillé' explosives κ, χ, τ, δ are composed of an occlusion with a fricative release; they thus differ from the explosives, properly so-called, which have an occlusion with an explosive release. With nasal openings there arise ɲ and ñ, the latter being the *n*-mouillé of the Romance and Slavic languages, and the former a *η*-mouillé. A relaxation of the articulation for τ, δ by a side contraction gives surd and sonant ʎ, or *l*-mouillé.

The audibility due to the explosion as in t, d, c, ɟ, k, g, etc., is lacking in m, n and η on account of the passage of the air through the nose, and in l through the side openings; the fricative form of release, which is distinctly audible in τ, δ and κ, χ, is scarcely heard in ɲ, ñ and ʎ.

ROUSSELOT'S palatograms [1] of κ, χ, τ, δ for various French dialects are closely analogous to those of LENZ.

[1] ROUSSELOT, Principes de phonétique expérimentale, 2me partie, 607, Paris, 1901.

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The mechanism of the mouillure is illustrated by OUSSOF'S palatograms[1] of the Russian mouillé labials. They all show that during the articulation for **p**, **b**, **f**, **v** the tongue places itself in the **j** position; the release is thus **j**-modified.

Experiments with exploratory bulbs (p. 333) show[2] that the *r*-mouillé differs from the ordinary **r** by a considerably greater rise of the tongue in the dorsal region, while the point of the tongue rises slowly instead of abruptly. The *n*- and *l*-mouillé seem[3] to be produced by more extensive tongue contacts. It is to be remembered that these two sounds may be continuously produced.

These explanations of the so-called 'mouillé' sounds may be completed in some particulars. The term 'mouiller' means 'to make wet,' 'to give a liquid sound to.' It refers primarily to the auditory impression. Such an impression of softness can be produced in occlusives by retarding the explosive release; this occurs naturally in those whose articulations are dorsal-prepalatal; it may be produced by retarding the tongue in the release of other articulations. The fact that forward **ĸ** and backward **т** are naturally 'mouillé' sounds has led to the identification of the motor-phenomenon with the auditory one. A sound like **l** or **n**, produced with a more backward region of articulation, is said to be 'mouillé.' The nature of the release in these sounds is, in my opinion, a minor matter; the continuous '*l*- and *n*-mouillé' are rather to be considered as members of the **l** and **n** series that to the ear differ merely in their cavity tones; a connection with the occlusive mouillé-sounds arises only from the auditory impression of softness.

Sounds like **č** and **ǰ**, **ş** and **ẑ**, etc., ROUSSELOT calls[4] 'semi-occlusives.' He asserts that they have developed from the mouillé consonants by further relaxation of the muscles constituting the 'vocal hindrance.' If the point of the tongue remains in the alveolar region with the dentals **т**, **δ**, or if it is placed there with the palatals **ĸ**, **γ**, the release is modified, and the mouillé sound becomes transformed into an articulation

[1] ROUSSELOT, as before, 604.
[2] ROUSSELOT, as before, 607.
[3] ROUSSELOT, as before, 610.
[4] ROUSSELOT, as before, 618.

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that appears double to the ears of those who cannot produce it. Persons who naturally employ the semi-occlusives cannot tolerate[1] the confusion with the sound groups tš, dž, ts, dz. ROUSSELOT's palatograms and records with exploratory bulbs at different points in the mouth show conclusively that the region of occlusion is much further back for č, ǰ, ʂ, ʐ, than for t, d (being rather that for ʈ, ɖ) and that the occlusion is weaker. The relative proportions of occlusion and friction vary from complete occlusion in t, d, to complete friction in s, z, š, ž.

Experimental records are still needed to show just where the separation is to be made between č, ǰ, ʂ, ʐ, and the corresponding diphthongs in each language. For Italian č, ǰ JOSSELYN has shown (p. 321) that the fricative element is like ǰ and not like š, ž. He seems to have proven that the sounds in č, ǰ are too closely unified to be treated as diphthongs; perhaps also we should say the same of the sounds represented here by ʂ, ʐ but on p. 321 by ts, dz.

JOSSELYN'S[2] experimental records of Italian articulations show varieties of 'soft *c*' extending from a purely fricative form to nearly a ʞ (*k*-mouillé). Indications of k → ʞ were even found in some cases. The change of Latin k before e or i to ʞ probably occurred in the same manner as the similiar change occurring at present in Parisian French (p. 315). The further change of ʞ to č is illustrated by JOSSELYN'S records.

Physical definitions of the consonants have been given by HERMANN[3] on the basis of his speech curves (p. 43).

A. Consonants with cord action (phonic consonants).

1. Smooth semi-vowels: l, m, n, ŋ. These are sounds, without noises, having one or more fixed characteristic resonance tones (formants) like the vowels; they differ from them in not having their force, openness and distinctly musical character.

[1] DAUZAT, *Contributions à l'étude des articulations consonantiques*, La Parole, 1899 I 619.

[2] JOSSELYN, *Étude sur la phonétique italienne*, 67, Thèse, Paris, 1900.

[3] HERMANN, *Fortgesetzte Untersuchungen ü. d. Konsonanten*, Arch. f. d. ges. Physiol. (Pflüger), 1900 LXXXIII 8.

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2. Remittent semi-vowels: r. The various forms of r have the same properties as the smooth semi-vowels, and the additional one of relatively slow periodic changes in intensity.

3. Phonic noise-continuants: β, v, ð, z, ž, j, γ. These consist of a noise accompanied by a cord tone, the characteristic tones (formants) in the noise having apparently no relations to the cord tone.

4. Phonic explosives: b, d, ȷ, g.

B. Consonants without cord action (aphonic consonants).

1. Aphonic noise-continuants: ɸ, f, θ, s, š, ç, χ. These are noises of very variable nature, containing certain characteristic tones.

2. Aphonic explosives: p, t, c, k. These have a silent period of occlusion, usually with a following explosion.

BRÜCKE'S motor definitions [1] may be summarized in the following classification. Where two letters are given, the former indicates the surd, the latter the sonant. The laryngeal sounds (*h*, Arabic *hha*, Arabic *ain*, laryngeal *r*) are placed in a separate class.

SIMPLE CONSONANTS

	1*st Series (lip)*	2*d Series (front of tongue)*	3*d Series (middle and back of tongue)*
Explosives	p, b { p^1, b^1 bilabial; p^2, b^2 labiodental }	t, d { t^1, d^1 alveolar; t^2, d^2 cerebral; t^3, d^3 dorsal; t^4, d^4 dental }	k, g { k^1, g^1 velar; k^2, g^2 palato-velar; k^3, g^3 palatal }
Fricatives	f, v { f^1, v^1 bilabial; f^2, v^2 labiodental }	s, z { s^1, z^1 alveolar; s^2, z^2 cerebral; s^3, z^3 dorsal; s^4, z^4 dental ($\theta, \eth$) }	χ, y { χ^1, y^1 velar; χ^2, y^2 palato-velar; χ^3, y^3 palatal }
L-sounds		λ, l { λ^1, l^1 alveolar; λ^2, l^2 cerebral; λ^3, l^3 dorsal; λ^4, l^4 dental }	
Vibrants	ϕ, κ	ψ, r	ξ, r
Resonants	m { m^1 bilabial; m^2 labiodental }	n { n^1 alveolar; n^2 cerebral; n^3 dorsal; n^4 dental }	π^1 velar; π^2 palato-velar; π^3 palatal

[1] BRÜCKE, Grundzüge d. Physiologie u. Systematik d. Sprachlaute für Linguisten u. Taubstummenlehrer, 1. Aufl., Wien, 1856; 2. Aufl., Wien, 1876.

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COMPLEX CONSONANTS

sχ, zy in various combinations of the forms of *s, χ, z, y*.

MOUILLÉ SOUNDS

ly, ny with various forms of *l* and *n*.

BRÜCKE'S treatment was a great achievement for the pre-experimental time. Later work has partially remedied its incompleteness and corrected its faults. *sχ*, *zy* (= *š*, *ž*) are no longer supposed to be complex sounds. The mouillure has been extended to other consonants than *l* and *n* and is known to be different from the addition of a parasitic *y* (ȷ). *p* and *b*, *t* and *d*, are known to differ in other ways than in regard to sonancy. We can no longer accept BRÜCKE'S view that for the consonants as for the vowels — with the exception of the diphthongs — the letters are not to be considered as signs for active movements of the organs of speech but as indications of definite conditions and definite adjustments of the mouth organs and glottis, in which they are found while the expiratory muscles seek to press out the air.

VIETOR'S classification is also motor.[1] To show the relations between the groups of sounds, I give his complete outline. *Laryngeal Articulation.* I. Sounds with laryngeal opening. II. Sounds with laryngeal narrowing or closure. *Mouth Articulation.* I. Sounds with opening of mouth: 1. sonants: vowels (p. 428); 2. surds: *h*. II. Sounds with narrowing or closure of the mouth: 1. *fricatives*: A. gutturals and palatals: (1) uvular *r*; (2) gutturals: *ɣ* and *c*; (3) palatals: *j* and *ç*; B. dentals: (1) sibilant sounds: *ž* and *š*, *z* and *s*; (2) *ð* and *þ*; (3) liquids: *r* and *l*; C. labials: *v* and *f*; 2. *occlusives*: A. without nasal resonance: a. gutturals and palatals: *g*, *k*; b. dentals: *d*, *t*; c. labials: *b*, *p*; B. with nasal resonance: a. gutturals and palatals: *ŋ*, *ṅ*; b. dentals: *n*; c. labials: *m*. VIETOR'S *ɣ* corresponds to γ of this book, *c* to χ, *þ* to θ, dotted *n* to ṅ.

[1] VIETOR, Elemente d. Phonetik, 4 Aufl., Leipzig, 1898.

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The *Association Phonétique Internationale* classifies and represents the consonants in the following way. (The misleading "g" has recently been replaced by a crossed *g*.)

	Laryngeal	Guttural	Uvular	Velar	Palatal	Lingual	Labial
Plosive	ʔ		qɢ	kg	cɟ	ʈɖ	pb
Nasal				ŋ	ɲ	ɳ	m
Lateral				ɭ	ʎ	l	
Rolled		ʀ	ʁʀ			r	
Fricative	h	ʜɦ	ʁʁ	(ʍʁ)xg	(ɥ)çj	ɹ,θð,ʃʒ,zs	fv ʍʁ ʋɥ

The steady progress in our knowledge of the consonants has lately been aided by experimental researches. The details, as far as summarized in this book, can be found by consulting the Index.

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CHAPTER XXX

SOUND FUSION

THE person producing a vocal sound is not distinctly conscious of the separate muscular movements involved. He has a more or less definite idea — derived from past auditory and motor experiences — of what he wishes to say, and he wills to do it. The auditory and motor experiences from the past and those of the actual production of the sound are, in ordinary speaking, fused in his mind into a single experience. It is only by attending to some of these groups of elements more than to others — that is, by introducing artificial conditions — that they can be made to appear specially prominent to him.

This fusion occurs not only among the elements at the same instant of time, but extends over intervals of time. Speech actions are fused into ' experiences ' that may cover a whole discourse, a paragraph, a sentence, a phrase, a word or a phonetic element.

To the ear speech is one continuous flow; even the pauses are just as effective mental elements as the sounds; an attempt to pick out elements of speech by the ear modifies and alters them from the sounds actually occurring. On the motor side the fusion is just as complete; there are no distinctly marked volitions for successive sounds, but a course of volition resulting in a course of movement.

Speech cannot be considered as made up of separate elements placed side by side like letters. In the flow of speech it is just as arbitrary a matter to consider certain portions to be separate sounds as to mark off by a line where a hill begins and the plain ends. Moreover, an assignment of char-

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acteristic portions that would be allowable for disconnected sounds or for some occasions would not be allowable for others. Thus, an independent surd occlusive (p, for example) can not be distinctly made without the movement of closing and the movement of explosion. The closing may be faintly audible, the time of complete occlusion is one of silence, the explosion is audible. In a word, however, not only may the time, movement and sound of the closing be fused with the preceding vowel,[1] but even the period of occlusion itself is to be considered — GRÉGOIRE[2] points out — as the final portion of the preceding syllable, while the explosion begins the following one. In ordinary speech a division into syllables of the French word **papa** would not be **pa-pa** but **pa**$|^{p}$-$<^{p}$**a** where the $|^{p}$ indicates the closing and occlusion of the p, and $<^{p}$ its explosion. Even in such a case, we must add, there is no sharp boundary between the portions of the p, owing to the varying relations of larynx and mouth action.

Having set aside the view of speech as an agglomeration of elements, we must attempt a consistent treatment on some other principle.

In all speech there is constant variation in the quantity of auditory and vocal energy from moment to moment. This quantity consists of the sum of all deviations from the medium conditions of pitch, intensity, duration and difficulty of enunciation. A rise or fall of pitch beyond the general tone of the discourse, a lengthening of a sound, an increase of intensity, a change to silence, and any increase in the difficulty of fixing the mouth to produce sounds — these are all elements that tend to make a sound more energetic. These elements in their varying degrees and combinations produce a total of energy that varies at each instant. The effect is directly related to the rapidity of change from the medium condition. The variations in energy may be utterly irregular, as in some

[1] VIETOR, Elemente d. Phonetik, 4. Aufl., 297, Leipzig, 1898.

[2] GRÉGOIRE, *Variations de durée de la syllabe française*, La Parole, 1899 I 161, 263, 418.

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cases of prose, or may show a great degree of regularity, as in verse.

We may try to treat speech as a phenomenon whose energy varies with the time. Such a curve of auditory impressiveness, or of vocal effort, might, for some phrase, be the imaginary one given in Fig. 324. The curve of energy rises and falls in a more or less regular manner; limits between sounds must be more or less arbitrary. Limits between syllables must be also very arbitrary; points of lowest energy might be assigned as limits, but there may be two neighboring points nearly alike. Points of maximum energy are frequently assigned as the most important parts of syllables; but in the case of two neighboring maxima a slight



FIG. 324.

increase of one over the other would hardly justify the utter neglect of the latter. The difficulties and the solutions for the curve of energy are the same as for all empirical curves of like nature. The points of maxima, minima and flexion all have their values, but detailed treatment is beyond practicability. Just as in the case of an irregular solid body, we are driven to pick out points at which we can consider the whole mass to be located without altering the result under discussion. This is the centroid theory of the auditory and motor nature of speech that corresponds to the centroid theory of the course of thought. Thus, for a certain purpose, such as beating time, we can consider the whole flow of speech energy in Fig. 324 to be concentrated into three material points whose positions are so determined according to the actual distribution of the energy that for the purpose in view the result is exactly the same;

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the points might occupy the positions indicated by the dots.

The curves of volition-energy, of muscular work, of vibration-energy in the air, of auditory impressiveness (sonority), etc. for a given portion of will differ from each other, although closely related. No experimental determinations of any of these curves have yet been made, although some experiments indicate the possibility of determining the auditory and motor curves of total energy with fair accuracy. Other experiments in connection with the rhythmic effect render it possible to locate with accuracy the position of the rhythm centroids (Ch. XXXV).

A full treatment of the flow of speech would take into account various factors of the total energy, such as energy of sensation, energy of emotional effect, energy of association, etc. For three such factors considered in combination the centroids would be like those of an irregular mass passing by a given point, or, to illustrate more concretely, of such a mass of iron passing by a coil of wire connected to a galvanometer whose needle indicates the effect.

It is perhaps necessary to say a few words concerning the concept of the syllable. The assignment of the limits of syllables as the moments 'where during continuous expiration there is a passage through a sound of less sound quantity' shows some hints of the conception of speech as a flow of auditory and motor energy, but misses the essential point. For example, the word 'manly' is said to contain two syllables; it can be spoken with two breath-puffs, but nobody ever does so in speech; its curve of energy may show various maxima and minima, but it can hardly be said that a minimum occurs between n and l. The word 'manly' represents *continuous* action of the breath organs, *continuous* action of the vocal cords with a smooth rise and fall of pitch, *continuous* movements of the lips, tongue and velum through various positions. In fact the word is a *continuous* sound-change with no limits or minima of any noticeable kind. The word is indicated by letters as a sum of separate things, but the ex-

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perimental results in similar words show that this is not the case. The word is to be considered as a fusion of a series of *continuous* changes, certain *stages* of which may be characterized as m, æ^n, æ, æ^n, n, l, i. As far as the vocal movements are concerned, the word is just as continuous as 'manned.'

According to MEYER[1] the answer to the question of how many syllables a word has is given by our feeling concerning the number of syllables into which it can be made to fall, not the number into which it actually does fall in a given case. MEYER'S thought that a word is monosyllabic or polysyllabic according to whether it can be spoken in the rhythm of speech with only one impulse or with more, seems to have some relation to the centroid view of the flow of speech.

I do not believe, however, that a division of the flow of speech into separate blocks (termed 'syllables') has the slightest justification or the slightest phonetic meaning. As long as speech is indicated by letters, it is easy to divide the letters into groups, but, as has been pointed out, speech really does not consist of any such elementary blocks of sound as the letters are supposed to indicate, or of any such large groups as syllables. The attempt to divide speech into syllables might be compared to a division of a landscape into hill-blocks and valley-blocks; there can be no dividing lines drawn. The terms 'hill' and 'valley' apply to *characteristics* of the land and not to separate divisions.

According to SIEVERS[2] the ear divides the flow of speech into certain portions, that is, into masses of sound that form relatively close unities, which we call syllables; the division rests upon discontinuities (minima) in the strength of the flow of sound. If instead of confining the first statement to the ear we make it read the 'ear, the vocal impulses, and all their associations' etc., and if we add to the second that

[1] MEYER, *Die Silbe*, Neuere Sprachen, 1898 VI 479.

[2] SIEVERS, Grundzüge d. Phonetik, 5. Aufl., 198, Leipzig, 1901.

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the division rests upon all factors that tend toward the effect of a series of unities in the flow of speech, we have practically the centroid theory that I have proposed. A word would be said to have as many syllables as it was *felt* to have centroids. A syllable would then be defined as a portion of speech within which a centroid is located, the boundaries of syllables being of all degrees of indefiniteness.

Just as in the case of any irregular body, we can find different grades of centroids by limiting the consideration to larger or smaller portions. There are thus phrase-centroids, syllable-centroids, sound-centroids, etc.

Systematic treatments of the syllable are to be found in the works of SIEVERS, VIETOR, etc.; so little experimental work has yet been done that a discussion is hardly in place here. To what has been said I will merely add that the centroid treatment of speech differs from what may be called the 'maxima-minima,' or 'apex-depression,' treatment mainly in considering the whole mass of speech — physically, physiologically or psychologically, as may be desired — in locating the critical moment, instead of locating it at the moment of greatest energy. The centroid will rarely coincide with the maximum of energy.

The continuity of speech action is strongly impressed on any one who attempts to study the curves of connected speech (Part I). There is often no possibility of assigning boundaries to phonetic sounds, words or phrases. Thus, in the record for mailitlai 'my little eye' in *Cock Robin* (p. 126) the speech curve is continuous from the beginning of m to the end of the last i; at various places along the record typical m, a, i, l, vibrations are to be found, but the change from one type to the next is a gradual one; this condition shows itself through the whole record. It cannot be said that the record is fully represented by ˌmˌaˌiˌlˌiˌtˌlˌaˌiˌ, where ˌ indicates a glide, unless each of the symbols is understood to represent a typical stage of a continuous process.

Speech records of all kinds seem to indicate the applicability of the concept of the centroid, or center of unification, of

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speech action. For example, the speaker considers something he wishes to say and executes a complication of movements which we indicate by 'my little eye.' That the idea he wished to express required a certain complication 'my little eye' and not 'mit meinem kleinen Auge' or ba or a was due solely to his past teaching; for him there would have been no essential difference between 'my little eye' and a except in the amount of labor involved. For him and for all purposes of speech this complication may be treated as having its whole effect at some point of time; in 'my little eye' it might perhaps lie at the moment of the closure of the t. Such a centroid of speech movement is the point in the flow of speech at which the total speech movement may be considered to have occurred without changing the result.

Centroids may be found for portions of speech. If it is found practicable to cut off certain subordinate portions without introducing too much error into the results, the centroids may be found for such portions. Thus, a portion may be taken from the speech record of 'my little eye' that may be considered to cover the 'i'; the limits must be arbitrarily assigned, but if, for the purposes of the investigation, this does not introduce too much error, then the i can be considered as definitely limited. This i will be found to be a phenomenon changing in its nature from beginning to end. For many purposes its acoustic effect and its motor production may be considered to be located entirely at a definite point of time, or at a definite centroid. Similar centroids may be found for other portions of the phrase.

The number and character of the centroids is really what is indicated by a phonetic spelling. Thus 'mailitlai' indicates that *for the purpose in view* — instruction in pronunciation, or discussion of phonetic change, or indication of parts of a record, etc., etc. — the entire speech quantity of 'my little eye' on the particular occasion discussed may without appreciable error be considered as occurring at nine different points of time and as consisting of nine speech elements whose characters are indicated by m, a, i, l, i, t, l, a, i. That a phonetic notation

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or an ordinary spelling indicates a construction of speech out of separate fixed elements, like a house out of bricks, is a notion that has arisen from a study of spellings instead of speech itself. A person speaking from printed characters or indicating what he says by written ones has no such notion; to him the letters singly or in groups are schematic signs, or ideograms (p. 128), that roughly indicate a desired result.

This view — which is a necessary result of a consideration of the general phenomena of voluntary action — seems to have been what PAUL had in mind. 'An actual separation of a word into its elements is not only very difficult, it is actually impossible. A word is not a placing side by side of a definite number of independent sounds, each of which can be expressed by a letter of the alphabet, but is nearly always a *continuous series of an infinite number of sounds*, and the letters indicate, in an incomplete fashion, nothing more than certain characteristic points of this series.'[1]

From the linguistic side it has been pointed out[2] that speech movements occur as unities; that there may be a unit volition for the movements required for a certain speech sound and also unit volitions for complex groups of movements such as are required for words [and phrases]; that the unit volitions for the complex groups have an independent existence and are not the sums of volitions for the elements. The unification of volitions is, according to KARSTEN, still more elaborate; the suffixes, prefixes and other parts of words become merely parts of a unit. Such volitional units become associated with corresponding auditory units. It is interesting to note that recent work on the cerebral cortex (p. 86) indicates separate anatomical centres for the various group movements.

Certain relations of similarity become established among sounds used in different word-units in the speech of a person, a community, a period, etc. The properties that remain

[1] PAUL, Principien d. Sprachgeschichte, 3. Aufl., 48, Halle a/S., 1898.

[2] KARSTEN, *Sprecheinheiten u. deren Rolle in Lautwandel u. Lautgesetz*, Trans. Mod. Lang. Assoc. Amer., 1887 III 186; also in Phonetische Stud., 1890 III 1.

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approximately unchanged in different units may be called the stable ones. The average properties that appear in the various word-units may be said to constitute the *typical* sounds. The properties of an *independent* sound generally differ from those of a typical sound in connected speech. The sounds used in actually spoken words may be called *specific* ones.

The relations between the typical sounds and the specific ones depend on sensory and motor laws.

The first topic now to be considered will be the differences between typical sounds and the specific sounds in connected speech. I shall attempt nothing more than to point out some of the more important facts to be looked for in experimental records. Fuller and more systematic treatments of speech fusion are to be found in the works mentioned in the REFERENCES at the end of this chapter.

The articulations of a sound are undoubtedly very much modified by the neighboring sounds in a phrase, by the idea expressed in the sentence, by the emotional condition of the speaker, etc. According to SIEVERS[1] phonetic investigation should begin with the sentence and proceed to the subdivisions, the artificially separated sounds being only abstractions. The physiological methods of registration, however, have not yet been sufficiently developed for long records, although the analysis by means of speech curves proceeds in just this way (p. 61).

One result of fusion is the tendency to ease of innervation, motor impulses being spared whenever possible. One form of this smoothing is found in the general law that contiguous articulations may be modified to produce easy passage from one to the other. This adaptation is, of course, instinctive, or 'unconscious' in the usual meaning of the word (p. 381).

An effect of this unification is seen in the neglect of differences in speech and in the approximation to easy curves of motion. This may go so far that long and complex move-

[1] SIEVERS, Grundzüge d. Phonetik, 5. Aufl., 8, Leipzig, 1901.

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ments are reduced to short, simple ones. The process represents economy in physical movement and in the number of changes of innervation. Examples are furnished by every spoken word; experimental results may be found throughout the preceding chapters.

This adaptation shows itself in avoiding changes. One of them is the omission of change in respect to sonancy. Surds may become sonants between two vowels, as in **sɔh.im** 'saw him' (pp. 24, 276) and in the numerous examples given on pages 360 to 362. Sonants may likewise become surds where a retention of sonancy would hinder unification (p. 361).

Illustrations of the smoothing off of tongue movements may be seen in '*anakts' → *ἄναξ*, '*nokts' → Lat. 'nox,' Lat. 'octo' → Ital. 'otto.' This phenomenon is constant in the 'smoothing' of the two elements of a diphthong, as ai → ā in O. Eng. 'stan,' ei → ē in Swed. and Dan. 'sten.'[1] A smoothing of the tongue action also changes intervocalic explosives to continuants as in Lat. 'paganum' → Fr. 'païen' (see also p. 372).

Velar smoothing may be assumed in the nasalization of consonants and vowels when adjacent to nasals. Many experimental illustrations have been given on pages 345 to 351, and 359 to 365.

Lip smoothing may be illustrated by Lat. 'obstinatum' → Ital. 'ostinato.' It appears also in the communication of lip action to preceding consonants by the Russian rounded vowels[2] (see also p. 364). Smoothing of the tongue-lip combination appears in '*entfangen' → Germ. 'empfangen.'

General smoothing off of all vocal innervations and movements may be said to occur constantly. It finally goes so far that various elements disappear altogether, as in **gmoin** 'guten Morgen' of the Germans, **sivple** or **siple** 's'il vous plait' of the French, **dæte,ə** for ***dædətə ə** 'Dada take him' in a case of child speech. Numerous examples are given by

[1] Sweet, History of English Sounds, 22, Oxford, 1888.

[2] Sweet, as before, 38.

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PASSY:[1] **tsepa** 'je ne sais pas,' **keseksa** 'qu'est-ce que c'est que ça?', **ša^{n}temnami** 'je suis enchanté, mon ami,' etc. Experimental data concerning such extreme fusion and condensation are not yet numerous, owing to the fact that most records have been made from careful speech and not from rapid conversation. The latest form of zonophone (or gramophone) apparatus (p. 53) is able to record conversation without the knowledge of the person speaking; it may be useful for this problem.

Curiously enough the effects of these condensations often remain unnoticed. Unconscious movements are present in speech as the remains of sounds that have been consciously made in the past history of the language but have disappeared. ROUSSELOT'S[2] tracings for a case of the Lorraine dialect show a difference between **ap** 'arbre' and simple **ap**; the larynx ceased to vibrate for **a** before the lips formed the **p** in the former case and not in the latter, the historical **r** being represented by a condition of silence, or unrecorded movement (see also p. 365).

Connected with and yet often opposed to the process of condensation, is the process of distinction which also is a result of fusion. To mark off unities the mind requires distinctions; the subordination of some elements implies the elevation of others. Illustrations of this fundamental law of mental action will probably be found in future experimental work. The lengthening of initial consonants for the purpose of accent, the use of the glottal catch before strong initial vowels, the retention of surd fricatives in tonic syllables, *may* occur for this purpose. It is perhaps an instinctive desire for more force in a word that leads to the surdation of intervocalic sonants, as in O. E. 'etan' from the same root as Lat. 'edere,' or to the pronunciation **ekzækt** instead of **egzækt** 'exact.'

In general it may be said that the less the importance of

[1] PASSY, *Changements phonétiques*, 123, Thèse, Paris, 1891.

[2] ROUSSELOT, *Les modifications phonétiques du langage*, 143, Rev. des pat. gallo-romane, 1891 IV, V; also separate.

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a speech element in reference to its function in expressing an idea, the less the amount of volition-energy given to it. Decrease in volition-energy is accompanied by decreased energy of movement, by decreased time given to it, by decreased accuracy of coordination, etc. But, on the other hand, the greater the mental importance of a sound, the greater the amount of energy given to it. To subordinate in speech what is subordinate in thought is but one example of a universal principle of human activity. It is also true that neglected or unimportant elements of all organisms and activities generally show greater tendency to variation than the important ones. In speech, for example, tonic syllables will resist changes that influence atonic ones.

The close relation between the density of ideas and the distinctness of speech has been asserted by JESPERSEN to 'account alike for most of the gradual sound changes in languages, and for . . . violent curtailings.'[1]

Another effect of fusion is found in changes in the coordinations of the various simultaneous movements. Examples of the almost innumerable experimental illustrations of this principle have been given in Ch. XXVI; only a brief summary of the typical cases will be given here.

A most frequent case of this kind occurs in the lack of completion of some element in a complex set of movements. Another case occurs in beginning some element too soon.

Failure to properly coordinate breath action to mouth action may result in the defect noted on p. 221. Failure to maintain breath pressure sufficiently long during final occlusives deprives them of their explosions, consequently of their full audibility and ultimately of their existence,[2] as in Fr. 'tout' → tu, 'trop' → tro. Failure to begin the breath action soon enough enfeebles initial fricatives and, if sufficiently extended, causes them to disappear, as in the common loss of initial h in Cockney English and in modern Spanish.

Failure to coordinate cord action to mouth action results

[1] JESPERSEN, Progress in Language, 55, London, 1894.

[2] PASSY, *Changements phonétiques*, 164, Thèse, Paris, 1891.

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in the partial surdation of intended sonants and in the partial sonation of intended surds.

The cord tone frequently begins too soon or lasts too long in a vowel bounded by a surd, with the result that the surd becomes partly or wholly sonant. A combination of both extensions gives sonant h in sɔh.im (p. 276).

A low cord tone is more readily lost than a high one. The great fall in pitch at the end of a phrase in French results often in making a final vowel surd, especially in the case of i, u and y (as in veky$_0$ 'vécu'). These are said to be still very audible when surd; but for u this does not agree with ROUSSELOT'S experiments on the whispered vowels (p. 114). In Portuguese the final vowels are frequently surd, as in ka^{n}mphu$_0$ 'campo.' Many languages have only surd consonants as finals. In German and Russian all final explosives and fricatives are regularly surd; in Icelandic the final explosives are surd, while the fricatives are more or less sonant; in French the Latin explosives and fricatives have all become surd at the ends of words except those that have been followed until recently by ə, as in 'vif, vive;' in Sanskrit the final explosives and fricatives are always surd unless the following word begins with a vowel, as 'tát' but 'tád ánnam;' in Dutch the same rule holds good in unaccented words, as in 'is, was,' but in others the final consonant is surd unless followed by a sonant consonant.[1]

Progression of cord action may add sonancy to a preceding surd. Tardiness in beginning the cord tone would cause initial surdation in initial sonants (p. 361); increasing tardiness would finally make them entirely surd (Fig. 287). This may be the reason for such changes as χείσομαι from the root '*ghend$_2$' 'fero' from '*bhero.' The late beginning of the cord tone regularly produces 'aspiration' in German after the surd explosives.

The alteration of the mouth articulation before the cords cease to sound gives the diphthongal character to English

[1] PASSY, as before, 160.

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vowels (pp. 103, 122). It occurs also in the Dutch vowels [1] e, o, œ$_1$, œ$_2$, ɐ, which in emphasized final syllables become ei, ou, œ$_1$i, œ$_2$u, ɐi [the ɐ is a sound difficult to define precisely]. Anticipation of lip action may labialize the preceding sound, as in Fr. t^{w}wa for 'toi.' In this word the cord action is, moreover, tardy and the w is partially or wholly surd, producing t^{w}ʍa in the extreme case.

Initial and medial consonants often differ greatly. Initial b is often partly surd in German while medial b in same word may be entirely sonant. Semi-surdation and semi-sonation in French have been illustrated above (p. 360); the frequent surdation of final sonants has also been discussed; numerous further examples have been collected by Rousselot.[2]

Any change in the tongue-lip relation will produce a vowel not exactly like the one intended. A relaxation of the lip-rounding for u with maintenance of the tongue position makes the vowel change in the direction of the vowel in the Gaelic 'laogh'; the change can be imitated by speaking u while the fingers pull out the corners of the mouth.

Examples of widely spread tendencies to change of lip action while the tongue action is preserved have been collected by Passy.[3] Among children and the illiterate there is a marked tendency to change the rounded palatals to neutral or wide ones, œ, y, œ^{n} to e, i, e^{n}, as in kivet for 'une cuvette,' e^{n} menje for 'un meunier.' This change is a common one in many German dialects, as in South German gît for 'güte' and kenə for 'können.'

Differences in motor coordinations intended to be the same may be found in all experimental records.

Sounds in fused speech differ from the typical ones on account of their auditory characters also (Ch. IX).

When a sound ceases to impress the ear, there is a tendency to neglect it. The unflapped ɹ is auditorily so weak

[1] Logeman, *Darstellung des niederländischen Lautsystems*, Phonet. Stud., 1890 III 283.

[2] Rousselot, *Principes de phonétique expérimentale*, 2me partie, 498, Paris, 1901.

[3] Passy, as before, 134.

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that it has disappeared in a large number of English words where its loss makes no noteworthy difference in the auditory physiognomy of the word, as in pəl for pəɹl. This can be observed constantly in American children, who say biŋ for 'bring,' tɔli for 'trolley' etc., because the faint unflapped ɹ escapes their notice.

It is generally the case that sounds in atonic syllables tend to become weakened in articulation and to partly or wholly lose their sonancy, and finally to disappear. This slurring of atonic vowels may be illustrated by 'glædlice → gladly,' 'cnihtas → knights,' 'populum → peuple,' 'facere → faire.' Such phenomena are perhaps due to the fact that the stronger portion of the word is sufficient to arouse the entire auditory image in the mind; in such a case the speaker or hearer might unconsciously not care what happened to the weaker portion and would instinctively condense it as much as possible. This view is supported by the experiments of BAGLEY (p. 131).

Whenever a sound element catches the ear — more or less consciously — with a force greater than what would usually come to it in its condition at the time, the speaker has an impulse to give it more prominence by increasing some of its factors of energy, such as length, loudness, abruptness, etc. Thus, wīld → wīld → waild probably because for some reason the ī before l caught the ear and was prolonged unconsciously (in the usual sense, p. 381) and unintentionally.

The development of glides into vowel elements is probably partly due to similar reasons. As it is difficult to keep the movements properly coordinated in a long vowel, the ending is liable to be different from the beginning; if this difference catches the ear the difference readily becomes exaggerated.

The replacement of one vocal movement by another that produces approximately the same sound is a constantly recurring phenomenon. It rests upon the auditory resemblances of vocal sounds. These have, unfortunately, received little attention and almost no experimental study, although very many phonetic changes can be attributed directly to them.

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The attempt to assign some of the auditory reasons for the motor changes has been made by PASSY. His conclusions concerning the vowels are based on a mistaken theory (p. 289); the few reasons assigned for consonant changes are deserving of notice as attempts in the right direction.

The replacement of one movement by another that produces a sufficiently similar sound is seen in[1] Northern French fiʎə 'fille' → fij, briʎe, 'briller' → brije; Lat. 'plenum' → Ital. pjeno; Cretan *αὐκά*, Attic *ἀλκή*; French 'chevaux' from 'chevals;' New Zealand pronunciations of English, as in rawiri for 'David,' the d being lacking and the r somewhat resembling d. The close resemblance of r and l favors the use of one for the other, as in O. French 'orme' from 'ulmum,' the Chinese pronunciation 'Melican' for 'American,' etc. The resemblance between γ and uvula r in German often leads to interchange; the resemblance of tongue r to uvula r may even lead to the use of the former for γ.[2] The close resemblance of χ and γ to uvula r is suggested by HERMANN'S curves of χ and uvula r in Fig. 33; the flapping of the uvula is plain in the curve for χ.

The continual occurrence of individual differences of speech movement held within the limits of 'sameness' of auditory effect has been described as 'sound compensation.'[3]

Some of the phenomena of fusion will be illustrated in the study of speech curves in Appendix II.

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For fusion in speech: SIEVERS, Grundzüge d. Phonetik, 5. Aufl., III. Abschnitt, Leipzig, 1901; VIETOR, Elemente d. Phonetik, 4. Aufl., Liepzig, 1898; PASSY, *Changements phonétiques*, Thèse, Paris, 1891; PAUL, Principien d. Sprachgeschichte, 3. Aufl., Halle a/S., 1898.

[1] PASSY, as before, 145.

[2] VIETOR, Elemente d. Phonetik, 4. Aufl., 165, Leipzig, 1898.

[3] SHELDON AND GRANDGENT, *Sound compensations*, Mod. Lang. Notes, 1888 III 358.

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CHAPTER XXXI

PROGRESSIVE CHANGE

THE specific sounds in speech at any moment vary around an average in each of their properties; the average sound has been called the 'typical' one (p. 454). Any change that takes place in the typical sound, resulting from a gradual change in the conditions, may be termed a 'progressive' one. The typical sounds of an individual may change gradually throughout life under the influence of internal and external conditions. Such changes we may term 'personal' ones. There are also average, or typical, sounds of a community speaking the same dialect; the progressive changes in such types may be termed 'dialectal' ones. In a similar way we may speak of 'national' changes. The typical sounds may be studied in respect to their differences as the locality differs; we then have progressive 'geographical' changes.

The work of the experimental phonetist in regard to the problem of sound change consists in establishing what changes actually do take place under any variation of conditions, in correlating them with similar changes of various kinds, and in deducing them from more fundamental changes in the human organism and its activities.

The historical data concerning the changes that have actually taken place in speech sounds have been collected with great care and completeness, but experimental data concerning the action of the vocal mechanism (in the widest sense of the term) that can bring about such changes are almost entirely lacking. All hypotheses concerning the historical changes proceed on the assumption that human beings were

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always subject to internal and external influences in much the same way as they are to-day. If changes are produced in speech to-day like those that occurred historically, the causes that produce the present changes can be assumed for the historical ones, with a probability increasing with the resemblance of all the conditions.

Some of the various causes which have been assigned for the small differences and gradual changes in sounds will now be considered briefly in order to point out what the experimenter must be on the watch for in all his records. For the various principles discussed I have used historical cases merely as examples.

The dependence of differences in speech sounds on differences in the structure of the vocal organs and consequently in their activity and control has been pointed out (LOTZE, BENFEY, MERKEL, SCHERER, PAUL) but the data are not yet numerous enough for generalizations.[1] It is unquestionably true that the vocal organs and their methods of control differ in individuals and that there are just about the same differences and likenesses among members of a family, of a community, and of a nation in these respects as in respect to their faces. The family, communal and national similarities and differences in speech depend to some degree on these factors. Moreover, although an infant of one race may learn to speak to apparent perfection the language of another race, we may expect that careful experimental records will show the differences that are unnoticed by the ear.

No extended study seems to have been made of individual differences in the auditory perception of speech (Ch. IX). They are perhaps just as efficient causes of change as the motor ones.

The results of motor weakening are familiar phenomena. Persons to whom occlusions or narrow passages are more difficult on account of the structure of the tongue frequently relax them in case of fatigue, excitement or timidity. In the case of a person with a predorsal-alveolar t due to short-

[1] OERTEL, Lectures on the Study of Language, 193, New York, 1901.

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ness of the frenum linguae (p. 237) I have repeatedly observed t → θ in such conditions. In the case of an overworked, excited German in a foreign seaport I have observed si → ši in his pronunciation of Italian.

The use of a mouillure instead of a sharp explosion I have recorded in the case of my own child at 16 months in the words kæᵀ 'cat,' hɔᵀ 'hot,' the ξ explosion being clearly noticeable (p. 437). I originally recorded the words as kætᵏ and hɔtᵏ (p. 119), not having considered the possibility of their containing the mouillé sound ᵀ.

PASSY's statement[1] that children never change explosives into fricatives is certainly incorrect for some cases. His supposition that it is easier to form an occlusion than a fricative opening is refuted by observations on speech during fatigue, alcoholism, etc. A weakening of the occlusion in explosives seems to have been the characteristic of many of the historic changes; thus, Spanish *b*, *d*, *g* are often pronounced as the fricatives β, ð, γ.

The muscular action during an occlusive may become less energetic during the latter part of the occlusion. When the sound continues to occupy the same time, this leads to shortening of the occlusion and lengthening of the explosive release into a fricative release. If the process goes far enough, the occlusion entirely disappears, leaving a fricative in place of the original occlusive. This is perhaps the process that produced the changes of p → ɸ → f, t → θ, k → χ or h, as illustrated by Lat. 'pallidus' — Engl. 'fallow' — Germ. 'fahl,' Lat. 'capio' — Goth. 'hafjan' — Germ. 'heben,' Goth. 'sliupan' — O. H. Germ. 'sliofan,' Lat. 'tres' — Eng. 'three,' Goth. 'bok' O. H. Germ. 'buoh.'

LENZ[2] considers the historical development σ̆ → ç → χ to be the result of a decrease of energy. The laxity of contact for σ̆ results in greater fricative surface, including the space between tongue and gums, and produces ξ → ç → χ.

[1] PASSY, *Changements phonétiques*, 144, Thèse, Paris, 1891.

[2] LENZ, *Zur Physiologie u. Geschichte d. Palatalen*, Diss., Bonn, 1887; also in Zt. f. vergl. Sprachforschung, 1888 XXIX 51, 55.

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Still further laxity changes the fricative sound entirely; it may be replaced by the glottal fricative h or by a *vowel.* LENZ asserts that in the last case a substitution is required for the loss of friction because there must be a balance between the breath pressure and the resistance to it; this he considers the fundamental law of all formation of sounds. This change s → ŏ̈ is to be added, although LENZ does not consider s → σ → ŏ̈ to be the result of weakening. The entire series is then s → ŏ̈ (š) → ξ → ç → χ → h or *vowel.* For the sonants the development is not the same; as the articulation is diminished in force the opening becomes larger as well as more backward, and the glottis must open in order to furnish an equal amount of breath; the fricative gradually becomes surd, or the friction disappears, leaving only the cord tone to lengthen the neighboring vowel. Thus we have z → ž̈ (ž) → . . . → χ (instead of γ) → h or *vowel.* As examples, LENZ gives: Fr. mezoⁿ 'maison,' Lorraine možoⁿ, Remilly mohoⁿ; Fr. plezir 'plaisir,' Lorr. piæži → piæhi; Fr. buš 'bouche,' Remilly boχ; Fr. muš 'mouche,' Remilly moχ.

The fact that the sonants b, d, g more readily become fricative than the surds p, t, k may be due to their less energetic contact (p. 317). In German the g has often become fricative, (as in vaγn 'wagen,' gejn 'gegen') while the k in corresponding positions has been retained.

The continued weakening of consonants leaves finally h for the surds and a vowel for the sonants, as in Sanskrit 'áçwas' → 'áçwah,' '*sweks' → Greek ἕξ, Lat. 'filium' → Span. 'hijo.'

The weakening of the rolled r produces the fricative or liquid ɹ. In Southern England and in parts of America the r has disappeared to a great extent, having become ɹ in some words, ə in others and entirely omitted in still others. In Parisian French the uvula r tends to become γ. HERMANN'S curve for the fricative χ in Fig. 33 (p. 42) looks like that of a weakened surd uvula r.

An excess of energy in articulation often occurs. This

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may be due to increased vitality of the organism, whereby all movements are affected, or to diminished accuracy of control.

Increase in the energy of speech movement has been assigned by LENZ[1] as the cause of the spontaneous development of palatal fricatives into occlusives, illustrated by the historical change of ȷ to δ and its later stages. The more seldom i → δ, l → ʎ, and n → ñ are likewise results of increasing energy of movement. The process may be illustrated by examples. It is a familiar fact that *cons.* + e + *vowel* → *cons.* + j [or ç] + *vowel* as the result of the narrowing of the e-passage between the tongue and palate so that e → i → ȷ → j [or ç]. A further narrowing produces the occlusion with fricative release, and j [ç] → δ [ʧ]. Such a development of Lat. ȷ has occurred in nearly all Romance languages.

The development Lat. *nn*, *ll* → Span. ñ, ʎ results from the more energetic dorsal-alveolar closure (in LENZ's opinion), whereby an increase of contact occurs further back in the mediodorsal-prepalatal region. Palatograms[2] of an energetic dorsal-alveolar l show contacts between those for ordinary l and ʎ.

The air from the glottis passes in the occlusives into a closed chamber; the pressure within the chamber must finally become equal to that in the thorax and the vibration of the cords must cease if the occlusion is sufficiently prolonged, unless the energy of action of both breath and occlusive muscles is increased. Double — that is, long — occlusives tend to become surd (p. 367), as in Italian 'addentro, aggettivo.'[3]

Economy of effort — motor, sensory and associational — is a fundamental principle of the human organism; it shows itself in varying degrees in every individual and in every activity.

[1] LENZ, *Zur Physiologie u. Geschichte d. Palatalen*, 49, Diss., Bonn, 1887; also in Zt. f. vergl. Sprachforschung, 1888 XXIX 55.

[2] LENZ, as before, 56.

[3] JOSSELYN, *Étude sur la phonétique italienne*, 157, Thèse, Paris, 1900; also in La Parole, 1900 II 451.

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The principle of economy has been proposed in explanation of most of the historical changes that have occurred by weakening or increasing the articulatory effort. It undoubtedly does explain many of them, but many others are just as certainly due to diminished or increased vitality of the nervous system. The slurring of articulations due to diminished vitality — due to laziness, as SWEET puts it[1] — is certainly quite different in its nervous origin from that due to economy; both cases result in a saving of labor, but the former implies a poor condition of nervous activity, while the latter is evidence of a good one. The objections to the explanation of sound changes as being the results of economy have generally been due to the misconception that the economy is entirely one of muscular work, to the expectation of large and sudden results, and to a confusion between economy and weakness. That an adaptation of neighboring articulations for economical production actually does occur constantly has been abundantly shown in the preceding chapter. It occurs as the result of the usual instinct to save energy quite independently of an increase in speed. The economy may also appear as an auditory one. Distinguishing differences involves labor of perception (p. 121). When a difference is felt to be too small for the necessary clearness of perception, the tendency to economy will require its exaggeration (p. 122). This may occur even at the expense of more articulatory effort; the principle of economy will strike a balance between the two. Economy, in its true sense, implies efficient activity of the adjusting organism; greater economy means a better activity of the nervous system.

Increased energy of articulation may result from economy, but, like all other human activities, it may be due directly to increased vitality of the nervous system.

A tendency toward extravagance is just as fundamental a principle of organisms as economy. Activities are constantly being exaggerated and these variations may be seized upon

[1] SWEET, History of Language, 32, London, 1900.

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and developed. We may expect to find many sound changes that arise from extravagance.

The nature of the vocal movements depends on the speed of utterance. A speaker ordinarily makes about the same effort during a conversation unless he wishes to produce a difference in effect. An increase in speed requires either an increase in effort or a decrease in the muscular work performed. For an expenditure of the same mental energy in a given time an increase of speed involves assimilation of contiguous movements and diminution in the energy, extent, accuracy and duration of the separate ones.

Speech depends directly on the energy of the idea to be expressed by it. Various observations have been reported concerning the details. Increase in energy of expiration as well as in emphasis may change sonants to surds because of a wider opening of the glottis,[1] which is due — I believe — to an *association* with the increased breath action and not to any necessity for letting the air escape at the moment; thus, emphatic 'dead' may → $d_{o}ed_{o}$ or $d_{o}ed_{o}h$.

Sensory or motor habits in the succession of sounds lead to preferences for one form instead of another; for example, of a vowel within an unfamiliar group of consonants, of a familiar succession of consonants for an unfamiliar one, etc.[2]

The influence of general habits of expression[3] has been suggested by WUNDT; for example, the habit of speaking with open mouth among the Iroquois is given as the cause of the absence of labials, that of subdued expression among the Chinese, English, Americans, etc. as the reason for some of their speech peculiarities.

The differences in the organism of the child (sensory, motor, associational) lead him to attain understandable speech in somewhat different ways from those of adults. These habits may remain to some degree as he becomes

[1] SIEVERS, Grundzüge d. Phonetik, 5. Aufl., 290, Leipzig, 1901; VIETOR, Elemente d. Phonetik, 4. Aufl., 278, 1898.

[2] OERTEL, Lectures on the Study of Language, 220, New York, 1901.

[3] WUNDT, Völkerpsychologie, 1900 I 359, 403; OERTEL, as before, 198.

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older and thus make his speech slightly different. The transmission of sounds is generally *practically* perfect;[1] but it is safe to assume that finer methods of observation will show that no sound is ever made in exactly the same manner by succeeding generations.[2]

The results of mental and bodily processes at work in progressive changes may be summarized by 'phonetic laws.' These are based on the principle that the human organism acts according to laws as precise and valid as those of the rest of nature; exceptions to a phonetic law (in this sense) indicate merely that the law has not been properly formulated. The term 'phonetic law' has been used to include not only the mental and bodily factors but also inferences concerning the history of sounds; such 'laws,' as frequently pointed out, are not the same as natural laws.

The changes among individuals and communities that are occurring under the influence of surroundings can be registered by experimental means. The accumulation of phonograms, palatograms, breath records, tongue curves, etc., etc., from an individual year by year under the influence of a certain environment or internal condition would indicate the results of such conditions. Agreement of results from different cases would lead to definite general conclusions.

The influences at work are generally very complex and very slow; experimental methods may often be devised that accurately determine the action of single factors or of many factors in a brief time. Such typical investigations of concrete sounds have been made by LENZ, ROUSSELOT, LACLOTTE, and others.

Investigations of more general problems have hardly been attempted. The various hypotheses that have been put forth as explanations of phonetic changes might be directly tested by reproducing the conditions and recording the speech results. Thus the hypothesis that the changes known as

[1] SWEET, History of Language, 20, London, 1900.

[2] ROUSSELOT, *Les modifications phonétiques du langage*, 349, Rev. des pat. gallo-rom., 1893 IV, V; also separate.

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GRIMM'S law are the results of increasing rapidity of speech might be tested by recording language spoken at different speeds; the finer details that cannot be detected by the ear could be measured in tracings made as described in Part I. If increasing rapidity was the cause of the historical changes, we can confidently expect to find indications of such changes in the phonograph records. Thus, if the Indogermanic '*ghortus' changed to 'chortus' and 'hortus' or to 'garto' and 'garten' as the result of increased rapidity, exactly similar changes of a less degree should be found to-day in similar words spoken with increased rapidity by persons ignorant of the object of the experiment. The methods of registration are now delicate enough to exhibit the details. The absence of such results in carefully executed experiments would tell heavily against the hypothesis, while their presence could be accepted as final proof.

Even if increased rapidity has brought about some of the changes, other changes have probably arisen from other mental factors. It is unquestionably true that mental and bodily vigor or weakness show themselves clearly in the speech of an individual. If speech records on individuals in various conditions of excitement, health, depression, fatigue, etc., show regular relations between these conditions and certain sound changes, and if similar relations are found between the vigor and the speech of communities now existing, there will be strong presumption of similar relations in the past history of speech.

The experiments may be extended to unusual, abnormal or pathological conditions of the individual. Thus the progressive defects in coordination of muscular action whereby thickness of speech is caused may be carefully observed in the progress of alcoholic or etheric intoxication. The effects of rapidity can be observed at each degree of speed in the slowly increasing rapidity of speech in some cases of mania. Various other conditions may be obtained by administering drugs.

It is quite possible that experimental data may definitely

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confirm any one of the hypothetical causes assigned, but the well-known facts of mental life make it quite as possible that all these causes and others also are involved. I may add here that arrangements have already been made for making gramophone plates of speech under various conditions of excitement, emotion and fatigue so that the curves can be traced off by the machine described in Chapter IV. Plans are also being developed for the systematic preparation and preservation of speech records in phonetic libraries.

References

For general works on phonetic change with references to monograph literature: Paul, Principien d. Sprachgeschichte, 3. Aufl., Halle a/S., 1898; Passy, *Changements phonétiques*, Thèse, Paris, 1891; Wundt, Völkerpsychologie, I, Leipzig, 1900; Oertel, Lectures on the Study of Language, New York, 1901; Sievers, Grundzüge d. Phonetik, 5. Aufl., IV. Abschnitt, Leipzig, 1901.

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CHAPTER XXXII

MELODY

A DISCUSSION of the melody of speech should, perhaps, include a treatment of melody in song, particularly the primitive song of uncultured peoples and the spontaneous song of children. The unconscious modifications of a musical melody made by a singer should also be treated in their dependence on different conditions of activity of intellect and emotion. In spite of the great importance of these topics very little experimental work has been done. Collections of phonograms of the voices of singers have been made but have not been studied. Several collections of the songs of the American Indians have been made; one of these was carefully studied by FILLMORE.[1] The present chapter will be confined to a study of pitch in speech.

It was pointed out by ARISTOXENUS[2] that the difference between the tones in song and those in speech lies in the fact that the voice in singing proceeds by jumps from one note to another, while in speech it continually slides up and down. The fact has been thus stated by STORM: 'Characteristic for the voice in speech is its continual gliding through several tones whereby these do not impress the ear as clearly different musical tones but as an impure mixed unmusical noise. . . . The character of speech music can hardly be completely

[1] FILLMORE, *The harmonic structure of Indian music*, Amer. Anthropol., 1899 I 297.

[2] ARISTOXENUS, Harmonica, I § 25, p. 8, Meib. (the passages are collected in JOHNSON, *Musical pitch and the measurement of intervals*, Thesis, Baltimore, 1896); ARISTOXENUS, Harmonica, I § 28, p. 8, Meib. (quoted in JOHNSON, *The motion of the voice in the theory of ancient music*, Trans. Amer. Philol. Assoc., 1899 XXX 47); GOODELL, Chapters on Greek Metric, New York, 1901.

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investigated without the help of a phonograph or a similar instrument which records and measures the musical glidings completely.' [1]

The pitch of short speech sounds is hard to catch by the ear not only because each sound contains many tones that influence the total impression (p. 95), but especially because the pitch is always changing. Even from a long sound the ear receives only a vague impression of pitch when it is a changing one. These difficulties render it impossible to obtain by the ear any reliable data concerning the melody of speech. Experiments by MARTENS,[2] in which the tone of a siren was made to fall continuously at different rapidities, showed that the ear heard two successive tones when the fall of pitch was very rapid, three when less rapid, etc.

A problem by itself is that of the impression the ear receives of the melody; in all except the vaguest generalities such as high and low, rising and falling, the impression differs from the actual melody produced. Many interesting and valuable observations have been recorded of the impressions of melody.[3]

An impression of a kind of average pitch may be obtained by disconnecting the side feed of the reproducer and placing it at any desired point on a phonograph record. It thus repeats continuously the sound contained in one turn of the groove.[4]

Experimental determinations of melody have been made by the methods described in Part I.

The interesting results obtained by MARTENS (p. 19) are summarized in the following Table. In the Figures (redrawn from his chart) the horizontal distance indicates the serial number of the vibration; it may be taken roughly to repre-

[1] STORM, Englische Philologie, 2. Aufl., I 205, Leipzig, 1892.

[2] MARTENS, *Ueber d. Verhalten v. Vokalen u. Diphthongen in gesprochenen Worten*, Zt. f. Biol., 1889 XXV 297.

[3] Summary by STORM, as before, 188.

[4] MARAGE, *Les phonographes et l'étude des voyelles*, Année psychologique, 1899 V 226; THIERRY, *Le tonal de la parole*, IVme Congr. Internat. de Psychol., Paris, 1900.

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sent time, the unit decreasing with a rise in pitch. MARTENS leaves no spaces for the intervals occupied by the consonants. The proper method of plotting the curve of melody is that described in Chapter V. These curves, however, may be considered as indicating approximately the melody of the words.

TABLE

PHRASE	VOICE	SOUND	LENGTH IN SEC.	FREQUENCY Lowest	Average	Highest
'Vater und Mutter' (Fig. 325)	Male voice, 71 years	a	0.231	139	165	178
		ə	0.331	168	185	201
		u	0.257	164	183	201
		u	0.123	158	187	201
		ə	0.136	139	174	189
'Der Donner rollt' (Fig. 326)	Male voice, 29 years	e	0.162	160	173	189
		o	0.126	170	183	206
		ə	0.189	201	211	221
		o	0.226	146	160	178
'Vater und Mutter' (Fig. 327)	Male voice, 13 years	a	0.181	362	394	453
		ə	0.249	342	425	447
		u	0.118	345	377	388
		u	0.140	428	441	453
		ə	0.262	296	338	362
'Oh nein' (high), 'oh nein' (reproachfully) (Fig. 328)	Male voice, 29 years	o	0.226	283	334	394
		ai	0.283	156	242	302
		o	0.261	133	178	197
		ai	0.417	103	133	158
'Lauf, mein Kind' (Fig. 329)	Male voice, 29 years	au	0.303	144	212	273
		ai	0.239	173	195	245
		i	0.106	197	228	238
'Back süsses Brot' (Fig. 330)	Female voice, 30 years	a	0.104	307	325	342
		Back	0.366			
		˥	0.205			
		y	0.153	312	347	370
		sü	0.172			
		e	0.095	288	296	324
		sses	0.411			
		˥	0.184			
		o	0.229	273	324	348
'Bau hübsche Häuser' (Fig. 331)	Female voice, 13 years	au	0.328	302	326	355
		Bau	0.342			
		˥	0.099			
		y	0.077	318	325	336
		hüb	0.194			
		ə	0.105	312	323	336
		sche	0.215			
		ɔi	0.216	292	328	351
		Häu	0.152			
		ə	0.083	229	252	263
		ser	0.203			

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FIG. 325.



FIG. 326.

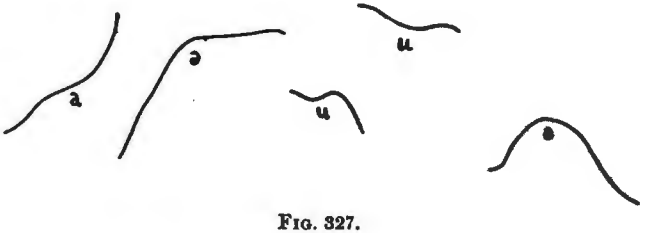

FIG. 327.

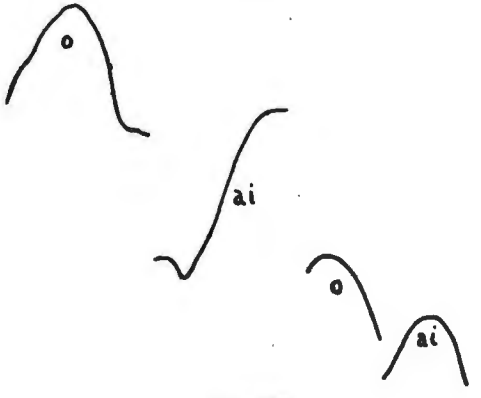

FIG. 328.

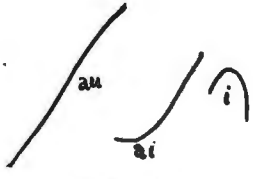

FIG. 329



FIG. 330.

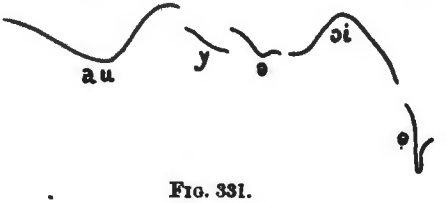

FIG. 331.

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Phrase	Voice	Sound	Length in Sec.	Frequency Lowest	Highest	Average
'Was giebt's dort?' (Fig. 332)	Female voice, 33 years	a	0.155	329	371	431
		was	0.201			
		¬	0.517			
		i	0.145	377	463	518
		giebt's	0.609			
		¬	0.311			
		o	0.178	273	309	342
		dort	0.325			
'Mein kleines Kind' (Fig. 333)	Female voice, 13 years	ai	0.267	292	313	336
		mein	0.473			
		¬	0.064			
		ai	0.157	307	321	336
		klein	0.283			
		e	0.051	304	311	318
		es	0.073			
		¬	0.073			
		i	0.116	283	309	345
		Kind	0.328			

Martens made no application of his results to speech melody. They seem to show clearly that the cord tone never stops on any note but is always rising or falling; even the shortest vowels show just as rapid changes as the long ones. The affirmative phrases end in a vowel of a lower average pitch than the others but of a 'circumflex melody.' The last vowel in the commands has a higher average pitch; the circumflex form of melody also appears in them.

In regard to the charts of the course of the cord tone given by Martens I may point out that in two independent words 'Mokka' and 'Mutter' the first vowel shows a rising pitch and the second a falling one; each word as a whole may be said to be of 'circumflex pitch.' The phrases also have usually a circumflex form to conform with which the word circumflexes are modified; some phrases, however, show other forms.

Schwann and Pringsheim[1] have made phonautograph records (p. 17) of French words and phrases. Measurements of the speech curves showed that as a rule both vowels in a two-syllable word were spoken at the same pitch, with the same intensity and with the same duration. A word at

[1] Schwann und Pringsheim, *Der französische Accent*, Archiv f. d. Studium d. neueren Spr. u. Lit., 1890 LXXXV 203.

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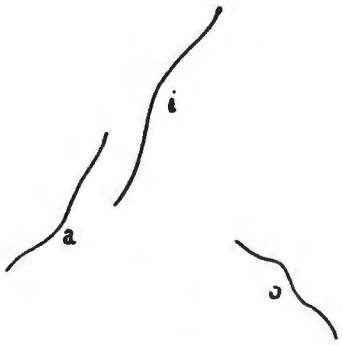

FIG. 332.

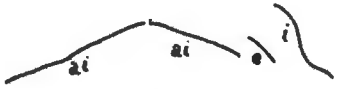

FIG. 333.

the end of a sentence differed from that within a sentence by having a lower pitch and a less intensity. An isolated word was pronounced like a word at the end of a sentence. One of the curves of melody is shown in Fig. 334; the horizontal axis indicates time in seconds.

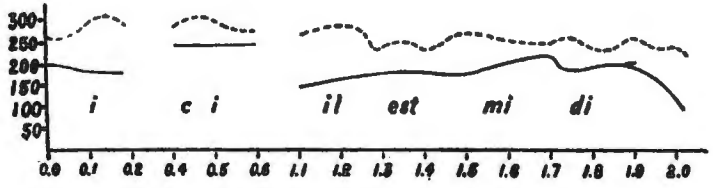

FIG. 334.

PIPPING (p. 121) gives melody curves for a number of independent Finnish words; they show without exception a circumflex pitch. When the changes in pitch are not of a complicated character, we can consider a vowel in which the average is higher than its beginning as a 'vowel of rising pitch' and one in which the average is lower than its beginning as a 'vowel of falling pitch.' PIPPING's dissyllabic and trisyllabic Finnish words showed without exception a vowel of rising pitch in the first syllable, a vowel of falling pitch in the last syllable, a vowel of steady or falling pitch in the

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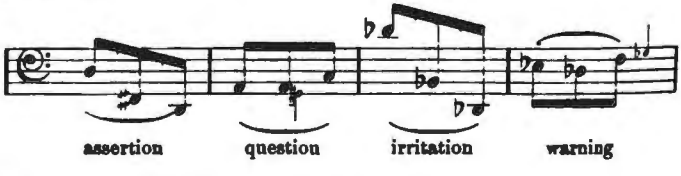
middle syllable of a trisyllabic word, the average pitch being lower for each succeeding syllable.

The curves of the vowels of German words spoken isolatedly, recorded on a phonograph and measured by the aid of a corneal microscope, have been studied by MEYER.[1] In a long German vowel, under the conditions given, the cord tone begins low and rises (region of tone-rise), remains a time at a maximum (region of tone-maximum), and falls (region of tone-fall). The course of pitch is greatly influenced by the neighboring consonants; the more emphatic the consonant, the greater is its influence on the pitch-curve; the following consonant often cuts the vowel off at or near the maximum. With short emphasized vowels the influence of the consonants is even greater than with long vowels. With short unemphasized vowels the cord-tone has only the region of tone-fall. Every vowel has a favorite pitch for its tone-maximum in this descending order: u, i, o, e, a. Emphatic consonants raise the tone-maximum. Greater loudness seems to be regularly accompanied by higher pitch, on the principle — I may suggest — of greater muscular effort in one direction being accompanied by greater effort in others.

The course of pitch in the cord tone can be registered with some accuracy on the breath-curve by a short tube from the lips to a tambour. Experiments by VIETOR[2] gave results for the u of ' du ' which are roughly indicated in the following notation:



The breath-curves for these forms of ' du ' are given in Fig. 87 (p. 218). Records of sentences showed that em-

[1] MEYER, *Zur Tonbewegung des Vokals im gesprochenen und gesungenen Einzelwort*, Neuere Sprachen, 1897 IV Phonet. Stud. 1.

[2] VIETOR, Elemente d. Phonetik, 4. Aufl., 293, Leipzig, 1898.

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phasis on any portion of the subject or the predicate raised its pitch.

Using a phonograph, MARICHELLE found[1] melody curves as follows (the staves are of the treble clef):

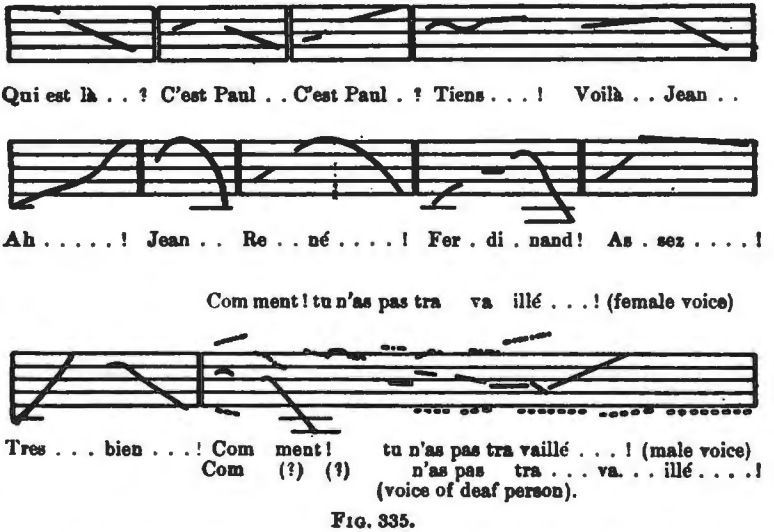

FIG. 335.

The curve of melody (or curve of pitch) for the tracing of JEFFERSON'S voice in *Rip Van Winkle's Toast* (p. 61), as reproduced in Plates III to XI at the end of this volume, is given in Plates XII and XIII.

The measurements of the successive periods of the cord tone were made and computed according to the methods explained in Ch. V. The plot was made as described on p. 65. The dots were, however, joined by straight lines, and a smooth curve was not drawn through them as in Fig. 44; the successive dots are more readily indicated in this way but the general course of the cord tone would be more truthfully represented by a smooth curve.

Horizontal distance in Plates XII and XIII indicates time

[1] MARICHELLE, La parole d'après le tracé du phonographe, Planche 11, Paris, 1897.

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at the rate of $1^{mm} = 0.0035^{s}$, or a reduction to one fifth the size shown in Plates III to XI. The vertical scales indicate frequency, or the number of vibrations a second. Each group of words refers to a portion of the melody-curve extending from its beginning to a group of large figures on the horizontal line; during each portion the horizontal line remains unbroken. The large figures indicate, as in Plates III to XI, the portions of straight line in the original tracings that were omitted in preparing the Plates; they are turned into time by the equation $1^{mm} = 0.0007^{s}$.

The interruptions in the melody-curve indicate surds, or very weak sonants, or pauses.

The curves in Plates XII and XIII indicate a very low and even melody of speech that is varied at times for emotional expression. In general each sentence begins low, rises gradually, and then falls, but variations occur. The changes in the tone are generally continuous.

'Come, Rip' shows a rise at the end, which is a common inflection for a cheerful, animated invitation. 'What do you say to a glass?' shows a low vowel, then a rise to the u of 'you'; this u, however, begins to fall just before the following word. 'Say' is of high pitch, as is frequently the case for the verb of a question; the fall at the end of 'you' may have been a kind of preparation by contrast for the high pitch of 'say.' The highest pitch for the phrase is found in 'glass'; it is even higher than in 'say,' probably because of the greater emphasis given to the word 'glass.' The pitch falls toward the end of æ in 'glass'; such a fall is usual in a sentence beginning with an interrogative word (or phrase) that is not specially emphatic. These words were spoken by JEFFERSON as introductory to the *Toast* itself. The invitation is followed by a long pause of 2.86^{s} before the reply comes.

The *Toast* begins with a repetition of the question of invitation. It is spoken in a rather soft manner, as appears not only to the ear but also in the small amplitude of the waves in Plate IV. The pitch curve is fairly level, with some rise

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at the end instead of a fall. This rise is the usual ending of a repeated interrogative sentence. The general pitch is lower than that of the invitation. A pause of 0.41^s follows.

The exclamation 'huh' is a kind of chuckle. It is of a very high pitch but small intensity and short duration. It is followed by a pause of 1.05^s.

'Now what do I generally say to a glass?' shows a very even rise and a very gradual fall; its general pitch is low. It is a kind of bantering statement. The long pause of 2.16^s seems to express a simulated expectation of a reply.

'I say it is a fine thing' is a decided statement with emphasis on 'fine thing.' It has the usual circumflex form as far as 'a.' If the sentence had been completed with no further emphasis, the pitch would probably have continued to fall. The rise in pitch for the specially emphatic 'fine thing' adds an accessory circumflex. The pause of 1.78^s and the fall in pitch lead the hearer to suppose the sentence finished.

'When there 's plenty in it' is muttered as a joke. Its pitch is not lower than usual. The emphasis on 'plenty in it' gives a higher pitch to the latter portion. The whole statement has the usual circumflex form. The long pause of 2.90^s is presumably occupied by the first sip of the toast.

The soft exclamation of satisfaction 'ha' has a falling pitch. It is followed by a pause of 1.79^s. The 'so' expresses deep satisfaction. It begins moderately high and falls steadily in pitch. To the ear it has a peculiar rattle of a low pitch as if some particles of liquid had lodged on the edge of the epiglottis, as is sometimes the case after drinking. This peculiar effect shows itself in the alternately louder and weaker character of the groups of vibrations shown in Plate VII. Such a curve could be produced by the cord explosions striking against a mass of liquid that would vibrate readily at a sub-multiple of the cord period; the portion of liquid would rise and fall, weakening the cord tone on alternate periods. It is quite probable that when speaking into the gramophone recorder JEFFERSON produced this effect by some muscular adjustment (epiglottis, ventricular bands)

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and not by an actual sip of some liquid. 'So' is followed by a pause of 2.00^{s}.

'You had it ten years ago, eh?' is spoken as a continuous sentence; there is complete fusion of the vowels at the end. The first part rises rapidly to a high pitch. The circumflex form is marked, the fall beginning in the o of 'ago.' The 'eh' has a circumflex form joined to the o curve. In spite of the complete fusion of these vowels we may perhaps consider 'eh' as a stressed tag with a pitch-curve of its own.[1] The sound indicated here by 'eh' begins with a very weak breathing and seems slightly nasalized; it thus inclines somewhat toward hə^{n}. The long pause of 2.45^{s} indicates perhaps the time of another sip.

'Ah' is an expression of satisfaction; it appears to the ear much lower and smoother than the 'ha.' The following pause is very short, 0.13^{s}.

'That's fine schnapps' is not an emphatic statement but expresses a decided conviction after a satisfactory trial. It shows the usual initial rise for a declarative sentence, but instead of falling at the end, it rises slightly. This peculiar rise seems to express conviction after a doubt. The figures 333^{mm} after 'that's' indicate the portion of tracing (tsf) left out in the original record, and not a pause. The sentence is followed by a pause of 1.92^{s}.

'I would n't keep it as long as that' has the usual circumflex form; it is followed by a brief pause of 0.29^{s}.

'Would I' is used to turn the declaration into a question. It is very brief. A short pause, 0.25^{s}, follows.

The very brief and faint chuckle 'huh, huh' is followed by a pause of 1.20^{s}.

The introductory 'well' — presumably spoken as the glass is lifted — rises steadily to a high pitch. It is followed by a long pause of 3.43^{s}.

'Here's your good health' rises steadily to a very high pitch. The speaker makes a rather long pause, 0.94^{s}, perhaps for emphasis. He then completes the thought in his mind by

[1] SWEET, New English Grammar, II 39, London, 1898.

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'and your family's.' This tag-phrase has, however, somewhat the character of a separate sentence; its pitch-curve is circumflex. It is followed by a pause of 1.54^s.

The invocation 'and may they all live long and prosper' appears to have the solemn steady intonation of a somewhat religious utterance. The pitch-curve shows great evenness; there is a rise at the beginning and a fall at the end. The fall appears during the first part of 'prosper'; during the last part the cords are so relaxed that they produce only a few rather irregular vibrations (Plate XI); the last syllable appears to the ear almost as a surd or whispered one. It is followed by a pause of 1.74^s, during which the toast is presumably drunk.

The 'ah' is a low, soft exclamation of gustatory satisfaction after the toast. The peculiar rattle is heard as in 'so' above; the same alternation in the character of the groups of cord vibrations appears in Plate XI. The pitch-curve shows a steady fall. The last vibrations are of a very low pitch; they appear clearly in the tracing but are probably too low in pitch for the ear to catch (p. 98).

Several series of experiments have been made on the melody of speech sounds, the *average* pitch of each sound being noted.

ROUSSELOT'S records[1] of the kind shown in Figs. 284 to 286 enabled him to give certain average frequencies, as, for example,

m	o^n	po	v	pj	a	r	e
	240	220			220	210	210

The melodies of two selections of his dialect were worked out in this way and expressed in musical notation. From these results ROUSSELOT[2] concludes for French: 1. In ordinary voice an isolated vowel has no fixed pitch for the cord tone. 2. Consonants are generally higher than vowels. 3. Generally the approximation of a vowel and a consonant

[1] ROUSSELOT, *Les modifications phonétiques du langage*, 109, Rev. des pat. gallo-rom., 1893, IV, V; also separate.

[2] ROUSSELOT, as before, 40.

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raises the pitch of the consonant and lowers that of the vowel. 4. The voice often varies gradually in pitch in a single syllable. 5. There is a musical rhythm which is less influenced by the physiological conditions of speech than the rhythm of intensity or that of duration, and which is consequently better adapted to render the shades of thought. 6. In words of two syllables the second one is raised in pitch in ROUSSELOT'S dialect, but this pitch accent is less firmly fixed than the duration accent. 7. In words of three and four syllables the musical accent of rise in pitch coincides generally with the accents of duration and intensity, with differences sometimes in the unstressed syllables. 8. Groups ending in an atonic have the pitch accent in the same place as the historical accent even when the atonic has become longer and louder than the tonic (as in **kokote**; frequencies: 480, 600, 520; periods in hundredths of a second: 6, 11, 9; the **e** still has its ancient accent shown by a rise in pitch). 9. The phrase is a song whose measure follows the intensity or the duration of the syllables and whose melody chiefly follows the changes in thought. 10. The pitch accent falls readily but not necessarily on the more intense or the longer syllables.

In the record of the first stanza of *Cock Robin* (p. 58), I find the average periods of various sonants as follows (in thousandths of a second): —

Wh o k i lled C o ck R o b i n?
3.3 5.1 4.2 1.8 5.3 5.6 8.4

I, s aid th e sp a rr ow,
18–4 5.3 5.3 5.3 2.8 5.2

W i th m y bow a nd a rr ow
5.3 2.1 5.3 5.6–3.6 7.0 5.3 4.2 2.5 7.0

I k i lled C o ck R o b i n.
12–4 5.6 7.0–5.3 3.9 3.9 4.2 5.6 8.8

In studying the melody of a vowel we may for some purposes disregard cavity tones, overtones and the peculiar characteristics of the cord puffs (p. 94, 260), and can conven-

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iently consider the tone as a simple sinusoid (p. 2); the equation of the vibrating particle will then be

$$y = F(t) \sin \frac{2\pi t}{f(t)},$$

where y is the elongation, $F(t)$ the amplitude, and $f(t)$ the period. If the amplitude is constant as in the curves of Figs. 19 and 31 (though this is rarely the case in a spoken vowel), we have $F(t) = a$.

A vowel during whose course the pitch remains constant can be said to be of 'sustained' pitch. If T is the period of vibration of the cords, we have in the ideal case

$$y = F(t) \sin \frac{2\pi t}{T}.$$

Vowels of sustained or constant pitch are not very common in the cases I have studied. Most vowels seem to rise or fall, yet some of them are approximately constant. The vowel i as found in 'see,' 'needle,' 'I,' etc., is approximately a sustained vowel although it generally falls slightly. The following measurements of i in 'see' are typical ($^{\sigma} = 0.001^{s}$): 2.3, 2.3, 2.4, 2.4, 2.8^{σ} . . . to the 22d vibration, 2.4^{σ} to the 42d vibration, 2.1^{σ} to the end at the 64th vibration. (*Cock Robin*, *Series I*, p. 58; see also Appendix II.)

The rather unusual case of two vowels of sustained pitch forming a diphthong is found in the word 'my' of the phrase 'With my bow and arrow.' The a has a constant period of 5.6^{σ} and the i that of 3.6^{σ}. The a has also a constant amplitude of 0.4^{mm}; the i, beginning with 0.5^{mm}, falls to 0 as usual in ai in an independent word (*Cock Robin*, as before). The diphthong ai is of nearly constant pitch throughout most of its length in two cases of 'thy' in *Lord's Prayer*, *Series I* (p. 58).

Nearly all vowels in the earlier parts of words in the records studied (p. 58), whether preceded by a consonant or not, are characterized by a rising pitch. In such a case the period is not a constant, T, but a function of the elapsed time, $f(t)$. A typical example of this kind of vowel is regularly

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found in the a of ai. A determination of the particular form of $f(t)$ for various vowels is a highly important matter, as different vowels and different manners of speaking are possibly characterized by different forms of this rise in pitch. Some of the cases of a suggest the form $f(t) = ke^{mt}$, a formula which expresses many of the phenomena found in nature (k and m are empirical constants, and e the constant 2.71828).

When the rise in pitch (decrease in period) is proportional to the elapsed time, we have

$$y = F(t) \sin \frac{2\pi t}{T_0 - mt},$$

where T_0 is the period of the first vibration and m the factor of proportionality. Such a vowel is found in the a of the fourth example of 'I' in *Cock Robin, Series I.* During an interval of 180^σ its period is shortened by 5.5^σ, or at the rate of $0.03t$. Its cord equation, on the suppositions made above, would be (in seconds)

$$y = F(t) \sin \frac{2\pi t}{9 - 0.03t}.$$

In the latter portions of words the vowels in the records I have examined are generally nearly constant in pitch, with often a slight fall as the intensity decreases. Typical examples are found in the cases of i in ai (Appendix II). This slight fall in pitch does not necessarily indicate a relaxation in the tension of the vocal cords; as the force of the expired current of air decreases, the frictional forces involved in the cord vibration may gradually lengthen the period. Yet the amount of fall is generally too great to be due to anything but a relaxation of the cords.[1]

Melody is used as a speech factor in different ways. As a method of distinction among speech sounds, it may be used like any other speech factor, such as an explosion or a resonance. In Chinese this use has reached a high degree of de-

[1] SCRIPTURE, *Researches in experimental phonetics (first series)*, Stud. Yale Psych. Lab., 1899 VII 93.

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velopment, the pitch of the cord tone being used phonetically just as all languages use the pitch of the cavity tones in the mouth to make different vowels. The words that to us appear, for example, as **ba** spoken on four different tones are for the Chinese perhaps more distinctly different than **ba, bo, bi, be** would be to us. I have observed this perception of the cord tone as a characteristic part of a speech sound by an infant who used the degrees and modulations of intonation for each sound as it occurred in the first speaker from whom the sound was learned. In most European languages this use of melody to distinguish special sounds is subordinate to its use as a means of expressing more complex mental states, as in assertion, question, etc.

The preceding account has treated the cord tone alone as the basis of melody; a fuller treatment would include all the relations of harmony among the various resonance tones and the cord tone; a vowel is in fact not a melody alone but a harmonized piece of music. Experimental data on this subject are almost entirely lacking; the harmony in vowels is illustrated in Appendix II.

References

For observations and literature on speech melody: Sievers, Grundzüge d. Phonetik, 5. Aufl., 242, Leipzig, 1901; Storm, Englische Philologie, 2. Aufl., 1, 203, Leipzig, 1892; Vietor, Elemente d. Phonetik, 4. Aufl., 290, Liepzig, 1898; Sweet, New English Grammar, II 37, Oxford, 1898; Hempl, German Orthography and Phonology, 167, Boston, 1897. For literature on and views of the nature of melody: Helmholtz, Lehre v. d. Tonempfindungen, 5. Aufl., Braunschweig, 1896; Stumpf, Tonpsychologie, Leipzig, 1883-1890; Wundt, Grundzüge d. physiol. Psychologie, 4. Aufl., Leipzig, 1893; and the large monograph literature in the bibliographies of Zt. f. Psychol. u. Physiol. d. Sinn., Année Psychol., and Psych. Rev.

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CHAPTER XXXIII

DURATION

As in the case of melody the treatment of the duration of speech sounds should include — perhaps begin with — a study of these sounds in song. The conditions in song are simpler than in speech, owing to the fact that a norm is imposed upon the singer, from which his variations are to be treated as measurable expressions of his personal rendering. Songs are never sung — or intended to be sung — exactly as written. Even the most mechanical popular tune is rendered differently by each individual, the differences lying mainly in the duration of the elements, in the stress assigned to them, and, above all, in the attack by the voice and the utterance of each sound. In artistic performances all these sources of variation are employed — mainly unconsciously — to express the thought or emotion of the singer. Concerning just how they are varied and how they are employed there are at present no experimental data. Curves of various songs have been traced off by the machine described in Ch. IV, but have not yet been studied.

The duration of a portion of speech may be registered 1. automatically, 2. by a special movement of the speaker, 3. by a movement of a different person. The results of investigations will be considered in connection with the method employed.

The automatic methods consist in direct registration of the voice vibrations (Part I) or of the vocal movements (Part III). The time occupied by the sound may be determined by any of the methods used in such cases.

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From the Tables (pp. 474, 476) of the results of measurements by MARTENS it seems clear that the length of a vowel in a given word varies greatly even for the same speaker. Thus, for 'Vater und Mutter' MARTENS found the following durations in thousandths of a second:

	V	A	T	E	R	U	N	D	M	U	T	T	E	R
Male voice, 71 years				231		331		257		123			136	
" " 52 "				269		—		120		148			94	
" " 29 "				183		133		121		67			179	
" " " "				145		122		97		64			—	
" " " "				205		127		150		98			—	
" " 28 "				166		213		296		151			—	
" " 26 "				318		222		117		116			—	
" " 13 "				181		249		118		140			262	
Female " 6 "				177		100		56		84			—	

We see here all sorts of variations. Even the so-called long *a* in 'Vater' on three occasions was found to be shorter than *e*. The so-called short u of 'und' was often longer than a of the 'Vater,' but was often also extremely short. Other similar cases may be found in the Table on pp. 474, 476.

Measurements of the lengths of the speech sounds in the JEFFERSON records were made by an assistant under my guidance. The completeness of the fusion of sounds in connected speech (p. 451) made it impossible to assign any very definite limits to most of the sounds. When a sound was next to a pause or a surd, its limit was placed at the extreme vibration. Thus the first vibration of ə in 'Come' (Plate III, line 1) and the last distinct one of i (line 4) gave fairly definite limits. Yet the curve shows quite clearly that the i-vibrations began to be weakened by closure for the p somewhere about 60^{mm} from the right end of line 4; faint vibrations can, however, be detected at about 15^{mm} from the end; thus even in a case like this it is impossible to mark off the limits of i, i-p glide, and p. In other cases there is no possibility of assigning any limits, because the sounds are fused into gradually changing ones; thus in line 13 the u of 'to' changes to ə 'a,' but the change is a gradual one beginning far back in the u and extending throughout the ə. In fact, there are *not* two sounds u and ə united by a glide; there is a changing sound which at some

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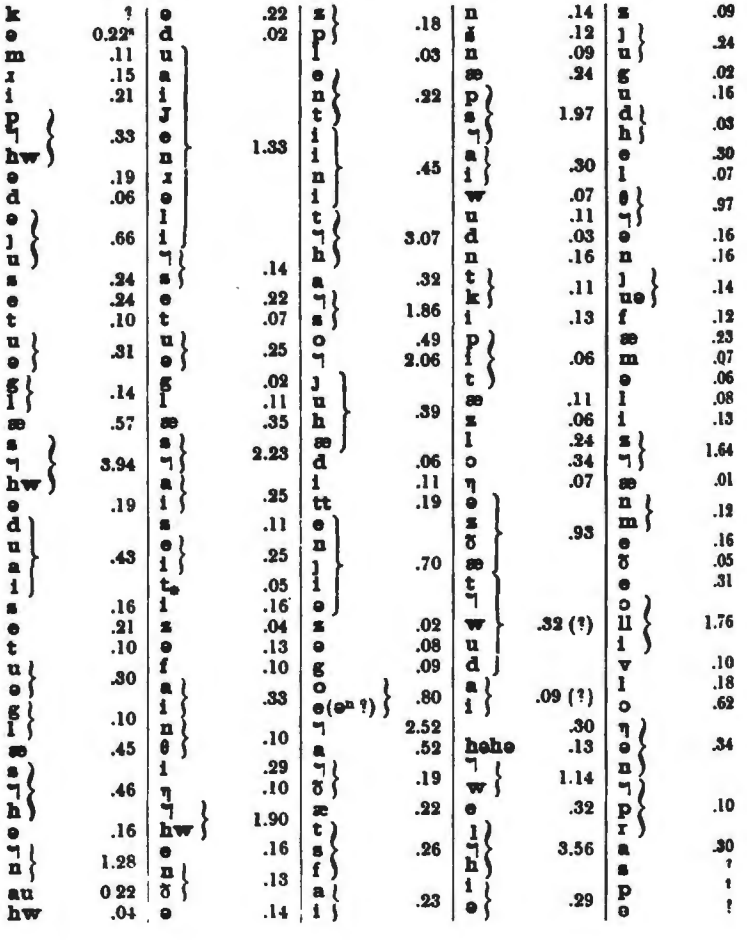
one instant may be an u and at a later one may be an ə, and which to the ear (trained to various associations) gives an impression resembling a sequence of u and ə. In spite of these facts I venture to give figures for the duration of sounds in the JEFFERSON records in order to furnish some approximate data; the figures are subject to the limitations just explained; where I have been utterly unable to decide on a limit I have indicated the fusion by a brace.

The phonetic notation is used in the following list merely



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to indicate the sounds in order to aid in marking off their duration; it is not intended as an accurate phonetic analysis. For example, the use of ə for the stressed vowel in 'what' does not necessarily mean that the sound is the same as the ə in 'come'; to the ear the brief vowel in this case seems related to a, ɔ, and ə, but it is hardly possible to decide on the degrees of likeness.

General averages of the lengths of the vowels have been made for Swedish and Finnish by PIPPING (references on p. 20).

The graphic methods described in Part III are also used for measurements of duration. A voice-key (Fig. 66) attached to a DEPREZ marker (Fig. 61) can be used to register the lengths of vowels.

By means of records from the larynx (p. 267) and the nose (p. 219) ROUSSELOT was able to establish the following facts for his own speech[1]:

1. In isolated words the explosive consonants are slightly shorter than the fricatives (a p a p a, a f a f a, a t a t a, a s a s a, a š a š a); the sonants are often shorter than the surds ($o^n fo^n$, $o^n vo^n$, $o^n to^n$, $o^n do^n$, etc.); the lengths of the consonants generally diminish with increased length of the word; the last consonant in a word is generally lengthened; 'double consonants' are really long and strong single consonants; consonants in groups tend to occupy less time than the sum for single ones. The numerals in the above examples indicate hundredths of a second.

2. In records such as *ȯ*, *ó*, *o*, *ȯp*, *óp*, *op*, *pȯ*, *pó*, *po*, *pȯp*, *póp*, *pop* for the vowels a, e, i, o, u, y, œ, the open (`) and close (') vowels were regularly somewhat longer than the medium ones (unmarked).

'The first lessons I received in grammar taught me to confuse quantity with timbre, and this confusion persists in my

[1] ROUSSELOT, *Les modifications phonétiques du langage*, 81, Rev. des pat. gallo-rom., 1891 IV, V; also separate.

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present appreciation of the vowels in my dialect. I perceive as long all open or close vowels, as short all medium vowels. That the appreciation contains exaggeration is shown by my measurements. But it is correct for isolated vowels.'[1]

3. In groups of two syllables the last vowel of the group is almost always the longer one; the difference between long and short vowels is often rendered almost imperceptible by an approximation of both to a medium length.

4. In groups of three or four syllables with one vowel checked (**papatpa**) as compared with all vowels free (**papapa**), the checking tends to abbreviate the vowel.

5. Groups of syllables show a decidedly iambic character, the principal forms being ⏑ –, ⏑ – –, – ⏑ –, ⏑ ⏑ – –, ⏑ – ⏑ –, ⏑ ⏑ – –, – ⏑ ⏑ –, where ⏑ indicates very short, ⏑ short, – long, – very long. The end of a group of syllables is always an iambus; the first part varies between iambic and trochaic.

6. In groups of two syllables with the same vowel, both stressed and unstressed vowels are long when open or close, and short when medium.

7. In groups of syllables with the same vowel, the vowels perceived as short are often longer than those perceived as long.

8. A vowel naturally short is strongly abbreviated when followed by a long vowel (**kŭtē**, ' couteaux,' 12, 19); when both vowels are naturally short or long the stressed vowel is the longer (**măti** ' matin,' 7, 13; **ōtŭr**, ' autour,' 6, 14).

9. The vowels, except **a**, are longer after **f**, **v**, **s**, **m** than after **b**, **p**; after **ž** than after **g**; after **v**, **z** or **ž** than after **f**, **s** or **š**; after **p** or **k** than after **b** or **g**; after **k** or **g** than after **p** or **b**; after **ñ** than after **n**. The vowel **a** is shorter after **m** than after **p**, **b**; after **v** than after **f**; after **p** than after **b**; after **g**, **k** than after **b**, **p**. The vowel **a** is longer before sonants than before surds; before **f**, **v** than before **p**, **b**; before gutturals than before dentals; before dentals than before labials.

[1] Rousselot, as before, 88.

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10. Diphthongs are shorter than the sum of the two separate vowels supposed to compose them; a stressed diphthong equals the two unstressed separate component vowels.

The above relations appear clearly in connected speech. The durations in hundredths of a second were calculated from experimental records (p. 359). In the following illustration of connected speech the lengths are marked beneath the vowels in hundredths of a second.

a^{n} t a^{n} t y ɹ š a^{n} t a k œ k u k y

13 6 9 11 10 14 14 6 15 6 18 6 9 8 10

t a e k u t š a^{n} t œ s o^{n} s u

8 9 6 10 15 16 15 14 15 16 15

'Entends-tu chanter ce coucou?
Ta! écoute! chante-t-il son saoul!'

ROUSSELOT finds in the records of connected speech that final atonics scarcely exist in his case except in plural nouns and in verbs in the second person. In only two cases did a final ə appear; these were under exceptional conditions.

In respect to the duration of different sounds in language the ear gives little correct information, as is shown by the graphic records. 'Vowels which I believed always long were often short; others that I regarded only as short often surpassed in length those I considered as long.'[1]

Experiments by BINET and HENRI[2] with ROUSSELOT'S microphone registering apparatus (p. 267) showed that in speaking a series of numerals the sound before a pause is lengthened, this being supposed to indicate that it is easier to change from one motor condition of articulation to another than to end a motor condition. Increase in velocity of speech shortened the pauses rather than the sounds. Stress lengthened a sound.

Using a mouthpiece connected to a MAREY tambour to

[1] ROUSSELOT, as before, 76.

[2] BINET ET HENRI, *Les actions d'arrêt dans les phénomènes de la parole*, Rev. philos., 1894 XXXVII 608.

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register breath impulses in French sounds, WAGNER[1] found that long vowels occur only in stressed syllables that end with a consonant; that all such vowels are long when followed by a sonant fricative or ȷ; that close o, velar a, and all the nasal vowels are long before a consonant; that the other vowels, i, y, u, open e, œ, o, and palatal a, are generally short when stressed and followed by a consonant that is not a sonant fricative or ȷ, but are generally half-short within a sound group; that consonants before a pause are the longest ones; that such consonants are not influenced by the length of the preceding vowel.

The variations in the duration of French syllables in different phonetic combinations have been investigated by GRÉGOIRE.[2] A mouthpiece connected to a MAREY tambour recorded the breath explosions and the cord vibrations.

Records were made on comparative groups of the following types: 'pâte: pâteuse, pâteuse: pâte, pâte: pâteuse: pâte, pâteuse : pâte: pâteuse;' they showed that the monosyllable with a long vowel is always longer when pronounced alone than when it enters into a dissyllabic compound ending in another long syllable. Examples may be seen in the records of

pâte	pâteuse	pâte
$\overline{33}$	$\overline{21}$	$\overline{35}$
pâteuse	pâte	pâteuse
$\overline{20}$	$\overline{33}$	$\overline{20}$
têtard	tête	têtard
$\overline{21}$	$\overline{36}$	$\overline{20}$
tête	têtard	tête
$\overline{37}$	$\overline{23}$	$\overline{39}$
il tâte	ils tâterent	il tâte
$\overline{34}$	$\overline{21}$	34

The figures give the number of hundredths of a second occupied in each case by the syllable *pâ*, *tê* or *tâ*. The ordinary

[1] WAGNER, *Französische Quantität*, Phonet. Stud., 1892 VI 1.

[2] GRÉGOIRE, *Variations de durée de la syllabe française*, La Parole, 1899 I 161, 263, 418.

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relation of length between the monosyllabic fragment and the same fragment in a dissyllable ending with a long syllable is about 1 : 0.6 with some considerable variations. Thus a comparison of $x_1^- : x_2^- y^-$ shows that $x_2 < x_1$.

When the fragment appears in a dissyllabic compound ending in a short syllable, the relation is approximately the same. Examples are

pâte	:	pâteux	:	pâte
36		27		38
tête	:	têtu	:	tête
38		24		36

Thus $x_1^- : x_2^- y^-$ gives also $x_2 < x_1$.

The duration of a monosyllable remains in general the same when it is made the final syllable of a polysyllabic word; for example,

prête	:	interprête	:	prête
37		40		37
interprête	:	prête	:	interprête
40		40		40

Thus $x_1^- : v \ldots y x_2^-$ gives $x_2 = x_1$. Before a suffix added to the polysyllable the fragment is shortened just as in the case of a monosyllable.

In comparing similar words of the types $- -$ and $- \breve{}$ it was found that in the majority of cases there was a slight lengthening of the first syllable in the trochee. In the following example the first of each set of figures gives the time of the syllable and the second the time of the occlusion of the t.

pâ teuse	:	pâ teux	:	pâ teuse
21 15		26 19		23 17

Thus $x_1^- y_1^- : x_2^- y_2^-$ gives $x_2 > x_1$.

GRÉGOIRE calls attention to the relatively long durations for the occlusions (not the explosions) of the occlusives. In a dissyllable the occlusion (not the explosion) comprised in the second consonant is often nearly as long as the whole

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first syllable. The shortest occlusions measured from 0.10^s to 0.18^s; many reached 0.18^s to 0.20^s — rather large figures in comparison with 0.30^s to 0.32^s for the preceding vowels. The occlusions are brief moments of silence that are not noticed as such. Even to the ear a word like 'pâteux' seems to be one continuous flow of sound, probably because the motor activity of the speech organs goes on just as vigorously during the occlusion as before and after, and by association unifies the auditory parts in the hearer. If we insist upon dividing words into syllables, to which syllable does the occlusion belong? For the ear GRÉGOIRE believes the following syllable to begin with the explosion while the occlusion belongs to the preceding one. In speaking at unintentionally different rates the duration of a syllable is increased by lengthening sometimes the vowel alone, sometimes the occlusion alone and sometimes both.

When used in a polysyllable, a long syllable is shortened as the number of following syllables increases. Thus, the syllable 'pon' in 'pontife' becomes shorter in 'pontificat' and still shorter in 'pontificalement.'

For a short syllable analogous results were found in all the preceding cases that have been discussed.

In groups of words in ordinary speech a monosyllabic fragment alters the proportion of its vowel to the following occlusion according as it is followed by a vowel or by a consonant, although the total of vowel + occlusion may remain the same. A typical result was

pâ te sucrée	pâ te et de crême
⏑ |	⏑ |
18 14	25 9

In this case the complication of the group ts for some reason shortens the vowel and lengthens the occlusion.

In discourse the union by contiguity shows its effect chiefly in shortening the monosyllables.

GRÉGOIRE also shows that a final syllable of a word becomes longer before a pause.

GRÉGOIRE'S explanation for the decrease in length of a

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syllabic fragment according as it occurs in a monosyllable, a dissyllable or a polysyllable is that a portion of the accent of the monosyllable is transferred to the other syllables in combinations and that the 'language,' foreseeing the effort required at the end of the word, shortens the earlier portion.

Records of the breath curve (p. 219) by VIETOR[1] for his own speech (Nassau, Germany) gave as typical lengths: extra-short vowels in K*a*mm, w*a*rt' (0.08^s); short in P*a*ppe, G*u*ttenberg, d*ă*! (0.15); half-short in S*e*kretär (0.19, 0.18), m*i*t, m*i*tteilen, P*a*ckkorb, T*au*ffeier (0.20); half-long in Unth*a*ten, M*i*tra (0.25); long in Th*a*ten, G*u*tenberg, th*u*st, Unth*a*t, b*ie*ten, B*au*mmeise, Mitr*a*, P*a*pe (0.30); extra-long in Sekretär (0.35), Th*a*t (0.37), w*a*r't, th*u*t, Fr*au*, M*ai*d, fre*u*', th*u*, fr*ei*, k*a*m (to 0.42), d*ā* (0.45). From these and similar results the following conclusions were drawn. *A*. The so-called 'long' vowels are (I) *extra-long* when tonic in the last syllable and followed by no consonant, a single consonant, or a liquid and a consonant; (II) *long* when tonic in the last syllable before several consonants, or in the next-to-last or some preceding open syllable (before a single consonant), and also *long* when having post-tonic secondary stress when the tonic vowel is extra-long; (III) *half-long* when tonic in the next-to-last syllable followed by several consonants, or when having post-tonic secondary stress when the tonic vowel is long; (IV) *half-short* when having pre-tonic secondary stress. *B*. The so-called 'short' vowels are (I) *half-short* when tonic in the last syllable before a single occlusive, and in the next-to-last syllable before a double or long occlusive; (II) *short* when tonic in the last syllable with no following consonant, and in the next-to-last or some previous closed syllable; likewise unstressed $e = ə$; (III) *extra-short* when stressed in the last syllable before a liquid or before a liquid and a consonant. *C*. The diphthongs show the same relations as the long vowels.

[1] VIETOR, Elemente d. Phonetik, 4. Aufl., 269, Leipzig, 1898.

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Similar records[1] for an Englishman from Sydney (Australia) living in Marburg (Germany) showed on one occasion half-long vowels in bite, pate (0.25ˢ); long in pat (0.30); extra-long in part (0.41), paid (0.45), bide (0.49), pad (0.55), pard (0.61); on another occasion short in beat (0.15ˢ); half-short in pat, goddess (0.20); half-long in bead, gaudy (0.25); long in pate, bite (0.30); extra-long in pad (0.35), part (0.36), god, gawk, gaud (0.42), paid (0.45), pard, bide (0.51); on a third occasion: short in pate, bite (0.15), half-long in paid, pad (0.25); extra-long in bide (0.36). The relations between the lengths of the vowels before the sonant and surd explosives were pad : pat :: 1.7 : 1; pard : part :: 1.5 : 1, or 1.4 : 1; bead : beat :: 1.4 : 1; paid : pate :: 1.7 : 1, or 1.4 : 1, or 1.9 : 1; bide : bite :: 1.9 : 1, or 1.6 : 1, or 2.1 : 1. The influence of a suffix was shown in god : goddess :: 1.9 : 1; gaud : gaudy :: 1.7 : 1. Great variations occurred in the relations of such pairs as paid : pad :: 1 : 1.2, or 1.3 : 1, or 1 : 1; pate : pat :: 1 : 1.2, or 1.6 : 1; bead : bid :: 1 : 1.5, the 'long' vowel being sometimes shorter than the 'short' vowel and likewise the reverse.

Records[2] from a native of Liège (Belgium) living in Marburg gave: dinde (0.50ˢ), tout, doux, dindon (0.27 to 0.31), viens-tu? (0.19, 0.20), l'eau coule (0.16, 0.30).

Records by VIETOR also gave: mit (0.10ˢ), Kamm (0.30), kam (0.29), Hohenheim (0.12), Kammer (0.12), kamen (0.14), Baumeister (0.15), Baummeise (0.33), Tauffeier (0.38), Baufeier (0.24), Schiffe (0.30), Schafe (0.23), thust (0.18), Baumeister (0.05), wart', war't (0.14), Sekretär (0.17), Baummeise (0.17). Consonants may be short or long; a consonant need not be longer after a short vowel.

MEYER'S measurements[3] of WAGNER'S records[4] of the Swabian dialect showed that a consonant was lengthened

[1] VIETOR, as before, 271.

[2] VIETOR, as before, 273.

[3] MEYER, *konzo'nantndaoer ?im dɔytʃn*, Maitre phonétique, 1901 XVI 114.

[4] WAGNER, *Der gegenwärtige Lautbestand des Schwäbischen in d. Mundart von Reutlingen*, Program, Reutlingen, 1889-91.

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after a short vowel; the ratio of consonantal length after a long vowel to that after a short one was for final surd occlusives 1 : 1.36, for final surd fricatives 1 : 1.20, for final nasals 1 : 1.13; and for medial surd occlusives 1 : 1.15. Records[1] of the Italian dialect of Bari (Apulia) showed that the length of t after a long vowel (as in fāta) bore the relation to that after a short one (as in făta) of 1 : 2.07. One similar case in Finnish showed a relation of 1 : 3.39 for k.

KRÁL and MAREŠ, employing a telephone whose vibrations electrically stimulated a nerve-muscle preparation (p. 188) arranged to write on a smoked drum, were able to record the lengths of various sounds.[2]

In Bohemian the first syllable of a word always receives the stress; 'long' and 'short' sounds and syllables are distinguished; the rhythm of verse is produced by the word-stress and not by the length of the syllables. The results of the investigation showed the following facts:

1. Even for the same person a vowel receives different lengths according as it is spoken with more or less stress;

2. The 'long' vowels are on the average a little — but only a little — longer than the average short vowels, short and long often occupying nearly the same time. The difference between 'long' and 'short' Bohemian vowels seems to lie rather in the mode of expending the breath; in a short vowel the beginning is strong and the decrease sudden; in a long vowel the stress is more nearly even; 'legato' and 'staccato' more appropriately express the two forms than 'long' and 'short.'

3. Diphthongs have about the same length as the vowels, ou being a little longer.

4. Consonants are very short. With a group of consonants the length of a syllable does not necessarily increase;

[1] MEYER, as before, 115.

[2] KRÁL A MAREŠ, *Trvání hlásek a slabik dle objektivné míry*, Listy Filologické, 1893 IV 17; the explanations and summary I owe to Prof. František Čáda of the Bohemian University in Prag.

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syllables ending in t are usually shorter than those with the t omitted, thus **akt** may be shorter than **ak**.

5. In scanning verses with the greatest possible evenness the various 'feet' continually vary; the thesis and arsis portions never have the relation 1 : 1 but approximately 31 : 30, 33 : 32, etc.

JOSSELYN'S records[1] of Italian speech showed that a double consonant was simply a single consonant strengthened and lengthened (p. 332); its effect on the preceding vowel was to deprive it of about a third or a half of its length. Examples, in hundredths of a second, are

c a p o	f a t a	c a d e	l e g a
26 16	24 26	20 20	20 19
c a pp o	f a tt a	c a dd i	l e gg a
14 29	10 37	9 36	12 32

When the portion of speech to be measured is a long one, less accurate but less laborious methods may be employed.

To obtain the duration of a sentence or a larger unit the method analogous to one familiar to navigators and astronomers may be conveniently employed. The recorder watches the face of the speaker who sits beside a clock having a seconds-hand. At the first word he turns his gaze as quickly as possible to the clock and notices the position of the hand; at the last word he again notices the position. By practice this method can be made accurate to $\pm 1^s$. With almost as great accuracy the recorder can observe the face of a watch while listening to the sounds.

Experiments by BOURDON,[2] presumably made by observing a watch, show the average ordinary length of a syllable in reading French to vary from 0.184^s to 0.234^s. The length varies somewhat with the emotion contained in the selection, with the temperament of the reader, etc.

[1] JOSSELYN, *Étude sur la phonét. ital.*, 146, Thèse, Paris, 1900; also in La Parole, 1901 III 226.

[2] BOURDON, L'Expression des émotions et des tendances dans le langage, Paris, 1892.

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The reaction method is an improvement on the preceding one. The recorder makes a movement of the finger at the moment the speech unit begins and another at the moment it ends. His time of response, or reaction time (p. 206), can generally be relied upon to be constant within 0.1^{s} at both beginning and end; a record made in this way thus gives the true time. The time between the two movements may be registered by a stop-watch, by a chronoscope, or by some form of the graphic method (pp. 152, 206).

The phonograph has also been used to measure the intervals between points of stress (centroids) in prose and verse of different kinds. This is accomplished by adding a contact wheel to the axle and recording electrically the number of contacts passed over between one point and another in the speech record.

Measurements, of feet, lines, etc., in verse by means of these methods will be considered in the chapter on rhythm.

Among the phenomena found in investigations of mental time-estimates we may notice 1. that judgments of the equality of two successive tones or empty intervals are more irregular with some persons than with others; 2. that with some persons or under some circumstances the first tone seems longer, with or under others shorter; 3. that by making a tone louder it can be made shorter without any apparent decrease in length; 4. that similar results are found for empty intervals marked off by sharp clicks; 5. that the apparent length of an interval bounded by clicks is made greater by inserting intermediate clicks. These results have important phonetic applications. Further investigation is needed of the manner in which loudness or change in pitch can be used to replace duration.

The experiments on speech sounds have made it clear that at best the terms 'long' and 'short' for the vowels or syllables of a word can mean no more than that they are on an average long and short. The assignment of definite relations of average length as two moras or one mora likewise means only that on a general average the relation will be more like

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2 : 1 than any other simple expression. The actual averages for any speaker or for any language will be found to differ from such a relation. The relations of duration in any particular word may be entirely reversed, the 'long' vowel occupying perhaps less time than the 'short' one. These terms express really a total mental effect that the hearer or speaker feels — or is taught to feel — to be one of duration. A stronger or more difficult sound may produce a greater impression; a person is readily taught to lump the whole as a matter of duration and consequently supposes himself to hear the sound as actually longer while it may be only stronger or higher. The illusion is a familiar one to psychologists. Such an illusion of considering staccato vowels as short and legato ones as long, while they are nearly equal in duration, has been shown (p. 499) to be the regular thing for Bohemian. In fact, the terms 'long' and 'short' are really terms for certain mental impressions that might more safely be expressed by some such general forms as 'of the first class' and 'of the second class,' or 'prime' and 'double prime,' etc. 'Strong' and 'weak' (referring to the auditory impressiveness and not to loudness) might be good substitutes. The amount of error that has entered into the teaching of languages and the discussion of verse by supposing that 'long' vowels are anything more than auditorily strong ones is very great.

References

For a general treatment of the length of speech sounds: Sievers, Grundzüge d. Phonetik, 5. Aufl., 254, Leipzig, 1901. For duration in verse: see Ch. XXXV (below). For a sketch of experiments and literature on time-estimates: Wundt, Grundzüge d. physiol. Psychol., 4. Aufl., II 408, Leipzig, 1893; Scripture, New Psychology, Ch. X, London, 1897.

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CHAPTER XXXIV

LOUDNESS

UNDER 'loudness' we may understand that property in which a sound (p. 109) may vary while its pitch and duration remain unchanged. The term 'stress' may be used to express the motor characteristic.

Direct measurements of the loudness of speech sounds are still impracticable. The loudness of a sound increases — other properties being constant — with the amplitude of the vibration, but not proportionately; the physical energy increases as the square of the amplitude, but the mental loudness follows some quite different law (p. 109).

The chief factor of the motor stress, the breath pressure, may be registered by any of the ways described in Ch. XVI.

In ROUSSELOT'S[1] experiments the rather weak French stress was found not to have an absolutely fixed place; the stress-accent may occupy the last syllable of a group, and it scarcely leaves this place in energetic pronunciation, although it tends to change to the next to the last syllable in phrases spoken in a soft or caressing tone or in phrases forming a conclusion.

The lungs practically always contain more than enough air for a phrase of speech; the breath is not renewed before each stressed syllable, but only for whole groups of them. These facts are sufficient to dispose of the supposition[2] that the weakening of unaccented final syllables in French is due to

[1] ROUSSELOT, *Les modifications phonétiques du langage*, 71, Rev. d. pat. gallo-rom., 1893 IV, V; also separate.

[2] MARCOU, *Influence of the weakness of accent-stress on phonetic change in French*, Publ. Mod. Lang. Assoc., 1890 V. 47.

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the failure of breath; this weakening is rather to be referred to some mental preference.[1]

In the records studied I have rarely found a vowel with a constant amplitude. Vowels at the beginnings of words show invariably a rise in amplitude. This rise may continue until the vowel ends in some other sound. Such is the case in a of ai, and in æ of 'and' in 'thread and needle.' Most independent vowels rise to a maximum and then fall. Such vowels might possibly be called vowels of circumflex stress. Even in the middle of the word the vowel has a tendency to the circumflex form, as is well shown in most cases of the i of ai. The rise and fall may be quite elaborate as in the case of the triple-circumflex vowel o of 'bow' (Plate I); this long o, however, might with propriety be considered a molecular union of three o's in succession. These changes in amplitude in the vowels appear clearly in an inspection of the Plates of speech curves at the end of this volume; measurements of some are given in Appendix II.

In a vowel of constant amplitude represented by the sinusoidal vibration (p. 2) we would have $F(t) = a$ and

$$y = a \sin \frac{2\pi t}{f(t)}.$$

In a rising vowel $F(t)$ might take some such form as mt, which expresses a proportional increase. We would then have

$$y = mt \sin \frac{2\pi t}{f(t)}.$$

In a circumflex vowel we may assume the amplitude to be of sinusoid form whereby

$$F(t) = E \sin \frac{2\pi t}{s}$$

and

$$y = E \sin \frac{2\pi t}{s} \cdot \sin \frac{2\pi t}{f(t)}$$

[1] WUNDT, Völkerpsychologie, I ii 278, Leipzig, 1900; OERTEL, Lectures on the Study of Language, 318, New York, 1901.

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where E would be the maximum amplitude and s the length of the vowel. When the pitch is constant the curve will have the form

$$y = E \sin \frac{2\pi t}{s} \cdot \sin \frac{2\pi t}{T}.$$

I have found one vowel, e in ' said ' in the line ' I, said the sparrow,' that can be considered as a circumflex vowel of approximately constant pitch. The equation of the curve traced from its record (p. 58) is (in seconds and millimeters)

$$y = 0.5 \sin \frac{2\pi t}{0.108} \cdot \sin \frac{2\pi t}{0.0053}.$$

It does not fill a complete period of circumflexion as it is suddenly cut short by the d.

Among the hundred or so English vowels that I have inspected, I have been unable to find one that can with any close approximation be considered as steady in intensity and constant in pitch. A vowel of the form $y = a \sin \frac{2\pi t}{T}$ must be a rare one. Some vowels during part of their course are of this form, but a change of some kind seems characteristic at some moment. Even such approximations have been found only in the interior of words, that is, with boundaries of consonants or of vowels with the vocal organs already in action. It seems to be the rule in English that a vowel following a pause shall be a rising or crescendo one, and one preceding a pause shall be a falling or diminuendo one.

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CHAPTER XXXV

ACCENT

GREAT unclearness prevails in the usual discussions of accent on account of the confusion among physical, psychological and physiological terms.

Physically the three properties of a tone to be considered should be the duration, the pitch and the energy (p. 89); the last depends on the pitch and the amplitude (p. 109), and for many comparisons where a proportional scale of energy is not well obtainable the amplitude may be used.

Mentally the case is utterly different; there are two associated factors of accent: auditory and motor. The one property that characterizes auditory accent is 'impressiveness;' this may arise from increase in loudness but also from decrease, from rise in pitch but also from fall, from lengthening of the duration but also from diminution — in short from any *change* that produces a mental effect. Motor accent represents volitional work. More work may arise 1. from a longer time of work; 2. from greater effort, as in increasing the breath pressure, or as in intentionally decreasing it, or in increasing the tension of the vocal cords, or in stronger muscular movements of any of the other speech organs; 3. from increased complexity of effort as in less familiar sounds, etc.

Physiologically the variable properties are in expenditure of muscle and nerve energy. The work of a muscle is something quite different from the work it performs in displacing bodies; a large amount of the energy is expended in heat, etc. The phenomenon of the breaking down of nerve compounds is still little understood. A sudden relaxation

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in breath pressure reduces the physiological work of the muscles, but it may represent increased volitional work and correspond to a very emphatic mental effort. A rise of the larynx tone represents a steady increase of muscular work and innervation, but it may — on account of its gradual character — fail to produce any auditory or motor emphasis, or may even produce the impression of decreasing emphasis on account of lack of the change that is required by the mind.

The term 'accent' may profitably be restricted to its psychological meaning; an accented sound is thus one that impresses the hearer more strongly or that requires more mental effort on the part of the speaker.

The first duty of a study of accent is to determine what mental elements are involved.

The main features of accent have been outlined by SIEVERS,[1] who has discussed the pitch of a sound, the pitch intervals between successive sounds, the rise and fall of pitch within a sound, the tremolo, the increase in loudness, the change in loudness, etc. Duration is considered by SIEVERS in a special section on 'Quantity' separate from 'Accent.' It will be noticed that the point of view is mainly auditory and that as an outline of auditory accent the sketch is practically complete. Motor accent requires a consideration of the factors of volition involved; these would also find expression in changes of pitch, intensity, etc., but in relations different from those of the auditory factors; the factor of volitional work would need to be added as a special one. The various treatments of accent rest upon judgments by the unaided ear. It is unquestionably the fact that here, as in all the senses without exception, attempts to specify anything beyond the general outline just given can result only in a statement of illusions. In a judgment of impressiveness the ear is unable to distinguish with any accuracy, except in extreme cases, the factors of pitch, loudness and length; accents stated to be due to increased stress may often be due to changes in pitch

[1] SIEVERS, Grundzüge d. Phonetik, 5. Aufl., 215, Leipzig, 1901.

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without any possibility of a detection of the fact by the ear. This difficulty of separating the two factors of loudness and change in pitch has been strongly emphasized by SIEVERS.

The inadequateness of a treatment of accent on the basis of a classification into accented and unaccented syllables has been emphasized by various writers.[1] Accent, we may say, is a continuous property that runs with the flow of speech.

So little experimental work has been done on accent that a general treatment of the subject beyond the outline already given would be out of place here; I shall confine the remainder of the chapter to a summary of the disconnected experimental results with no attempt to work them into a theory.

PIPPING[2] distinguishes three factors of accent 'in addition to psychological phenomena': the energy of articulation, the energy of the sound waves, the intensity of the auditory sensations. His calculations of the average physical energy of the sound waves (intensity, p. 109) give the following relations:

s	a	t	a	m	a	s	a	d	a	n	m	y	l	y	n
	5660		4011		1460		15649		2243			672		474	
	$g^{0\sharp}$		g^{0}		c^{0}		$g^{0\sharp}$		$c^{0\sharp}$						

The average pitch of each vowel is also indicated in five cases; in mylyn the first vowel was the higher. The general relation between musical accent and physical intensity appears clearly.

In an investigation by SQUIRE,[3] records were made by a ROUSSELOT voice-key (p. 154) of the repetition of the syllable mi by school-children. When the children were asked to emphasize the first syllable and then every alternate one (trochaic rhythm), the records showed the emphatic syllable usually longer than the unemphatic one, the relation varying from approximately 87 : 31 to 1 : 1; the pauses varied from 6 : 35 to 41 : 44.

[1] HIRT, Der indogermanische Akzent, 11, Strassburg, 1895.

[2] PIPPING, *Zur Phonetik d. finnischen Sprache; Untersuchungen mit Hensen's Sprachzeichner*, 227, Mém. de la Société finno-ougrienne, XIV, Helsingfors, 1899.

[3] SQUIRE, *A genetic study of rhythm*, Amer. Jour. Psychol., 1901 XIII 492.

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When the second syllable and then every alternate one were emphasized (iambic rhythm), the relations of length varied from 61 : 69 to 56 : 36; the pauses varied from 27 : 74 to 41 : 35. When the first syllable and every third following one were emphasized (anapestic rhythm), the general type of relations of lengths of the syllables was for one subject 67 : 61 : 44, for another 37 : 39 : 31 and for a third 41 : 30 : 33, with pauses in the typical relations of 17 : 16 : 34, 17 : 18 : 29 and 44 : 50 : 52 respectively; the variations were, however, considerable. When the third and every third following syllable were emphasized (anapestic rhythm), characteristic relations of length were for one subject 33 : 28 : 46, for another 39 : 33 : 28, and for a third 31 : 29 : 47, with pause relations of 10 : 11 : 35, 13 : 18 : 52, and 32 : 41 : 58 respectively.

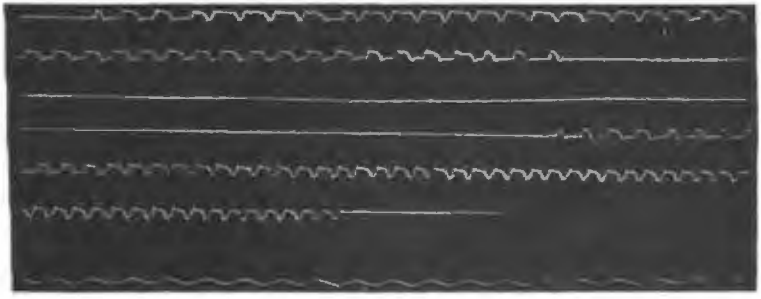

FIG. 336.

Experiments on the relations between stress and duration and between stress and pitch have been made by MIYAKE.[1] The voice key (p. 154) was connected to a DEPREZ marker (p. 92). This might have been done by any appropriate battery arrangement; it seemed most convenient to connect the key to one of the sockets of a four-socket lamp battery, while the marker was connected to the other so that the key made a high-tension shunt around the marker (p. 210, Fig. 81, key to socket *C*, marker to socket *G*). Any other method of recording voice vibrations might have been used.

[1] MIYAKE, *Researches on rhythmic action*, Stud. Yale Psych. Lab., 1902 X 22.

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The subject repeated the sound a continuously in what he felt to be a trochaic rhythm (thus, a' a a' a a' a . . .), or an iambic (a a' a a' a a' . . .), or a dactylic (a' a a a' a a . . .), or an amphibrachic one (a a' a a a' a . . .). The marker registered the vibrations on the smoked drum; a specimen record with time line in 0.01^s at the bottom is shown in Fig. 336.

The following summary is from MIYAKE'S tables; the letters indicate different persons; each separate record is the average of a separate experiment of ten measurements.

Subject.	Ratio a' : a.	Ratio a : a'.	Ratios a' : a : a.	Ratios a : a' : a.
E	1.00 : 0.86	0.92 . 1.00	1.00 : 0.82 . 0.81	0.83 : 1.00 : 0.79
	1.00 : 0.93	0.87 : 1.00	1.00 0.87 0.77	0.99 : 1.00 : 0.93
	1.00 : 0.87			
	1.00 : 0.83			
K	1.00 : 0.96			0.92 . 1.00 : 0.92
	1.00 : 0.86	0.85 : 1.00	1.00 . 0.76 : 0.63	0.90 : 1.00 : 0.92
	1.00 : 0.96	0.90 : 1.00	1.00 0.89 : 0.78	0.92 . 1.00 . 0.91
B	1.00 : 0 61	0 69 : 1.00		
	1.00 : 0.68	0.80 : 1.00		

From the table we may generalize as follows: 1. a stressed syllable was always longer than an unstressed one; 2. the relation between the two varied with different individuals and on different occasions; 3. in a dactyl the first unstressed syllable was slightly longer than the last one.

Since each vibration was indicated, the records used in the preceding case were also available for determining the pitch of the cord tone in the stressed and unstressed syllables. For example, in an experiment on a' a with subject K, the successive periods of a' were: 7, 7, 7, 7, 7, 6, 6, 6, 6, 6, 6, 6, 6, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 4, 4, 4

The changes in the lengths of the periods were not sudden but very gradual in this record as well as in all other records. The accented syllable began with a period of 7^{σ} and changed gradually through 6^{σ} and 5^{σ} to 4^{σ}, which was reached at the 30th vibration and maintained to the end. That is, the pitch rose from 143 complete vibrations through 170 and 200 to 250 per second.

The unaccented syllable, on the other hand, began with a period of 8^{σ}, and reached 7^{σ} at the 12th vibration, which was kept to the end. That is, the pitch changed from 125 upward to 143 complete vibrations a second, and remained fixed thereafter.

The results of various experiments are shown in Plate XIV at the end of this volume; the specific measurements are given in the original monograph. The horizontal axis indicates time, while the vertical ordinates give the numbers of cord vibrations a second. The space between the curves corresponds to the empty interval between the syllables.

An inspection of the Plate is sufficient to show 1. that the accented syllable had a higher pitch than the unaccented syllable; 2. that the accented syllable began in general with a higher pitch than the unaccented syllable; 3. that even in the cases where both accented and unaccented syllables began with the same pitch, the former glided upward higher than the latter; 4. that the pitch of the accented syllable underwent greater changes than that of the unaccented one; 5. that the pitch of the accented syllable always glided upward; 6. that the pitch of the unaccented syllable also glided upward in the majority of cases, but sometimes glided downward.

MIYAKE makes the following observations:

'According to MITFORD,[1] the strengthened syllables in English have an acuter tone or a higher note. The fact can be abundantly proved, he supposed, if we find or coin a word which is composed of syllables without variety of vowel sound and pronounce it with a strong accent on either syllable.

[1] MITFORD, Inquiry into the Principle of Harmony in Language and of the Mechanism of Verse, Modern and Ancient, 57, London, 1804.

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'MITFORD supposed that when we pronounce an accented syllable, we raise the tongue near to the palate, with the consequence of the rise of the height of tone. "To produce the proper English intonation," he says, "the tongue must be raised up in pronouncing the strengthened syllable, the vibration will be felt more about the palate and the tone will be acuter, it will be a higher note." The change of the position of tongue in the mouth cavity would only affect the resonance tone and not the cord vibration. It thus gives no explanation of the fact.

'MÜLLER[1] noticed that in a larynx separated from the body the pitch of the tone might be raised by an increase of the force of blast. He thought that one of the modes of producing high notes without increasing the tension of the vocal ligament is to blow with greater force, by which means the notes may without difficulty be raised through a series of semi-tones to the extent of a "fifth."

'BRÜCKE[2] supposed that in strong accentuation the vocal cords are more stretched on account of the strong pressure of the air and come closer to each other and that, as a consequence of the increase of the tension of the cords, the pitch of the tone is raised. SCRIPTURE[3] thinks that the relation between the rise of pitch of the cord tone and the increase in the force of the puff would naturally result from a gradual tightening of the vocal muscles which is due to associated habits of innervation and not to the physical effect of the air pressure in stretching the cords.'

MÜLLER'S supposition concerning the relation between pitch and intensity arose from the fact that a thin membrane under a constant tension gives a higher tone as the pressure of the blast is increased. The action of the cords as now known (p. 263) indicates that the two properties are not

[1] MÜLLER, The Physiology of the Senses, Voice and Muscular Motion, with the Mental Faculty, trans. by Baily, London, 1848.

[2] BRÜCKE, Die physiologischen Grundlagen der neuhochdeutschen Verskunst, 3, Wien, 1871.

[3] SCRIPTURE, *Nature of vowels*, Amer. Jour. Sci., 1901 XI 302.

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physically interdependent to any notable extent. A rise in pitch is the result of increased tension in the vocal cords, which is probably brought about entirely by contraction of the cricothyroid muscle and not by breath-pressure on the vocal bands. A loud, high tone represents thus not only increased respiration work but also increased larynx work.

It is safe to say that, in English at least, increase in duration and rise in pitch are ordinarily associated with increased stress, and that these associations are essentially mental ones and not interdependent physical or physiological phenomena. This relation seems to hold good in general for initial vowels; it may be seen in many of the vowels in the JEFFERSON records (Plates III to XI). In other cases a change in pitch does not go with a change in intensity; the intensity may even decrease while the pitch remains constant. To keep a constant pitch with a changing air pressure there must be continual readjustment of the vocal bands. As the pressure rises the tension of the bands must decrease or their weight must increase (p. 263). As these adjustments are of considerable difficulty, it naturally results that loudness and rise in pitch readily occur together. In song a fixed relation between pitch and intensity is carefully avoided.

The utter inability of the ear to distinguish the loudness, pitch and duration factors in accent has been strikingly illustrated in the discussions of Lithuanian accent.[1] The discussion has stimulated experimental work.

The Lithuanian and Lettic accent is mainly one of stress, two forms of accented syllables being distinguished: the broken, or rough ('gestossen'), and the slurred, or soft ('schleifend'). The factors of loudness (as indicated by breath pressure) and duration appear in records made by SCHMIDT-WARTENBERG.[2]

[1] Literature and summary in HIRT, as before, 102.

[2] SCHMIDT-WARTENBERG, *Zur Physiol. d. litauischen Akzents*, Indogerm. Forschungen, 1897 VII 211; *Phonetische Untersuchungen zum lettischen Akzent*, Indogerm. Forschungen, 1900 X 117; *Further contributions to the Lithuanian accent question*, Trans. Amer. Philol. Assoc., 1901 XXXII xxiv.

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Records of the dialect of Mariampol show that the medium long quantity does not exist there, and that KURSCHAT'S contested description of the two accent varieties, the slurred and the broken, is true with regard to that dialect at least.[1] In a curve of the Lithuanian buti (Fig. 337) the 'broken tone' u shows greater intensity at the beginning followed by a sudden fall and then by a small recovery near the end of the u due to a slight aspiration, after which the vowel stops abruptly; the t, indicated by the low curve, is followed by the breath-rise for the i. A curve for būdas shows a similar condition for the 'slurred tone' u without the final aspiration and with a more gradual ending.



Fig. 337.

The expiratory curves of various Lettic words show that there exists — in the district of Wolmar — a third variety, the 'falling' accent,[2] by the side of the lengthened intonation and the 'Stosston.' It is this falling accent that corresponds historically to the slurred accent ('geschleifter Akzent') of Lithuanian speech, not the 'Stosston' as hitherto supposed. As to the quantity of the three accents there is no difference. The lengthened tone is rising or level as to expiration, the falling tone is gradually decreasing in intensity, the 'Stosston' breaks the vowel or diphthong into two parts by means of an energetic explosive utterance of the second part, which may be preceded by a closure of the glottis.

[1] SCHMIDT-WARTENBERG, *Further contributions to the Lithuanian accent question*, Trans. Amer. Philol. Assoc., 1901 XXXII xxiv.

[2] SCHMIDT-WARTENBERG, *Phonetische Untersuchungen zum lettischen Akzent*, Indogerm. Forschungen, 1900 X 117.

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In the case of diphthongs this second expiration lies within the glide. The curve of the Lettic pūt (Fig. 337) shows the u aspirated at the end, followed by the closure for the t and its explosion. The curve for pùt (Fig. 337) shows the decrescendo or 'falling' accent for the ù followed by the closure for t and its explosion as before. The curve for ka'ut shows a rise for the a followed by a small decrease for the so-called 'Stosston' and a rise for u, the t being indicated as before; the 'Stosston' between the two parts of the diphthong seems to occur without complete cessation of breath. This 'Stosston' is probably an incomplete glottal catch (p. 278).

GAUTHIOT has studied[1] the relations among the 'accent of loudness,' the 'accent of pitch' and the duration. The first two do not necessarily coincide and, in fact, do so only in certain definite cases. Records of breath pressure show that the 'rough' accent is one of strong initial stress suddenly decreasing and that this form is invariable. The 'soft' accent has two summits of stress, one at the beginning and one at the end of a medial or final vowel; in an initial vowel the first summit is lost; the accent of pitch and the duration remain the same for initial, medial and final vowel.

GAUTHIOT'S records show that there are two main classes of vowels in respect to duration — long and short, whose average lengths bear the remarkably constant relation of 4 : 2. The influence of the accent shows itself in the abridgment of 'short' vowels to 'extra-short' ones in a tonic medial syllables; these vowels may perhaps be grouped as a third class, making in all three groups with the relations of duration 4 : 2 : 1. These extra-short vowels are of modern origin.

Applications of these facts to the study of phonetic changes in Lithuanian and Greek have been made by GAUTHIOT and MEILLET.[2]

[1] GAUTHIOT, *De l'accent et de la quantité en lituanien*, La Parole, 1900 II 143.

[2] MEILLET, *À propos de l'article de M. R. Gauthiot sur les intonations lituaniennes*, La Parole, 1900 II 193.

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Researches by WALLIN[1] indicate that in both prose and verse the average emphatic syllable is invariably longer than the average unemphatic one, that the ratios between the two vary with different persons and that the ratios are never expressible by simple numbers.

REFERENCES

For complete account of Indogermanic accent and references: HIRT, Der indogermanische Akzent, Strassburg, 1895. For the individual languages: HEMPL, German Orthography and Phonology, 167, Boston, 1898; SIEVERS, Grundzüge d. Phonetik, 5. Aufl., 215, Leipzig, 1901; also the works mentioned on pages 307, 311, 314.

[1] WALLIN, *Researches on the rhythm of speech*, Stud. Yale Psych. Lab., 1901 IX 1.

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CHAPTER XXXVI

AUDITORY AND MOTOR RHYTHM

In the flow of speech there appears a phenomenon that is recognized as extending through all the mental experiences of the individual; this is known as 'rhythm.'

As an auditory phenomenon rhythm appears in certain relations of sounds. These may be illustrated by the following experiments. In describing them I shall merely indicate the general plan, leaving the details of technique to the skill of the experimenter.[1]

A tone may be sounded for a definite time at definite intervals. The result is a 'rhythm of sound and pause,' or, more briefly, a 'pause rhythm.'

Two tones of the same quality with equal energies and durations but of different pitches are alternated with no silence between them. The result is a 'rhythm of pitch.' The experiment can be performed by a contact apparatus, forks, telephones, resistances, etc. It can be illustrated by using two organ tones or two voice tones, but the higher tone will have a greater energy for the same blast and the mental relations of duration and energy impel the performer to falsify the equality of duration.

Two tones of the same quality, duration and pitch, but of different energies, can be used to produce a 'rhythm of intensity.' When the duration, pitch and energy are the same but the quality different (as in tones from two different musical instruments, or from two different voices), the result is a 'rhythm of quality.' A 'rhythm of duration' is also a

[1] Apparatus suggestions may be found in Scripture, *Elementary course in psychological measurements*, Ex. XIII, Stud. Yale Psych. Lab., 1896 IV 127, and in Scripture, New Psychology, Ch. X, London, 1897.

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fundamental form arising when the tones are of different lengths; it cannot be readily illustrated by simple tones of the same quality, pitch and energy without introducing a break or a click to mark off the first from the second; this break is a new factor that modifies the results. It can be readily illustrated in combination with some other factor.

Similar experiments may be made with three or more tones.

These experiments illustrate the fundamental law that rhythm in tones is dependent on changes in quality, pitch, intensity and duration, or, if by r we indicate the rhythmic effect (or rhythmic feeling), $r = f(x, y, z, w)$ where x, y, z, w indicate the factors just mentioned. Investigations should be made on the strength of the rhythmic feeling as depending on each one of the factors by varying one while the others are kept constant in the usual way. For example, a series of rhythms graded by equal steps of effectiveness might be established by adjusting the intensity alone; the law connecting the two factors would be the law of intensity rhythm. Likewise the just perceptible difference (p. 100), the just perceptible change (p. 101), etc., might be similarly determined. If the laws of rhythm prove to be linear functions (e. g., $r \propto \log x$, $r \propto x^2$, or similar relations), the ultimate expression of $r = f(x, y, z, w)$ ought not to be looked upon as impossible. It must be borne in mind that x, y, z, w represent *changes* from the average (or, perhaps, expected) quality, pitch, intensity and duration, and not the actual amounts of these quantities themselves.

On the assumptions 1. that the rhythmic feeling increases or decreases with increase or decrease of each one of these factors (or $r \propto x$, $r \propto y$, $r \propto z$, $r \propto w$) and 2. that in their effect on the rhythmic feeling the factors x, y, z, w act independently, we can deduce the following laws:

1. The total rhythmic effect varies with the total change in the factors of rhythm;

2. Any factor may be used to replace another in producing the rhythmic effect.

These laws are of fundamental importance for the theory

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of verse; their proof, extension or refutation forms one of the most important problems that can be undertaken by experimental phonetics. The first of the above assumptions is a highly probable one. The second is still unsubstantiated; it may, perhaps, be tested by establishing equalities between rhythmic feelings produced by different factors; for example, if, in a rhythm produced by a combined change in pitch and intensity, a decrease in one of the factors can be compensated by an increase in the other without any diminution in the rhythmic feeling (perhaps without our perception of a change), the assumption would be verified for the particular case. Some experiments on tones[1] have shown that a change in pitch can be used as a substitute for or as an intensification of intensity.

Stronger forms of rhythm may be produced by varying two or more factors. One tone may be made higher and louder, or higher and longer, or louder and longer, or higher, louder and longer than the other one.

Complex forms of rhythm are produced by using several degrees of one factor, as in • · · • · · or • · · · • · · · etc.

In the preceding experiments each element of rhythm has been supposed to be of constant character throughout its duration, and the change from one element to the other to be sudden; thus, a pause, quality, pitch or intensity rhythm of



FIG. 338.



FIG. 339.



FIG. 340.



FIG. 341.

this kind would be of the character indicated by Fig. 338. Another typical form of rhythm would be one in which one factor rises and falls evenly, with sudden changes, as indicated by Fig. 339. Still other forms involve less easily de-

[1] SQUIRE, *A genetic study of rhythm*, Amer. Jour. Psychol., 1901 XIII 560.

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scribed changes, such as in Fig. 340 or Fig. 341 or Fig. 342. The rhythmic effect depends not only on the amount and direction of the change but also on its rapidity and regularity.



FIG. 342.



FIG. 343.

Very sudden changes of strong rhythmic effect are produced by alternations of sharp noises and much longer silences; the rhythm would be as indicated in Fig. 343. Most of the experiments on auditory rhythm have been made on such a scheme by use of sharp clicks. The conditions do not closely resemble those of the flow of speech, but the results show some of the fundamental facts of auditory rhythm.

In some experiments by BOLTON [1] an apparatus was so constructed that a sequence of sounds was produced which did not vary in pitch, intensity, or quality. The rate at which the sounds were made to succeed one another could be varied from one in two seconds to ten in one second. When a person listened to the series and gave his attention closely to it, the series seemed to break up into groups of sounds; it did not appear uniformly continuous. These groups contained a larger or smaller number of sounds according as the rate was fast or slow. If the rate was slow, groups of two sounds seemed the more natural. At a faster rate grouping by threes or fours was more easy and pleasing, and with the fastest rates the sounds seemed to form groups either by sixes or eights, and sometimes the sequence seemed to rise and fall in intensity at regular intervals of one second or more. The grouping was not distinct. Whatever the rate, the sounds might be made to group by suggesting to the subject a pendulum or some other rhythmical instrument. Groupings

[1] BOLTON, *Rhythm*, Amer. Jour. Psychol., 1893 VI 214; the following account is condensed from a summary in my New Psychology, Ch. XI.

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might be suggested by counting 2's, 3's, 4's, 6's, or 8's, accenting the first sound. It was difficult and even impossible with most persons to group by 5's or 7's. The grouping was usually accompanied by some muscular movement. Frequently it was tapping with the foot or fingers; sometimes it was beating time with the hand or the thumb. Some subjects nodded the head, others counted inaudibly, and still others felt indefinitely localized muscular contractions in the larynx, diaphragm, viscera, scalp, eyelids, etc. Muscular twitchings were to be seen in the muscles of the face and limbs at times when the subject declared he felt nothing of the kind.

The grouping was accomplished by placing a stress or accent upon the first sound in a group. In groups of three the first and second sounds were accented, the first more strongly than the second. In groups of four the first and third were accented, the first again being the stronger. Groups of four seemed at times to break into two groups of two sounds each, groups of six into two groups of three, and groups of eight into two groups of four. In groups of six the accents came always upon the first and fourth, and in groups of eight upon the first and fifth. The accents were apparently at the basis of the splitting up of the longer groups, and, when they did so break up, the subject felt a tendency to swing forward or backward or from side to side. This invariably suggested the pendulum. Many persons pictured or visualized some moving object which seemed to swing or revolve as the sounds were grouped.

When the various rates at which the different groupings were felt to be most pleasing and natural were compared and the average times for each taken, it was found that the time limit of each group was nearly the same — a little more than a second. The explanation of this was based upon the rhythmical character of the attention. Attention is periodic, and, when it is concentrated upon a continuous series, becomes quite regular in its period. An object that does not change cannot be attended to for more than a few seconds.

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The attention will pass involuntarily from the object to some one of its parts or to one of its associates.

The experiments showed that an even series of clicks is subjectively transformed into groups by accenting some of them. Thus, in one case the even series

. . . .

would be subjectively made into

● . ● . ● . ● . ●

The supposition of BOLTON is that this accentuation is one of intensity; it apparently did not occur to him that it might contain other factors.

There is no doubt but that the accentuation includes factors of pitch and quality also. The accented sounds receive different characters; a series of clicks from a telegraph sounder is heard not as tick-tick-tick-tick but as tick-tock-tick-tock (the sounds from a clock differ physically).

WUNDT notices[1] an apparent lengthening of the interval before each loud click in a series of alternate loud and soft ones; thus the even series

appears as ● . ● . ● . ● . ●
● . ● . ● . ● . ●

A short interval filled with clicks or mental work of any kind appears longer than an equal empty one;[2] thus, in such a series of clicks as

. . . .
a *b* *c*

the time from *a* to *b* appears longer than that from *b* to *c*. The relation is reversed for long intervals. Louder series of clicks appear to have shorter intervals. A stronger click inserted in the middle of an interval between two short ones makes the first half appear shorter. A louder click at the beginning of an interval makes it seem longer than the following intervals with weaker clicks.[3]

[1] WUNDT, Völkerpsychologie, I ii 380, Leipzig, 1900.

[2] HALL AND JASTROW, *Studies of rhythm*, Mind, 1886 XI 62; MEUMANN, *Beiträge zur Psychologie des Zeitbewusstseins*, Philos. Stud. (Wundt), 1896 XII 127.

[3] MEUMANN, *Beiträge zur Psychologie des Zeitsinns*, Philos. Stud. (Wundt), 1893 IX 306.

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As a motor phenomenon rhythm appears in repeated actions; it is a mental activity utterly different from and, except by association, entirely unconnected with auditory rhythm. It is convenient to use the term 'rhythmic action' or 'motor rhythm' in contrast to 'auditory rhythm.'

The laws of rhythmic action may be illustrated by the following experiments.

Repeated actions tend to be regularly repeated. This observation has been carefully tested by SMITH,[1] SQUIRE[2] and MIYAKE.[3]

In a series of experiments in which children repeated the syllable mi six times in succession, SQUIRE[4] usually heard an involuntary rhythm produced by variations in duration, intensity or pitch, but found no rhythm when the effort of articulation was so great that attention was necessarily directed on the separate syllables and when two syllables occupied more time than the normal pulse of attention (time between two maxima of attention, usually 2^s to 3^s).

In MIYAKE'S experiments two MAREY tambours were arranged so that the recording point of one of the tambours drew a line on the smoked surface of a drum.[5] The subject was required to hold the lever connected with the other tambour between his thumb and index finger, and, his eyes being closed, to move it up and down at intentionally irregular intervals at a rather rapid rate.

The experiments were made on three subjects; a specimen record is shown in Fig. 344. The height of the curve is related to the amplitude of the movement, and therefore to the intensity of the exerted muscular energy, while the horizontal distance indicates the length of the time between the successive movements. The line at the bottom indicates

[1] SMITH, *Rhythmus und Arbeit*, Philos. Stud. (Wundt), 1900 XVI 282.

[2] SQUIRE, *A genetic study of rhythm*, Amer. Jour. Psychol., 1901 XIII 497.

[3] MIYAKE, *Researches on rhythmic action*, Stud. Yale Psych. Lab., 1902 X 1.

[4] SQUIRE, as before, 516.

[5] Details of the arrangement are given in SCRIPTURE, *Elementary course in psychological measurements*, Ex. VIII, Stud. Yale Psych. Lab., 1896 IV 108, 109, and are shown in Fig. 71 above.

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fifths of a second. It was observed in this record as well as in the others (1) that there is a constantly recurring tendency to repeat equal intervals in succession, (2) that the same

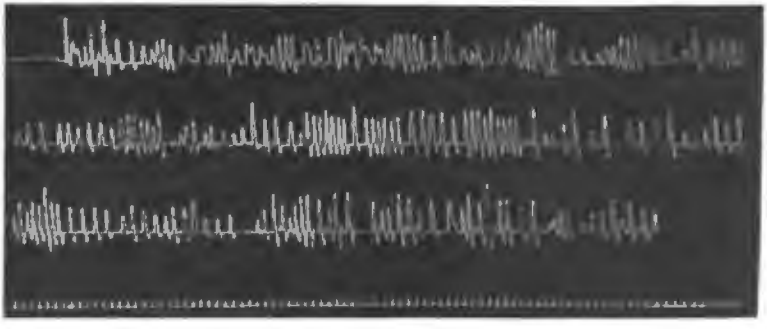

FIG. 344.

intensity of the muscular energy is also often repeated, and (3) that the weak and strong intensities often alternate. The attempt at irregular action thus shows a persistent tendency to revert to action regular in time and intensity.

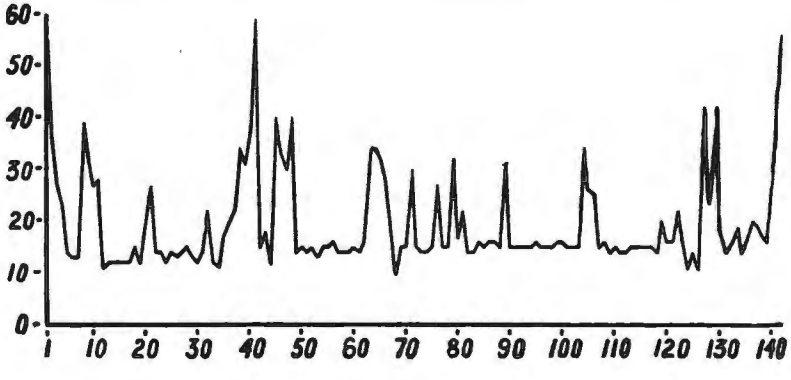

FIG. 345.

The records obtained in the above experiments show the characteristics of arhythmic action under the various circumstances for the various subjects. Accurate measurements of the lengths of the intervals could be better obtained by another

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method. A DEPREZ marker (p. 92) and a key with a break contact were put in series in a 1^{am} current. The pointer of the marker was rested lightly against the smoked surface of a drum. The subject was asked to tap the key at intervals as irregular as possible, the longest time between two successive beats being limited to about one second. He was seated comfortably before the apparatus and his eyes were closed during the experiments. The results of many experiments are averaged in the diagram (Fig. 345), in which the figures on the horizontal axis indicate the serial number of the tap and those on the vertical axis the length of the successive periods, $\Sigma = 0.01^s$ being the unit.

The diagram shows the following facts: (1) there are repetitions of equal or about equal periods; (2) the unequal periods, which occur after or in the middle of a group of the repeated equal periods, are, in many cases, simple multiples of the latter; (3) the periods from 12 to 17 are most frequent; (4) rhythmic alternations of long and short intervals also occur.

These facts seem to indicate that arhythmic movements have a constant tendency to become rhythmic, notwithstanding the voluntary effort of the subject to execute the movements at irregular intervals. The subjects of the experiments invariably agreed in confessing that the arhythmic tappings required strenuous effort and that the performance was very fatiguing.

The involuntary tendency to rhythmize sounds appears in the attempt to repeat the same sound monotonously. It can be very strikingly shown by having the sounds registered in a phonograph and studied at leisure. In some experiments of this kind the sounds **a a a a a a a a a lo lo lo lo lo lo lo lo lo** were spoken in what was intended to be a perfect monotone. Each record was made by one of three persons and the judgment of the character of its rhythm was thereafter made by the other two while listening to the phonograph. The judgment by *J* and *M* on a record made by *S* was that it was 'spoken in trochee with emphasis produced by increased intensity and rise in pitch;' on listening

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to the record the speaker *S* made the same judgment. A record by *J* was judged by *M* and *S* to have the same characteristics as the preceding one. The record by *M* (Japanese) was judged by *S* to begin with syllables of equal emphasis and to end with trochaic rhythm produced as in the preceding cases, but by *J* to have an iambic character.

Two entirely different forms of regularly repeated action are to be distinguished.[1] In one form the subject is left free to repeat the movement at any interval he may choose. This includes such activities as walking, running, rowing, beating time, and so on. A typical experiment is performed by taking the lever of a MAREY tambour between the thumb and index finger and moving the arm repeatedly up and down; the recording tambour writes on the drum the curve of movement (Fig. 71). Another experiment consists in having the subject tap on a telegraph key or on a noiseless key and recording the time on the drum by sparks or markers. Other experiments may be made with an orchestra leader's baton having a contact at the extreme end, with a heel contact on a shoe, with dumb-bells in an electric circuit, and so on.[2] For this form of action I have been able to devise no better name than 'free rhythmic action.'

In contrast with this there is what may be called 'regulated rhythmic action.' This is found in such activities as marching in time to drum-beats, dancing to music, playing in time to a metronome, and so on. A typical experiment is that of tapping on a key in time to a sounder-click, the moment of the click and that of the movement of the finger being registered on a drum.

Regulated rhythmic action differs, I believe, from free rhythmic action mainly in the manner of judging the coincidence of the movements with the sound heard (or light seen, etc.). This view puts aside all purely physiological theories

[1] SCRIPTURE, *Observations on rhythmic action*, Science, 1899 X 807; also in Stud. Yale Psych. Lab., 1899 VII 102.

[2] SCRIPTURE, Thinking, Feeling, Doing, 2d ed., Ch. on Rhythm (in press).

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of regulated rhythmic action. One of these theories[1] is based on the assumption that the labyrinth of the ear contains the tonus-organ for the muscles of the body. It asserts that vibrations arriving at the internal ear affect the whole content, including the organ for the perception of sound and the tonus-organ. Thus, sudden sounds like drum-beats or emphasized notes would stimulate the tonus-organ in unison, whereby corresponding impulses would be sent to the muscles. This theory has very much in its favor. It is undoubtedly true that such impulses are sent to the muscles. Thus, at every loud stroke of a pencil on the desk I can feel a resulting contraction in the ear which I am inclined to attribute to the *tensor tympani* muscle (p. 78). Likewise a series of drum-beats or the emphasized tones in martial or dance music seem to produce twitchings in the legs. FÉRÉ has observed that, in the case of a hysterical person exerting the maximum pressure on a dynamometer, the strokes of a gong are regularly followed by sudden increased exertions.[2] Nevertheless, these twitchings are not the origin of the movements in regulated rhythmic action. For many years I have observed that most persons regularly beat time just before the signal occurs; that is, the act is executed before the sound is produced. Records of such action have been published,[3] but their application to the invalidation of the tonus-theory was first suggested by MIYAKE. This does not exclude the use of muscle sensations, derived from tonus-twitches, in correcting movements in regulated rhythmic action, although they presumably play a small or negligible part as compared with sounds.

Another argument in favor of the subjective nature of regulated rhythmic action is found in the beginning of each experiment on a rhythm with a new period; the subject is quite at loss for a few beats and can tap only spasmodically

[1] EWALD, *Untersuchungen über d. Endorgan d. Nervus octavus*, 294, Wiesbaden, 1892.

[2] FÉRÉ, Sensation et mouvement, 35, Paris, 1887.

[3] SCRIPTURE, Thinking, Feeling, Doing, as before; New Psychology, 182, London, 1897.

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until he obtains a subjective judgment of the period. If the tonus-theory were correct, he should tap just as regularly at the start as afterward.

The conclusion seems justified that regulated rhythmic action is a modified free rhythmic action, whereby the subject repeats an act at what he considers regular intervals, and constantly changes these intervals to coincide with objective sounds which he accepts as perfectly regular.

In free rhythmic action there is one interval which on a given occasion is easiest of execution by the subject. This interval is continually changing with practice, fatigue, time of day, general health, external conditions of resistance, and so on.

'It has long been known that in such rhythmic movements as walking, running, etc., a certain frequency in the repetition of the movement is most favorable to the accomplishment of the most work. Thus, to go the greatest distance in steady traveling day by day the horse or the bicyclist must move his limbs with a certain frequency; not too fast, otherwise fatigue cuts short the journey, and not too slow, otherwise the distance traveled is unnecessarily short. This frequency is a particular one for each individual and for each condition in which he is found. Any deviation from this particular frequency diminishes the final result.'

It is also a well-known fact that one rate of work in nearly every line is peculiar to each person for each occasion, and that each person has his peculiar range within which he varies. Too short or too long a period between movements is more tiring than the natural one. This law appears also in some experiments made by SMITH.[1]

It is highly desirable to get some definite measurement of the difficulty of a free rhythmical action. This cannot well be done by any of the methods applicable to the force or quickness of action, but it may be accomplished in the manner described in Appendix III.

[1] SMITH, as before, 302.

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The function of the ear in free rhythmic action has been investigated by MIYAKE[1] by a method and with apparatus that seem specially adapted to the determination of the fundamental laws of motor rhythm. Analogous experiments should be made for song and speech.

The experiment of MIYAKE consisted in tapping on a noiseless key. The small 'strap' key used in this experiment was made of an elastic brass strip *B*, 46mm long and 9mm wide, mounted on a wooden block *E*; a brass stop *C* kept the free end of the spring from rising more than 4mm from the block. A slight pressure on the button *A* at the free end of the strap forced it nearer the block and broke its contact with the brass stop. Platinum points *D* were used to ensure good contact between the strap and the stop. The key was put in a rubber bag and packed in felt so that the sound was rendered absolutely inaudible; the key was thus a perfectly noiseless one. The wires *F G* projected from the bag. A spot on the surface of the rubber bag under which the button of the key was situated was marked with a sign. It indicated the point where the tapping was to be done. The adjustment of the key was such that the slightest touch broke the circuit. This highly successful instrument is the first solution of the problem of an absolutely noiseless key breaking contact exactly at the moment touched.

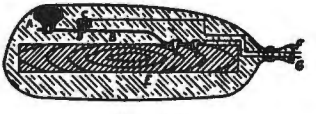

FIG. 346.

For producing the auditory stimuli a pair of discharging points were connected to a spark coil. The two brass rods were put in a horizontal line with a distance of about 2mm between them and connected to the poles of the secondary circuit. When the primary circuit was broken, a sound was produced by the spark. The points were put behind a black screen, so that the spark could not be seen by the subject.

The general plan of the arrangement is shown in the ac-

[1] MIYAKE, as before, 8.

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companying diagram (Fig. 347). The noiseless key *K*, with condenser *C* around the break, was placed in the circuit with the battery *B* and the primary circuit *P* of a spark coil. The secondary coil *S* was connected in series with the metallic registering point of a PFEIL marker (p. 91) *M*, the recording-drum *D*, and the discharging points *J*, so that a break in the primary circuit would produce a dot (p. 12) on the time-line at the point of the marker and also between the discharging points at the same moment. Thus the movement of the finger on the key, breaking the primary

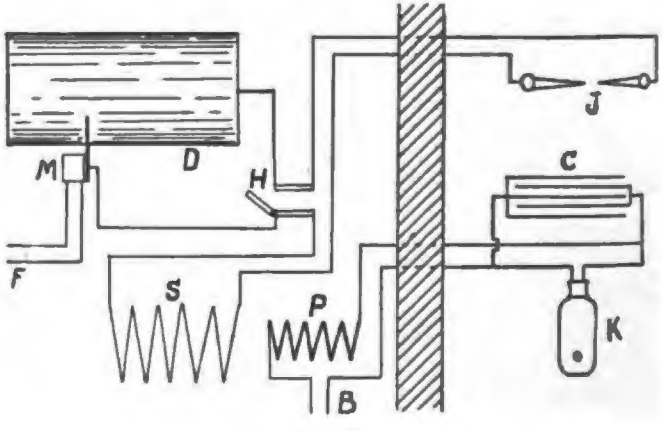

FIG. 347.

circuit, resulted in a sound of the spark between the discharging points and a record on the smoked drum *D* simultaneously.

A switch *H* was put in the secondary circuit around the discharging points. When the switch was closed, the short-circuit prevented sparks at the discharging points, and the tapping on the key was not accompanied by the sound of the spark, although still recorded on the drum. A time-line was drawn on the drum by the marker *M* run by a fork (pp. 15, 91).

The key and the discharging points were placed in a special quiet room; the rest of the apparatus was in another room.

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The subject with closed eyes beat time with the index finger of his right hand at what he considered to be a constant interval. The rate of the movement was left entirely to his own choice.

The average time chosen by the subject, his immediate probable error p (calculated as on p. 201), and his relative probable error $r = p/n$ expressed as a percentage, are given in the following table in thousandths of a second.

Subject.	With Sound.			Without Sound.		
	Average time.	p	r	Average time.	p	r
M	519	10.8	2.1%	575	17.1	2.9%
H	375	13.6	3.6%	379	20.5	5.4%
Y	718	23.4	3.3%	838	28.0	3.2%
C	747	12.1	1.5%	729	21.3	2.9%

A comparison of the corresponding probable errors in the same horizontal line will show that those of the free rhythmic movement with the sound are in general smaller than those of the movement without the sound. This holds true for both the simple and the relative probable errors. The general conclusion may be drawn that free rhythmic movement with the sound is more regular than that without the sound.

It can be also noticed in the table that the length of the period is in general shorter in the movements with the sound than in those without the sound. This is especially clear in the cases of the subjects *M* and *Y*, in which the periods with the sound are always shorter than those without the sound. The apparently contrary case with *C* is due to one erratic set of results differing entirely from the rest. This general difference is probably due to the fact that the interval which is marked off by the muscle, joint and skin sensations and the auditory sensations appears longer to the subjects than the equal interval which is marked off by the former group alone, and that thus the subject is unconsciously influenced by the relative degrees of fulness or emptiness (p. 522).

Another problem of fundamental importance in the con-

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sideration of speech and song as motor phenomena lies in the relation between intensity and interval in rhythmic action.

EBHARDT[1] made two series of experiments on this problem. In the first series the tapping was done on an electric key, and in the second on a piano with electric connections. The records were taken in both cases on a kymograph (p. 198). The results showed that the interval following the emphasized beat was lengthened as compared with that which followed the unemphasized beat. In EBHARDT'S experiments the tapping was accompanied by the noise of the instrument.

MIYAKE'S work[2] includes a study of movements without noise. The noiseless key (p. 529) was put with the PFEIL marker (p. 91) in series in a 1^{am} current. The metallic point of the marker was connected with one pole of the secondary coil of a spark coil, the other pole being connected to the base of the recording drum. The current from a 100-fork (p. 15) was sent through the primary coil. In this way the beats were recorded by checks in the line on the drum; these were divided by the sparks into equal spaces, each of which corresponded to $\frac{1}{100}$ of a second. The subject tapped with his finger (generally with the index finger of the right hand) on the noiseless key, according to the following schemes:

(*a*) 1′–2, 1′–2, 1′–2, . . .
(*b*) 1–2′, 1–2′, 1–2′, . . .
(*c*) 1′–2–3, 1′–2–3, . . .
(*d*) 1–2′–3, 1–2′–3, . . .

where the beat to be emphasized is marked with the sign ′. In the scheme 1′–2, for instance, the subject was asked to emphasize every first beat of the rhythmic group, but he had, at the same time, to try to keep always a uniform interval between two successive beats, not only between 1′ and 2, but

[1] EBHARDT, *Zwei Beiträge zur Psychologie des Rhythmus und des Tempo*, Zt. f. Psych. u. Physiol. d. Sinn., 1898 XVIII 99.

[2] MIYAKE, as before, 13.

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also between 2 and 1′ although he was to think of the groups as in pairs 1′–2, not 2–1′. The speed of the movements was left to the choice of the subject.

The results showed that the lengthening of the interval following the emphasized beat was more marked with the scheme 1–2′ than 1′–2. The average ratios of the two intervals in the two different rhythmic schemes were

	1′–2	1–2′
	1′ to 2 : 2 to 1′	1 to 2′ : 2′ to 1
C. W.	1.00 : 0.94	0.82 : 1.00
M. M.	1.00 : 0.93	0.90 : 1.00
J. K.	1.00 : 0.91	0.90 : 1.00

The expression ‘ 1′ to 2 : 2 to 1′ ’ means the ratio between the average time from the emphasized first beat to the second beat and the average time from the second beat to the emphasized first one.

The relative lengths of the long and short intervals are not the same in the two different schemes; the interval which comes after the emphasized beat is comparatively longer in 1–2′ than in 1′–2. The same fact was observed by EBHARDT.[1]

Why is the interval following the emphasized beat lengthened more in one rhythmic scheme than in the other? This can be accounted for by assuming another factor, besides emphasis, that lengthens the period of the movements. It is due, as already pointed out by EBHARDT, to the formation of the rhythmic group. Rhythmic movements with grouping differ in their nature from those without grouping. The latter is merely a series of repeated movements at a uniform interval, in which every single movement is regarded as a coordinate unit. In the former, a series of the movements is divided into groups containing a certain number of movements as their content, and each of such groups is regarded as a unit.

EBHARDT supposed that at the end of the rhythmic group

[1] EBHARDT, as before, 99.

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a suspension of attention takes place and that the moment of suspension can be considered as a dead time, which is to be added to the length of the foregoing group. We are not certain whether such suspension of the attention takes place or not. But it seems to be more probable that we have a tendency to insert some 'pause' between two successive rhythmic groups, in order to mark off the groups distinctly from each other. The 'pause' is to facilitate the formation of the groups.

We may suppose then that a certain length of 'pause' was inserted between the groups in the scheme 1′–2 as well as in 1–2′, and that because the interval from 2′ to 1 of the scheme 1–2′ is lengthened both by the 'pause' and the emphasis, it is made considerably longer than the time from 1 to 2′, whereas in the scheme 1′–2 the time from 1′ to 2 is lengthened only by the emphasis, while the time from 2′ to 1 is lengthened by the 'pause,' whereby the difference between 1–2′ and 2′–1 is not so great.

The averages of the ratios for the schemes 1′–2–3 and 1–2′–3 were

	1′–2–3	1–2′–3
	1′ to 2 : 2 to 3 : 3 to 1′	1 to 2′ : 2′ to 3 : 3 to 1
M. M.	1.00 : 0.60 : 0.94	0.60 : 1.00 : 1.00
J. K.	1.00 : 0.94 : 0.92	0.92 : 1.00 : 0.99
C. W.	1.00 : 0.98 : 0.95	0.99 : 1.00 : 0.97

The scheme 1′–2–3 shows again that the interval following the emphasized beat was the longest. The scheme 1–2′–3 shows likewise the same tendency. The interval 3 to 1 is longer than 1 to 2′, evidently including the 'pause.'

If 1–2′–3 is compared to 1′–2–3, we find that there is a remarkable difference between the two rhythmic schemes in regard to lengthening of the intervals between the groups. The interval 3 to 1′ of the scheme 1′–2–3 is not so much lengthened as 3 to 1 of 1–2′–3. In other words the 'pause' between the groups is longer in 1–2′–3 than in 1′–2–3. This

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fact indicates that the length of the ' pause ' is not the same in all rhythmic forms. It depends, probably, on the amount of difficulty in the formation of the rhythmic groups. The more difficult the formation of the groups, the longer is the pause. In the case 1′–2–3 with the first beat of a group emphasized, the group can be easily marked off from the preceding or the following groups, and the rhythmic group can be formed, without lengthening very much the interval between them. But the case is different with the scheme 1–2′–3, where neither the first nor the last beat of a group is emphasized. Of the two similar beats one comes at the end of a group and the other at the beginning of the next group; the two successive groups can be marked off distinctly only by lengthening the interval between them.

From this series of experiments the conclusions can be drawn 1. that the interval which follows an emphasized beat is lengthened, 2. that the interval which comes between rhythmic groups is lengthened, 3. that the lengthening of the interval between rhythmic groups is not equally great in all the rhythmic schemes.

It will be noticed that the forms of motor rhythm investigated were the trochee, iambus, dactyl and amphibrach; it is to be regretted that the spondee and anapest were not included.

Using a similar method MIYAKE extended the experiments to the sounds of speech; the results have been summarized in the preceding chapter in their bearings on accent.

The grouping of rhythmic impressions and movements by twos is easier than that by threes.[1] The tendency shows itself in the preponderance of iambic and trochaic verse over the anapestic and dactylic. The trochaic and dactylic forms seem easier than the iambic and anapestic ones.

Researches of the kind described in this chapter have as their object the determination of the fundmental laws of

[1] BOLTON, *Rhythm*, Amer. Jour. Psychol., 1893 VI 216; SMITH, *Rhythmus und Arbeit*, Philos. Stud. (Wundt), 1900 XVI 217; SQUIRE, *A genetic study of rhythm*, Amer. Jour. Psychol., 1901 XII 535.

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rhythm. These laws appear also in the rhythm of speech and help to an understanding of its complexities.

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CHAPTER XXXVII

SPEECH RHYTHM

THE earliest experiments on the rhythm of connected speech were by BRÜCKE,[1] who recorded, with a marker on a smoked drum, the movements of a finger in beating time while he recited verses in iambic hexameter, and in alcaic and sapphic meters, in a scanning fashion; he also made records of the movements of the lips. He found that the lengths of the successive feet were equal, as far as his apparatus indicated; this was, however, not fine enough to detect small differences.

The records of KRÁL and MAREŠ[2] (p. 499) for various lines of verse gave results like the following (*F* denotes length of foot in different records, *T* length of thesis, *A* length of arsis, all in hundredths of a second):

	F_1	T_1	A_1	F_2	F_3	F_4
Louka ko	61	30	31	92	84	62
sou seče	65	32	33	87	91	62
ná voňa	67	37	30	80	83	55
vé tady	61	40	21	77	78	56
zá pachy	63	38	25	80	73	55
dá vá	—	—	—	—	—	—

(VINAŘICKY, 'The sowed field sends forth perfume.')

	Naše	Labe	vody	valí	proudem	mocným	v dálnon	zem.
F_1	51	52	47	59	56	57	57	—
F_2	52	51	49	70	64	56	54	—

(The mighty waves of our river Elbe flow far into the world.)

[1] BRÜCKE, Die physiologischen Grundlagen d. neuhochdeutschen Verskunst, Wien, 1871.

[2] KRÁL A MAREŠ, *Trvání hlásek a slabik dle objektivné míry*, Listy Filologické, 1893 XX 257.

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Their results indicate that even with the same person the same vowel has a different length according as the emphasis is greater or less when a verse is recited in a scanning fashion; and that neither in intensity-verse nor time-verse are the lengths of feet ever exactly equal, the ratio of the emphasized part to the unemphasized part of a foot not keeping a relation like 1 : 1, but rather like 30 : 31, or 32 : 33.

In HURST and MCKAY'S[1] experiments on the time relation of poetical meters the subject recited poems representing each of the four usual meters, iambus, trochee, dactyl and anapest, while he beat in unison with the finger on a pointer which registered the lengths of the beats on a smoked drum. It was found that in iambic meter the syllables had a ratio of about 1 : 2, in trochaic of a little less than 1.5 : 1, in anapestic of about 1 : 1 : 1. 2, and in dactylic of 1.6 : 1.1 : 1. In these experiments the investigators did not take any records of the spoken sounds, but only of the rhythmic strokes of the hand.

Since even in scanning the syllables do not have simple relations of length, it is justifiable to conclude that in naturally spoken verse the relations differ even more widely from the theoretical ones. Indeed, what is known of the psychology of human action makes it quite incredible that any such simple relations as 1 : 2, etc. ever occur (or have occurred) regularly in actually spoken verse.

The problem of where the stroke of the hand occurs in beating time to verse was investigated by MEYER,[2] with the purpose of determining the position of the thesis in rhythmic articulation. For recording the voice he used a mouth trumpet ending in a MAREY tambour (p. 219) covered with a fine rubber membrane to which a small straw lever ending in a light pointer was attached. The beat of the finger was made on an apparatus comprising a plate of hard rubber connected by a string to a time marker (p. 91). The subject

[1] HURST AND MCKAY, *Experiments on the time relation of poetical meters*, Univ. of Toronto Stud., Psychol. Series, No. 3, 1899.

[2] MEYER, *Beiträge zur deutschen Metrik*, Nenere Sprachen, 1898 VI 1, 121.

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recited some syllables into the tambour through the trumpet, while he beat time on the rubber plate. Thus the breath curve and the moment of beating could be recorded simultaneously on the smoked drum. In all cases, except where the syllable began with a sonant explosive (b, d, g), the beat came before the vowel. Both the tambour and the beating apparatus used in the experiment had considerable latent times which could be only roughly estimated to be about 0.008^s for the former and 0.025^s for the latter.

More accurate experiments have been made by MIYAKE.[1]

The subject spoke into the voice key described above (p. 154). As the light diaphragm of platinum vibrated very easily at a short distance from the mouth, it recorded the first vibration of the voice with a latent time of not over half a thousandth of a second. The voice key was put in one of the circuits of a lamp battery (p. 210) and a DEPREZ marker (p. 92) in the other. The latent time of the marker was less than 1^σ, as had been previously determined by frequent tests (p. 92). For the beating apparatus the noiseless key in a rubber bag (p. 529) was used. The tension of the key was very small and the slightest touch was enough to overcome the resistance for breaking the contact; the time lost in compression of the finger before the key acted was infinitesimal. The key was connected to the primary circuit of a spark coil (p. 12) while the metallic point of the DEPREZ marker was attached to one pole of the secondary circuit (p. 530). The arrangement for drawing the time line was the usual one of a 100-fork (p. 15). The drum was run by a motor with a storage battery; a very constant speed was attained.

The subject held the voice key in his hand and, putting its mouth-piece close to his lips, recited a syllable in a scanning manner, while he beat time on the noiseless key with a finger of his right hand (generally the index finger), the rate of the recital being left to his choice.

[1] MIYAKE, *Researches on rhythmic action*, Stud. Yale Psych. Lab., 1902 X 39.

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The following syllables were used by different subjects: (1) **a**, (2) **ʾa**, (3) **ma**, (4) **ha**, (5) **pa**, (6) **ăp**, (7) **āp**, (8) **măm**, (9) **mām**. In these the a was pronounced like a in '*f*ather.' The **a** had the usual smooth English entrance (p. 429). The **ʾa** was the same as **a**, but with a slight glottal catch at the beginning (p. 278). Both **ă** and **ā** were the same in quality, but **ă** was shorter than **ā**, as the sign indicates. All the consonants were pronounced as in English.

A summary of the results of the experiments is given in the following tables. The positive signs indicate the deviations when the beats of the finger came before the vowel, and the negative ones those when the beats came after the beginning of the vowel. The fourth and fifth columns in the first table give the number of the cases in which the positive and negative deviations occurred.

SUMMARY FOR SOUNDS

	Average time of beat before vowel.	Number of measurements.	Number of +.	Number of −.
ma	+ 132	210	209	1
pa	+ 143	206	205	1
ha	+ 118	190	187	2
ʾa	+ 131	170	90	0
a	+ 52	20	107	12
ăp	+ 59	100	92	8
āp	+ 52	90	65	25
măm	+ 57	80	80	1
mām	+ 62	80	78	1

Unit of measurement, $\sigma = 0.001^s$.

SUMMARY FOR INDIVIDUALS

Subject.	ma	pa	ha	ʾa	a	ăp	āp	măm	mām
K	+ 76	+ 96	+ 56		+ 19	+ 30	+ 10	+ 54	+ 60
E	+ 120	+ 140	+ 103	+ 132		+ 88	+ 94	+ 61	+ 64
T	+ 169	+ 181	+ 133		+ 86				
M	+ 163	+ 157	+ 172	+ 130					

Unit of measurement, $\sigma = 0.001^s$.

The tables show that the beat of the finger comes before the beginning of the vowel under the following conditions: (1) when the vowel is preceded by a consonant and is not followed by any other sound; (2) when the vowel has the glottal catch at the beginning; (3) when the vowel is neither pre-

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ceded nor followed by any sound; (4) when a short vowel is followed by a consonant; (5) when a long vowel is followed by a consonant; (6) when the short vowel is preceded and followed by consonants; (7) when the long vowel is preceded and followed by consonants. The conclusions, of course, are valid only for independent syllables, but they probably apply — with some modification — to those in connected speech.

It will be observed also that the amount of time by which the beat occurs before the beginning of the vowel is not the same for the different combinations in which the vowel stands.

The results for the subjects *K* and *T* show that the length of time by which the beat occurs before **a**, when not preceded by a consonant, is considerably shorter than that before the vowel when preceded by a consonant. This fact indicates that the consonant lengthens the time between the beat and the beginning of the vowel.

The amount of time between the beat and the beginning of the vowel differs with the different consonants which precede it. The subjects *K*, *E*, *T* all agree in making this difference greatest in **pa**, next greatest in **ma**, and least in **ha**.

The amount of time by which the beat is ahead in ·**a** is not very different from that in **ma**, **pa** and **ha**. It is probably due to the fact that the glottal catch at the beginning of the vowel is of the same nature as a consonant in so far as the complexity of action of the vocal organs is concerned.

The results for **măm** and **mām** seem to indicate, if not in a very conclusive manner, that when a vowel is preceded as well as followed by a consonant, the beat tends to come nearer the beginning of the vowel than when the vowel is preceded by a consonant but not followed by another.

The preceding observations show that the finger beat occurs before the vowel. But where does it come in respect to a consonant which precedes the vowel?

Among the three consonants **m**, **p** and **h** which formed the objects of the experiments in combination with the vowel **a**, the last two (**p** and **h**) could be found in the records. The curve for the consonant in the records did not consist of

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vibrations like those of the vowel, but of a smooth deviation from the record line, due to the air pressure. The lengths of the consonants could thus be measured. The results of the measurements may be summarized as follows:

FINGER BEAT WITH ha

Subject.	Average length of h.	Immediate absolute probable error.	Average time of beat before h.	Immediate absolute probable error.	Number of measurements.	Number of +.	Number of −.
E	39	6.7	+ 51	9.6	30	30	0
K	116	15.5	− 62	23.8	50	1	48

FINGER BEAT WITH pa

Subject.	Average length of p.	Immediate absolute probable error.	Average time of beat before p.	Immediate absolute probable error.	Number of measurements.	Number of +.	Number of −.
E	48	6.2	+ 69	15 3	50	50	0
K	58	15.3	+ 15	16.5	60	42	17

SUMMARY

Subject.	Average length of p.	Average time of beat before p.	Average length of h.	Average time of beat before h.
E	49	+ 69	39	+ 51
K	59	+ 15	117	− 61

Unit of measurement, $\sigma = 0\ 001''$.

The following points may be observed in the tables: 1. for the syllable pa two subjects agree in beating time before the beginning of the consonant; 2. for the syllable ha, with the subject *E* the beats come constantly before the beginning of the consonant, but with *K* they come in most cases after the beginning of the consonant, about midway between the consonant and the vowel which follows it.

From the observations reported in this investigation the final conclusion can be drawn that the beat of the finger in connection with the rhythm of speech comes before the vowel and before or in the course of the consonant which precedes the vowel.

MIYAKE adds the following observations concerning the point of emphasis in rhythmic articulation. The question is first raised as to the relation of the beat of the finger to the point of greatest emphasis. Our experience seems to show that when we recite a verse while we beat time with the

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hand, the point of the highest emphasis in the rhythm comes at the same moment with the beat.

Although it is not certain whether the innervations of the movements of the hand and vocal organs proceed from their nervous centers at exactly the same moment, still we may suppose that the two movements are so closely associated that the innervations take place almost simultaneously. But when we attempt to determine the position of the point of emphasis from the beat of the finger, we find that it cannot be easily done. It does not follow that the movements themselves are executed at the same time from the mere supposition that innervations of the movements of hand and vocal organs take place simultaneously.

MEYER[1] supposed that the movements of hand and vocal organs would take place at the same moment, provided the nerve fibers which transmit the impulses are equal in length. He calculated from the rate of nervous transmission that the impulse reaches hand about 0.015^{s} later than vocal organ. Adding the latent time of the apparatus to this lost time of nerve transmission he arrived at the final conclusion that the point of emphasis lies in the course of a sonant consonant or shortly before it when it follows an explosive.

The difference in the length of the nerve fibers is not the only factor which disturbs the simultaneity of the two movements. KÜLPE's experiments[2] showed that we have difficulty in moving the hands at the same time to react to a single stimulus. If even the two hands — alike in construction and symmetrically arranged — are not moved simultaneously, it must be still more difficult to execute the movements of two disparate organs like the hand and vocal organs at the same moment.

Besides these differences there may be several other factors which cause the deviation of the two movements. The difference in the complexity of the construction in the two organs

[1] MEYER, *Beiträge zur deutschen Metrik*, Neuere Sprachen, 1898 VI 121.

[2] KÜLPE, *Ueber die Gleichzeitigkeit von Bewegungen*, Philos. Stud. (Wundt), 891 VI 514.

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might be one of such factors. The condition of attention during the movements might be another. Therefore, until we know all the conditions on which the simultaneity of the two movements depends, we cannot state exactly the relation of the point of emphasis to the finger-beat although we may conclude that they do not differ by more than a few hundredths of a second. 'Simultaneous,' like other terms, depends for its meaning on the degree of accuracy involved; for most purposes we may regard the finger beat as simultaneous with the point of emphasis (centroid of speech effort, p. 428) although the relation may vary in different individuals and in varying circumstances.

If we assume, then, that the movements of the hand and vocal organs are executed simultaneously, we can conclude from the foregoing experiments that the point of emphasis in rhythmic speech comes before the vowel and before or in the course of the consonant which precedes the vowel. In other words, the point of emphasis in rhythmic articulation lies at the *beginning* of the movement of the vocal organs for the production of the sound.

The length of time between two points that are felt to be emphatic may be studied by the following method. The speech is recorded on a phonograph in the usual way (p. 32). A contact wheel is then prepared by under-cutting the teeth of a gear wheel so that the bases of the spaces are larger than the tops, filling the spaces with rubber, vulcanizing it, and turning it true. This wheel is placed on the axle of the phonograph and a contact brush is applied to its edge. When an electric current is sent through it, the circuit is closed as each tooth passes under the brush. A magnetic counter (EWALD chronoscope, p. 162) placed in the circuit will indicate the passage of each tooth as long as the current is sent through it. Two shunts are placed across the circuit, one around the counter and the other around the contact wheel. Each shunt contains a key held down in contact by the finger. On releasing the former key the counter begins to register the teeth of the contact wheel as they pass the

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brush; on releasing the second key it stops. A simple calculation from the number of teeth in the wheel and the speed of the phonograph gives the time between the action of the two keys.

This method I have used to measure the intervals between what I felt to be the points of emphasis in a specimen of French verse. By measuring the so-called 'feet' separately, in twos, threes, etc., an idea could be obtained of the constancy of the method; there was rarely any difference between the total time for two or three feet and the sum of the times for the separate feet.

For the first stanza of *Le sonnet d'Arvers* spoken by M. MAÎTRE I obtained the results indicated by the figures over the lines in the following scheme. By measuring the time from the last point of emphasis of one line to the first of the next the length of the final pause and the following initial syllable was obtained; by special measurements the length of this initial syllable was obtained separately; the pause was found by subtraction.

	255						117
3	135	50	70	73			
Hélas!	j'aurai	passé	près	d'elle	inaperçu		
	212						110
28	87	53	72	85			
Sans	cesse	à	ses	côtés	et	toujours	solitaire
	217						112
25	75	68	58	51			
Et	j'aurai	jusqu'au	bout	fait	mon	temps	sur la terre
	183						
50	57	60	67				
N'osant	rien	demander	et	n'ayant	rien	reçu.	

Unit of measurement, 0.01^s.

Let us call a point at which the emphasis is felt to be located a 'centroid'; and the time from one centroid to the next a 'centroid interval.' The centroid intervals within a line give the averages $a_1 = 0.85^s$, $a_2 = 0.71^s$, $a_3 = 0.72^s$, $a_4 = 0.61^s$ for the respective lines, and $a = 0.72^s$ for all four lines. The intervals from the first centroid to the last one in the same line are $b_1 = 2.55^s$, $b_2 = 2.12^s$, $b_3 = 2.17^s$, $b_4 = 183^s$, and $b = 2.17^s$ for all four. The initial intervals for each line are

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$c_1 = 0.02^s$, $c_2 = 0.28^s$, $c_3 = 0.25^s$, $c_4 = 0.50^s$, and for all four $c = 0.34^s$. The intervals from the last centroid in one line to the first in the next are $d_1 = 1.17^s$, $d_2 = 1.10^s$, $d_3 = 1.12^s$, and for the three cases $d = 1.13^s$. The pauses between the lines measure $e_1 = 0.73^s$, $e_2 = 0.85^s$, $e_3 = 0.51^s$, and for all three $e = 0.70^s$. The average intervals for the line including the internal centroid intervals and the final pause are $f_1 = 0.82^s$, $f_2 = 0.73^s$, $f_3 = 0.62^s$, and for the three $f = 0.72^s$. The lengths of the lines up to the last centroid are $g_1 = 2.58^s$, $g_2 = 2.40^s$, $g_3 = 2.42^s$, $g_4 = 2.13^s$, or for all four $g = 2.38^s$. The lengths of the lines including the final pauses are ($h_i = g_i + e_i$ [$i = 1, 2, 3$]) $h_1 = 3.31^s$, $h_2 = 3.25^s$, $h_3 = 2.91^s$, and for all three $h = 3.15^s$. The intervals between the last centroid in one line and the last in the next are $k_1 = 3.29^s$, $k_2 = 3.28^s$, $k_3 = 1.95^s$, and for the three cases $k = 2.13^s$.

When one phenomenon occurs more regularly than another, it may be assumed to be more characteristic of subject investigated. On this principle we may draw several important conclusions concerning this specimen of verse. Since $d_i = e_i + c_i$ ($i = 1, 2, 3$) and since d_i is very constant, the effective element in the passage from line to line is the time between final and initial centroids; the filling of this passage-interval is made up of pauses (which are effective elements both in movement and to the ear) and sounds adjusted to each other. The facts that $d > a$, that a often shows considerable variability within a line, and that the length of the line (g or h) is quite constant, seem to indicate that the line is itself felt as a unit in the composition. The fact that g and h are almost equally constant (that is, have the same probable errors) indicates that a line may be considered as ending either with the last centroid or with the completion of the pause.

The rhythm in speech may be studied by an analysis of the speech curve.

A short portion of the speech curve of the *Cock Robin* record (p. 58) has been studied in reference to the elements of rhythm; the results for the first stanza are given in the following tables.

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The first column gives the sounds in the phonetic transcription used in this book. The second column gives the duration of each sound as determined by measurements of the

Line 1: *Who killed Cock Robin?*

Sound.	Duration in thousandths of a second.	Pitch (period in thousandths of a second).	Intensity (maximum amplitude in mm.).	Syllable effect.	Remarks.
h	>10				Very short sound, not distinguishable in the record, not over 10σ in length.
ū	189	3.3	0.4	strong	Forcible vowel, large amplitude in earlier portion, rises somewhat in pitch, average period 3.3.
k	119				Appears in the record as a straight line.
i	154	1.8	0.6	strong	Long vowel, large amplitude throughout, double circumflex in amplitude. The high pitch of this i is in contrast with that of 'killed' in the 4th Line (below).
l	74	1.8	0.1		
(d)	0				No sound of d can be heard in this record; the record plate speaks 'Who kill Cock Robin?'
k	53				Appears in the record as a straight line.
a	126	4.2	0.5	weak	Rises somewhat in pitch to 4.2 in the main portion, weak on account of lowness in pitch.
k	101				The vibrations of the a are suddenly cut short by a few vibrations of a different form that rapidly decrease in amplitude. In listening to the record plate the ear hears no glide between a and k; the word seems to be simply and distinctly kak and not kaək.
r	74	1.8	0.3		Very distinctly and heavily rolled r; pseudobeats are apparent in the tracing.
a	140	5.3	0.5	strong	Of very low but constant pitch; steady rise in intensity till the vowel is cut short by b; forcible on account of length and amplitude.
b	49				Straight line from a to i.
i	56	5.6	0.3	weak	Short but distinctly heard; weak on account of shortness, lowness and faintness.
n	74	8.4	0.2		Falls in pitch and amplitude.
⌐	770				

curves in the records. The third column gives the periods of the cord tone, and the fourth gives the amplitudes of the vibration in the tracing, not the amplitudes of the vibration

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on the gramophone plate or of the movement of the vocal cords. The fifth column gives what I consider to be the character of the syllable in respect to being 'strong' or 'weak'; the judgment is based on the sound of the gramophone record, aided by the tables.

The analysis of the first stanza of *Cock Robin* as given

Line 2: *I, said the sparrow.*

Sound.	Duration in thousandths of a second.	Pitch (period in thousandths of a second).	Intensity (maximum amplitude in mm.).	Syllable effect.	Remarks.
ai	452	18 to 4	0.7	strong	Strong by length, pitch of i and amplitude; tracing given in Plate II.
ɹ	210				
s	?				Very brief sound, no trace in record.
e	105	5.3	0.5	weak	Rather long and loud, but low in pitch.
d	81	5.3	0.1		Pitch falls from 5.3.
ð	32	?	>0.1		Very weak vibrations.
ə	84	5.3	0.2	weak	
sp	273				Impossible to distinguish between the two sounds in the tracing; the s is heard as a brief sound.
ʔ	18	1.9	0.4		Distinct sound different from the following æ, exaggerated explosion of p ?
æ	170	5.3	0.5	strong	Constant very low pitch but steadily increasing amplitude; falls snddenly in intensity during 5σ to r; strong on account of length and amplitude.
r	11'	2.8	0.2		Clearly marked vibrations; the rolling of the r can be distinctly heard.
ō	294	5.2	0.6	strong	Very long vowel of constant pitch, but of rising and then falling intensity; strong by length and amplitude; followed without pause by w of next Line. Tracing of 'spȧrrow' given in Plate I.

in these tables shows that it contains not only an intensity rhythm but also a pitch rhythm and a duration rhythm. The three elements — length, pitch and intensity — are all used to produce strength. Thus the forcible vowel ū in Line 1 is short but moderately high and loud.

The strength of a syllable may be kept the same by increasing one of the factors as another one decreases (p. 549). The

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vowel a of ' Robin ' in Line 1 is strong on account of its length and intensity, although its pitch is low. A syllable necessarily short may be made as strong as a longer one by making it louder or higher; or a syllable necessarily of small

Line 3: *With my bow and arrow.*

Sound.	Duration in thousandths of a second.	Pitch (period in thousandths of a second).	Intensity (maximum amplitude in mm.).	Syllabic effect.	Remarks.
w	108	5.3	0.2		Amplitude rises from 0.
i	60	2.1	0.4	strong	Circumflex sustained vowel; strong by pitch and amplitude.
ŏ	56	?	0.1		
m	74	5.3	0.1		
ă	179	5.6	0.4	strong	Both parts of this diphthong are nearly constant in pitch and amplitude; strong by length and amplitude.
i	112	3.6	0.5		
˥ b	140				' My ' is followed by a brief rest in order to bring out the b distinctly. The b makes no curves in the record.
ŏ	490	7.0	0.4	strong	Extremely long vowel of very low pitch with two maxima of intensity; it might be considered as a close succession of those o's; strong by length and amplitude; tracing given in Plate I.
˥	11				
æ	382	7.7–5.3	0.2	weak	The æ begins at a very low pitch 7.7 and rises steadily to 5.3, which is maintained throughout the n. The form of the curve for æ differs from that for n, yet the change is so gradual that it is impossible to assign any dividing line.
n		5.3	0.1		
d	18				Straight line in the record.
ə	102	5.3	0.4		This extra vowel arises from the attempt at extra distinctness in speaking.
æ	189	5.2	0.3	strong	Strong by length and pitch.
r	39	2.5 (?)	0.1		Rolled r, brief
ŏ	331	7.0	0.6	strong	A single vowel of circumflex intensity, strong by length and amplitude.
˥	420				

intensity may be strengthened by lengthening it or raising its pitch. Thus, the short i of ' with ' in Line 3 is strong on account of its high pitch and large amplitude; and the weak æ of ' arrow ' in Line 3 is strong on account of its high pitch and its length. This might be called the *principle of substitution.*

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It appears necessary to attempt some interpretation of the foregoing experiments on speech rhythm. As previously

Line 4: *I killed Cock Robin.*

Sound.	Duration in thousandths of a second.	Pitch (period in thousandths of a second).	Intensity (maximum amplitude in mm.).	Syllable effect.	Remarks.
ai	334	12–4	0.6	strong	Strong by length, pitch of i and amplitude.
k	125				Straight line in the record.
i	324	5.6	0.2	weak	It is impossible to assign any definite point as the limit between these two sounds; weak, low i in contrast to the i in the first Line above.
l					
d	33				This d is distinctly heard; compare d in first Line above
ə	81	4.9	0.2		Additional vowel due to the extra distinctness in speaking the d; it arises from the explosive opening of the mouth; the pronunciation of the word 'killed' is different from that in the first Line chiefly in the great difference in pitch and in the greater distinctness of the d.
k	133				Straight line in the record.
a	147	7.0–5.3	0.3	weak	Pitch rises from beginning to end.
k	122				See the same word in the first Line above.
ɹ	60	3.9	0.6	strong	The r is more vowel-like than the corresponding r in the first Line; the strong roll is not heard; the curve of ɹa very much resembles in period and amplitude the curve of an ai in 'thy' turned backward; the period of the cord tone is practically constant; the resonance tone of the mouth undergoes a continuous change; any assignment of a limit between the two sounds must be somewhat arbitrary; ɹa is apparently a rising diphthong; the sound ɹa is strong by length, pitch and amplitude.
a	103	3.9	0.5		
b	53	4.2	0.1		The b cuts off suddenly the sound of a.
i	82	5.6	0.4	weak	The i is heard, but not so distinctly as in the first Line above.
n	74	8.8	0.1		Weak, low, diminuendo.
ɳ	955				

indicated (p. 447), speech is a flow of auditory and motor energy with no possibility of division into separate blocks such as letters, syllables, words, feet, etc., except in a

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purely arbitrary manner that does not represent the actual case. To the speaker and the hearer this flow may be treated in its rhythmic effect as a series of centroids (p. 451). This is the basis of all comparisons of verse with rhythmic clicks and with rhythmic movements. In prose the centroid is the place at which the whole effect of accent can be placed; the factors that make accent are those that locate the centroid. In verse the centroids are located by the prose effect, and also by the rhythmic swing of the movement of the verse form itself. Experiments with beating time to verse are attempts to locate the centroids.

Spoken language is usually classified as prose or verse. It might, perhaps, be better to say that in spoken language there are certain elements that may be present in greater or lesser degrees; the forms with little of these elements are termed 'prose' while those with more of them are termed 'verse,' without the possibility of always making a sharp distinction. These elements include rhythm, melody, and probably also agreeableness of quality, etc. The speech of some persons appears to be totally lacking in melodiousness; the voice has no tunefulness, the words come out without inflection and there is no regular distribution of the emphatic elements in a sentence. Other persons naturally speak even the simplest sentences in a melodious manner; the pitch of the successive syllables rises and falls pleasantly and the points of emphasis are evenly distributed. This may go so far that the spontaneous utterances of a speaker possess all the charm of blank verse, or may even be indistinguishable from it. An example of such speech can be found in JEFFERSON'S rendering of *Rip Van Winkle's Reverie;* it is contained on the gramophone plate numbered 699. This prose speech possesses all the beauty of verse without rime. The plate has not yet been traced off and the elements that produce the melodiousness are still undetermined.

As a model of vocal rhythm we may assume that the series of vocal sounds is divided into relatively large portions of equal lengths, or 'measures'; these measures are divided either

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into two portions, thesis and arsis, bearing simple relations of length, or into a number of small equal portions termed 'morae' or χρόνοι πρῶτοι. The relations of length between thesis and arsis will be as 2 : 1, 1 : 1, etc. Such a mathematical relation was called by the Greeks ῥητός, which has been translated as 'rational.' A rhythm with such simple relations of length may be called a 'rational rhythm,'[1] or, perhaps preferably, an abstract rhythm. In vocal music we would expect to find the nearest approach to the relations of abstract rhythm, although even here measurements will show that the actual relations are not exact or constant.

The relation 2 : 1 for thesis and arsis does not occur, except by chance, in spoken verse; verse rhythm is 'irrational.'[2] The traditional doctrine that a long syllable has twice the length of a short syllable rests upon a not clearly understood application of musical expressions to actual speech.[3]

In prose the various syllables have lengths that depend on general usage, on accent, emotion, etc. In verse these 'natural' lengths may be more or less modified. The actual concrete rhythm of a particular piece of verse is a compromise between the natural lengths and those required by abstract rhythm.[4]

According to SIEVERS,[5] modern spoken verse has properly only one kind of time-division, the foot. In respect to time it cannot properly be divided into smaller units, or morae; and there is no definite relation between thesis and arsis. The syllables are lengthened or shortened so that the desired time is occupied by a foot. An attempt to speak modern verse with regard to the lengths of the syllables at once destroys its character as verse and turns it into a hybrid thing known as 'scanned verse.'

By foot SIEVERS appears[6] to mean the time from one mini-

[1] SIEVERS, *Metrische Studien, I.*, Abhandl. d. k. sächs. Ges. d. Wiss., philol.-hist. Kl., 1901 XXI 34.

[2] ARISTOXENUS, see GOODELL, Chapters on Greek Metric, Ch. II, New York, 1901; SIEVERS, as before, 41.

[3] SIEVERS, as before, 41.

[4] SIEVERS, as before, 42.

[5] SIEVERS, as before, 43.

[6] SIEVERS, as before, 49.

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mum of speech energy to the next; for reasons apparent in Ch. XXX it would seem preferable to define the foot as the time between two centroids of speech energy.

In place of the unit-times of abstract rhythm we have to consider the number of syllables per foot in verse. Modern so-called iambic and trochaic forms of verse have two syllables per foot, anapestic and dactylic three. The lengths of the syllables in no wise enter into consideration.

The time of a foot is approximately constant. When a two syllable foot occurs in the midst of three syllable feet, it takes approximately the time of the others; and contrariwise.

The simplest English poetical line seems to consist of a quantity of speech-sound distributed so as to produce an effect equivalent to that of a certain number of points of emphasis at definite intervals.

The location of a point of emphasis is determined by the strength of the neighboring sounds. It is like the centroid of a system of forces or the center of gravity of a body in being the point at which we can consider all the forces to be concentrated and yet have the same effect. The point of emphasis may lie even in some weak sound or in a surd consonant if the distribution of the neighboring sounds produces an effect equivalent to a strong sound occurring at that point. Thus the first point of emphasis in the third line lies somewhere in the group of sounds 'mybow,' probably in 'b' between 'y' and 'o.'

With this view of the nature of English verse all the stanzas of *Cock Robin* can be readily and naturally scanned as composed of two-beat (or two-point) verses. The proper scansion of the first stanza would be:

Who killed Cock Robin?
I, said the sparrow,
With my bow and arrow
I killed Cock Robin.

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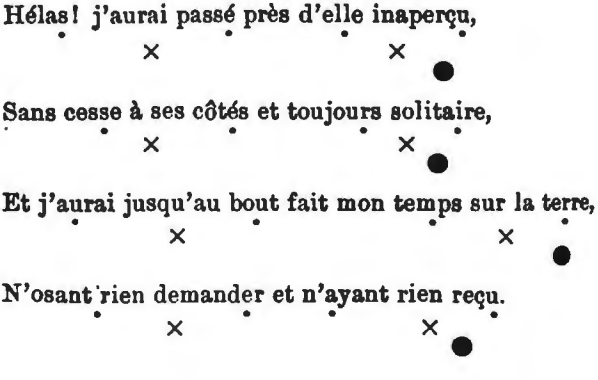
The study of this and other specimens of verse has made it quite clear that the usual concept of the nature of a poetical foot is erroneous in at least one respect. *Lines* in verse are generally distinct units, separated by pauses and having definite limits. A single line, however, is not made up of smaller units that can be marked off from each other. It would be quite erroneous to divide the first stanza of *Cock Robin* into feet. No such divisions occur in the actually spoken sounds and no dividing points can be assigned in the tracing. In fact there does not seem to be any system of feet that can be assigned to it or any form of such rhythm under which it can be classified. Yet it is felt distinctly as verse and has been a factor in forming the rhythmic feeling for verse in the history of our language and in individuals. Treated on the centroid method, it is perfect verse with two centroids to the line.

In verse the centroids are grouped. One group may form the line, another the stanza, etc., or, in blank verse, the various phrases may be made into more or less complicated groups.

As in all forms of rhythm (p. 523) there is a tendency to arrange the centroids regularly. Thus, in the *Sonnet d'Arvers* (p. 545) the internal centroids come at about 0.72$^{\sigma}$ apart, the line centroids at about 2.13$^{\sigma}$.

A centroid analysis of this stanza would be approximately



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The small dots • indicate the primary centroids (or 'foot centroids'), the crosses × indicate the phrase centroids, and the large dots ● the line centroids. The positions of these centroids might be determined by having the listener beat on a telegraph key at the moments he feels them to occur. I have indicated them only approximately without making measurements. Influenced by the rhyme and the long pause, I feel the line centroid to occur during the last word in each.

The distribution of energy around the centroids differs in different cases, but there are certain typical forms of distribution to which definite names have been given, as iambic, trochaic, etc.

In much English verse there is little or no regularity of distribution; just so many centroids are grouped into a line and there is no feeling for the distribution of energy between centroids. In a stanza like

The Cities are full of pride,
• • •
Challenging each to each —
• • •
This from her mountain-side,
• • •
That from her burthened beach
• • •

(KIPLING)

it would be quite a mistake to say that the meter is iambic, anapestic, trochaic or dactylic. Even if this particular stanza might be said to be mainly dactylic and trochaic, the following ones change constantly. In the minds of both the speaker and the hearer the only rhythmic essential lies in the presence of three beats to a line. Such verse should be called 2-beat, 3-beat, 4-beat verse, etc.; an attempt to force on verse of this kind the classical schemes cannot have the slightest justification.

In other cases of English verse there is a careful (generally unconscious) regularity in the distribution of energy. Thus,

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And the stream will not flow and the hill will not rise,
And the colors have all passed away from her eyes
(MOORE)

shows clearly a regular distribution of energy with a slow rise and a sudden fall. Again,

Merrily swinging on brier and weed
(BRYANT)

appears to rise suddenly and fall slowly. A moderately slow rise with quick fall appears in

The way was long, the wind was cold
(SCOTT)

and a quick rise with moderately slow fall in

Fifty times the rose has flowered and faded.
(TENNYSON).

These are specimens of the types known as anapest, dactyl, iambus and trochee. They are distinct types, although the poet may sometimes mix his forms and often lapse to the form of simple beat verse. In some specimens of English verse the distribution of energy around the centroids is very carefully elaborated so as to produce effects analogous to those of classical verse. In still more highly developed forms of verse the poet may use relations of duration among the syllables to produce a truly quantitative verse.

Concerning the influence of rime and alliteration in establishing centroids, and concerning the relations between the natural prose rhythm of a portion of speech and the verse rhythm into which it is fitted, we have no experimental data.

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APPENDICES

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APPENDIX I

FOURIER ANALYSIS

An understanding of the underlying principles is desirable but not necessary for the use of the Fourier analysis. The following exposition to the words 'In practice,' on page 566 may be omitted if desired.

The theory and practice of the analysis have been well presented by Hermann.[1]

According to Fourier's theorem any periodic function of t may be represented as the sum of a series of harmonic sine and cosine functions as follows:

$$y = \tfrac{1}{2}a_0 + a_1 \cdot \cos \frac{2\pi}{T}t + a_2 \cdot \cos \frac{2\pi}{\frac{1}{2}T}t + a_3 \cdot \cos \frac{2\pi}{\frac{1}{3}T}t + \cdots$$

$$+ b_1 \cdot \sin \frac{2\pi}{T}t + b_2 \cdot \sin \frac{2\pi}{\frac{1}{2}T}t + b_3 \cdot \sin \frac{2\pi}{\frac{1}{3}T}t + \cdots,$$

where a and b are the amplitudes of the harmonics, T the period of the lowest harmonic, and $\frac{1}{2}a_0$ a constant expressing the distance of the curve above the t axis.

By putting $\sqrt{a_1^2 + b_1^2} = c_1$, $\sqrt{a_2^2 + b_2^2} = c_2$, . . .,

and $$\frac{a_1}{b_1} = \tan q_1, \quad \frac{a_2}{b_2} = \tan q_2, \ \ldots,$$

we get

$$y = \tfrac{1}{2}a_0 + c_1 \cdot \sin\left(\frac{2\pi}{T}t + q_1\right) + c_2 \cdot \sin\left(\frac{2\pi}{\frac{1}{2}T}t + q_2\right) + \cdots$$

We thus have the curve expressed as the sum of a series of sine harmonics, that is, of sinusoids with periods that are sub-multiples of the longest one. The quantities q_1, q_2, . . . indicate the different phases of the sinusoids.

[1] Hermann, *Phonophotographische Untersuchungen, II.*, Arch. f. d. ges. Physiol. (Pflüger), 1890 XLVII 45.

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Such a series can well be used to find the partials in the curve of a violin tone or of any sound of a similar nature. When an empirical curve of this nature is given, the periods and amplitudes of the sinusoids may be found in the way described here.

After the ordinates have been measured (p. 74), the computation may be carried on as follows. The length of one period (group) is divided into n parts of h units each; the length T of the period is thus nh. In the FOURIER series as expressed above we substitute distance along X for time, whereby $nh = T$ and $x = t$. Thus

$$y = \tfrac{1}{2}a_0 + a_1 \cdot \cos\frac{2\pi}{nh}x + a_2 \cdot \cos 2\frac{2\pi}{nh}x + a_3 \cdot \cos 3\frac{2\pi}{nh}x + \cdots$$
$$+ b_1 \cdot \sin\frac{2\pi}{nh}x + b_2 \cdot \sin 2\frac{2\pi}{nh}x + b_3 \cdot \sin 3\frac{2\pi}{nh}x + \cdots,$$

wherein the constants a_0, a_1, b_1, a_2, b_2, . . . are determined by the equations

$$a_r = \frac{2}{nh}\int_{-\frac{nh}{2}}^{+\frac{nh}{2}} y \cos r\frac{2\pi}{nh}x\,dx = \frac{2}{nh}\int_0^{nh} y \cos r\frac{2\pi}{nh}x\,dx,$$

$$b_r = \frac{2}{nh}\int_0^{nh} y \sin r\frac{2\pi}{nh}x\,dx$$
$$(r = 0, 1, 2, \ldots).$$

These constants are to be approximately determined from a limited number of measurements of y for a number of values of x. We possess the set of values x_0, y_0; x_1, y_1; x_2, y_2; . . . from which we must calculate a_0, a_1, b_1, a_2, b_2, . . . The results will come nearer the truth the greater the number of ordinates included, being absolutely true only for an infinite number. For a finite number the integral equations are changed to sums in which the successive values of x run through the series $x_0 = 0$, $x_1 = h$, $x_2 = 2h$, . . ., whereby the successive values differ by h, or $dx = h$. We substitute h for dx as the expression is changed from an integral to a summation, and cancel h in both numerator and denominator. Another simplification arises by considering the whole period measured to be equal to 2π. For each value of x the summation will reach from $x = 0$ to $x = (n-1)h$, and the expression νh is substituted for x, whereby we mean that the summation is to be extended from $\nu = 0$ to $\nu = n - 1$; the upper limit of summation is thus

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$\nu = n - 1$. We likewise indicate by y_ν the corresponding values of y. We have finally

$$a_r = \frac{2}{n} \sum_{\nu=0}^{\nu=n-1} y_\nu . \cos r\nu h,$$

and likewise

$$b_r = \frac{2}{n} \sum_{\nu=0}^{\nu=n-1} y_\nu . \sin r\nu h,$$

$$(r = 0, 1, 2, \ldots)$$

The successive coefficients are thus

$$a_0 = \frac{2}{n}\Big(y_0 . \cos 0 + y_1 . \cos 0 + y_2 . \cos 0 + \cdots + y_{n-1} . \cos 0 \Big).$$

$$a_1 = \frac{2}{n}\Big(y_0 . \cos 0 + y_1 . \cos h + y_2 . \cos 2h + \cdots + y_{n-1} . \cos (n-1)h \Big),$$

$$b_1 = \frac{2}{n}\Big(y_0 . \sin 0 + y_1 . \sin h + y_2 . \sin 2h + \cdots + y_{n-1} . \sin (n-1)h \Big),$$

$$a_2 = \frac{2}{n}\Big(y_0 . \cos 0 + y_1 . \cos 2h + y_2 . \cos 4h + \cdots + y_{n-1} . \cos 2(n-1)h \Big),$$

$$b_2 = \frac{2}{n}\Big(y_0 . \sin 0 + y_1 . \sin 2h + y_2 . \sin 4h + \cdots + y_{n-1} . \sin 2(n-1)h \Big),$$

. . . . . .

$$a_i = \frac{2}{n}\Big(y_0 . \cos 0 + y_1 . \cos ih + y_2 . \cos 2ih + \cdots + y_{n-1} . \cos (n-1)ih \Big),$$

$$b_i = \frac{2}{n}\Big(y_0 . \sin 0 + y_1 . \sin ih + y_2 . \sin 2ih + \cdots + y_{n-1} . \sin (n-1)ih \Big),$$

. . . . . .

By inserting in the original equation the constants of amplitude thus obtained the original curve is resolved into a series of cosine and sine harmonics. By uniting the two series as indicated above, the resolution into a single set of harmonics is obtained.

Such an elaborate computation would be ordinarily quite im-

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practicable without various shortenings, of which HERMANN has suggested a number.

Let the number of ordinates be $n = 40$, whence, since $2\pi = nh$, $h = 9°$. Then

$$a_1 = \tfrac{1}{20}(y_0 \cdot \cos 0° + y_1 \cdot \cos\ 9° + y_2 \cdot \cos 18° + \cdots + y_{39} \cdot \cos 351°)$$
$$b_1 + \tfrac{1}{20}(y_0 \cdot \sin 0° + y_1 \cdot \sin\ 9° + y_2 \cdot \sin 18° + \cdots + y_{39} \cdot \sin 351°)$$
$$a_2 = \tfrac{1}{20}(y_0 \cdot \cos 0° + y_1 \cdot \cos 18° + y_2 \cdot \cos 36° + \cdots + y_{39} \cdot \cos 702°)$$
$$b_2 = \tfrac{1}{20}(y_0 \cdot \sin 0° + y_1 \cdot \sin 18° + y_2 \cdot \sin 36° + \cdots + y_{39} \cdot \sin 702°)$$

. . . . . .

$$a_i = \tfrac{1}{20}(y_0 \cdot \cos 0° + y_1 \cdot \cos [i \times 9]° + y_2 \cdot \cos [2i \times 30]° + \ldots)$$
$$b_i = \tfrac{1}{20}(y_0 \cdot \sin 0° + y_1 \cdot \sin [i \times 9]° + y_2 \cdot \sin [2i \times 30]° + \ldots)$$

There are thus 40 multiplications for each a and b, or 1600 multiplications for the first 20 harmonics. But when n is a factor of 360, the sines and cosines repeat themselves (thus, cos 702° = cos 342°), the values cos 18°, cos 27°, . . . are repeated a number of times, and there are simple relations between sines and cosines (thus, cos 9° = − cos 181° = − cos 189° = cos 351° = sin 81° = sin 99° = − sin 261° = − sin 279°). The result is that with $n = 40$ only nine trigonometric values are needed in addition to 0 and 1, making a total of eleven.

These eleven values are then to be properly multiplied with the forty values of y. To do this the products are arranged in a table as indicated on this page.

Angle	0°	9°	18°	27°	36°	45°	54°	63°	72°	81°	90°
Cosine	1	0.99	0.95	0.89	0.81	0.71	0.59	0.45	0.31	0.16	0
	y_0	$0.99\,y_0$	$0.95\,y_0$	$0.89\,y_0$	$0.81\,y_0$	$0.71\,y_0$	$0.59\,y_0$	$0.45\,y_0$	$0.31\,y_0$	$0.16\,y_0$	0
	y_1	$0.99\,y_1$	$0.95\,y_1$	$0.89\,y_1$	$0.81\,y_1$	$0.71\,y_1$	$0.59\,y_1$	$0.45\,y_1$	$0.31\,y_1$	$0.16\,y_1$	0
	y_2	$0.99\,y_2$	$0.95\,y_2$	$0.89\,y_2$	$0.81\,y_2$	$0.71\,y_2$	$0.59\,y_2$	$0.45\,y_2$	$0.31\,y_2$	$0.16\,y_2$	0
	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.
	y_{39}	$0.99\,y_{39}$	$0.95\,y_{39}$	$0.89\,y_{39}$	$0.81\,y_{39}$	$0.71\,y_{39}$	$0.59\,y_{39}$	$0.45\,y_{39}$	$0.31\,y_{39}$	$0.16\,y_{39}$	0

The smaller figures indicate those that are to be multiplied and written by the experimenter. In the column 0° all the values of the forty ordinates are written; in the column 9° all these values multiplied by 0.99 are written; etc. A multiplying table (p. 70) is of great use.

To obtain a_0 the numbers in the column 0° would be added; this is not necessary for selecting the harmonics and is omitted.

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For a_1 add the first main diagonal thus $+ (y_0 + 0.99y_1 + 0.95y_2 + \cdots + 0.16y_9 + 0)$; then the diagonal $- (0.16y_{11} + 0.31y_{12} + \cdots + y_{20})$; then the diagonal $- (0.99y_{21} + 0.95y_{22} + \cdots + 0.16y_{29} + 0)$; then $+ (0.16y_{31} + 0.31y_{32} + \cdots + 0.99y_{39})$. The diagonal sums are to be taken + and − as indicated; the sign changes always at the right-hand edge.

For a_2 add the series $+ (y_0 + 0.95y_1 + 0.81y_2 + 0.59y_3 + 0.31y_4 + 0) - (0.31y_6 + 0.59y_7 + \cdots + y_{10}) - (0.95y_{11} + 0.81y_{12} + \cdots + 0) + (0.31y_{16} + 0.59y_{17} + \cdots + y_{20}) + (0.95y_{21} + 0.81y_{22} + \cdots + 0)$ — etc. The successive jumps are like the knight's move in chess.

For a_3 add the series $+ (y_0 + 0.89y_1 + 0.59y_2 + 0.16y_3) - (0.31y_4 + 0.71y_5 + 0.95y_6) - (0.99y_7 + 0.81y_8 + 0.45y_9 + 0) +$ etc. The successive jumps omit two columns.

For a_4, a_5, . . . add similar series, with three omitted columns for a_4, four for a_5, etc.

For b_1 add the series along the diagonal $+ (0 + 0.16y_1 + 0.31y_2 + 0.45y_3 + \cdots + y_{10}) + (0.99y_{11} + 0.95y_{12} + \cdots + 0.16y_{19} + 0) - (0.16y_{21} + 0.31y_{22} + \cdots + y_{30}) - (0.99y_{31} + \cdots 0.16y_{39})$; the sign changes always at the right-hand edge.

For b_2 the numbers are taken by skipping one column as for a_2 but on diagonals downward from right to left. For b_3, b_4, . . . the procedures are as for a_3, a_4, . . . but along diagonals in the direction for b_1 and b_2.

Each of the values thus obtained would need to be multiplied by $\frac{1}{15}$ to give a_1, a_2, . . . b_1, b_2, . . . but, since only the relations between the ordinates are desired, the constant multiplier is omitted.

For 12 ordinates, $n = 12$ and $h = \dfrac{2\pi}{n} = 30°$. Then

$$
\begin{aligned}
a_1 &= \tfrac{1}{6}(y_0 . \cos 0° + y_1 . \cos 30° + \ldots\ ) \\
b_1 &= \tfrac{1}{6}(y_0 . \sin 0° + y_1 . \sin 30° + \ldots\ ) \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
a_i &= \tfrac{1}{6}(y_0 . \cos 0° + y_1 . \cos (30i)° + \ldots) \\
b_i &= \tfrac{1}{6}(y_0 . \sin 0° + y_1 . \sin (30i)° + \ldots) \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots
\end{aligned}
$$

For cos 0, cos 30°, cos 60°, cos 90° we have 1, 0.87, 0.50, 0; from which the values of all the cosines and sines are obtained by prefixing the proper signs.

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We thus have the scheme:

Angle	0°	30°	60°	90°
Cosine	1	0.87	0.50	0
	y_0	$0.87y_0$	$0.50y_0$	0
	y_1	$0.87y_1$	$0.50y_1$	0
	y_2	$0.87y_2$	$0.50y_2$	0
	.	.	.	.
	.	.	.	.
	.	.	.	.
	y_{11}	$0.87y_{11}$	$0.50y_{11}$	0

For a_1 take the first main diagonal thus $+ (y_0 + 0.87y_1 + 0.50y_2 + 0)$, then the diagonal $- (0.50y_4 + 0.87y_5 + y_6)$, then the diagonal $- (0.87y_7 + 0.50y_8 + 0)$, then the diagonal $+ (0.50y_{10} + 0.87y_{11})$, and add the results. For a_2 take $+ (y_0 + 0.50y_1) - (0.50y_2 + y_3 + 0.50y_4) + (0.50y_5 + y_6 + 0.50y_7) - (0.50y_8 + y_9 + 0.50y_{10}) + 0.50y_{11}$. Proceed likewise for the other values.

In practice the computation proceeds according to schedules prepared once for all beforehand according to the preceding principles. The use of such schedules can be illustrated by a case with 12 ordinates.

The values of the 12 ordinates are written in the first column of a table; each is then multiplied by 0.87 to fill the second column and then by 0.50 to fill the third.

The curve shown in Fig. 49 gives ordinates with values as in column 1 of the following table. Multiplication by 0.87 gives — after the last decimal is dropped — the values in column 0.87, and by 0.50 those in the last column.

The computation proceeds according to the following schedule.

	1	0.87	0.50
y_0	0	0	0
y_1	10	8.7	5.0
y_2	31	27.0	15.5
y_3	36	31.3	18.0
y_4	30	26.1	15.0
y_5	18	15.7	9.0
y_6	8	7.0	4.0
y_7	11	9.6	5.5
y_8	26	22.6	13 0
y_9	35	30.5	17.5
y_{10}	30	26.1	15.0
y_{11}	8	7 0	4.0

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SCHEDULE FOR 12 ORDINATES

(Multipliers: 1, 0.87, 0.50.)

	a_1	a_2	a_3	a_4	a_5	a_6	b_1	b_2	b_3	b_4	b_5	b_6
y_0	+ · ·	+ · ·	+ · ·	+ · ·	+ · ·	+ · ·	· · ·	· · ·	· · ·	· · ·	· · ·	· · ·
y_1	· + ·	· · +	· · ·	· · −	· − ·	− · ·	· · +	· + ·	+ · ·	· + ·	· · +	· · ·
y_2	· · +	· · −	− · ·	· · −	· · +	+ · ·	· + ·	· + ·	· · ·	· − ·	· − ·	· · ·
y_3	· · ·	− · ·	· · ·	+ · ·	· · ·	− · ·	+ · ·	· · ·	− · ·	· · ·	+ · ·	· · ·
y_4	· · −	· · −	+ · ·	· · −	· · −	+ · ·	· + ·	· − ·	· · ·	· + ·	· − ·	· · ·
y_5	· − ·	· · +	· · ·	· · −	· + ·	− · ·	· · +	· − ·	+ · ·	· − ·	· · +	· · ·
y_6	− · ·	+ · ·	− · ·	+ · ·	− · ·	+ · ·	· · ·	· · ·	· · ·	· · ·	· · ·	· · ·
y_7	· − ·	· · +	· · ·	· · −	· + ·	− · ·	· · −	· + ·	− · ·	· + ·	· · −	· · ·
y_8	· · −	· · −	+ · ·	· · −	· · −	+ · ·	· − ·	· + ·	· · ·	· − ·	· + ·	· · ·
y_9	· · ·	− · ·	· · ·	+ · ·	· · ·	− · ·	− · ·	· · ·	+ · ·	· · ·	− · ·	· · ·
y_{10}	· · +	· · −	− · ·	· · −	· · +	+ · ·	· − ·	· − ·	· · ·	· + ·	· + ·	· · ·
y_{11}	· + ·	· · +	· · ·	· · −	· − ·	− · ·	· · −	· − ·	− · ·	· − ·	· · −	· · ·

The squares with + and − in the schedule for a_1 indicate the figures of the table that are to be added in order to give the value a_1. Thus, for a_1 we have $0 + 8.7 + 15.5 + 15.0 + 7.0 - 15.0 - 15.7 - 8.0 - 9.6 - 13.0 = -15.1$. For b_1 we have $5.0 + 27.0 + 36 + 26.1 + 9.0 - 5.5 - 22.6 - 35.0 - 26.1 - 4.0 = +9.9$. The schedules for a_2, a_3, . . ., b_1, b_2, b_3 . . . are used in like manner. The values $c_1 = \sqrt{a_1^2 + b_1^2}$, $c_2 = \sqrt{a_2^2 + b_2^2}$, . . . give the relative amplitudes of the partials.

With these schedules the values obtained from the table are, for the curve under consideration:

	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6
	−15.1	+9.9	−98.0	−7.0	−13.0	+8.0	−3.0	−1.8	+4.1	−1.1	+7.0	0
Squares	228	98	9604	49	169	64	9	3	17	1	49	0
$a^2 + b^2$	326		9653		233		12		18		49	
$\sqrt{a^2 + b^2}$	18		98		15		3		4		7	

The nearest whole number is taken as the value of $\sqrt{a^2 + b^2}$. The indices attached to the values for c give the serial numbers of the partials. The second partial is thus the main tone present in this curve.

To save the labor of consulting the schedules they may be reproduced on a large scale as diagrams with black and white squares, the white squares bearing the signs + and − as required. A piece of tracing paper is placed over the first diagram and the values of the ordinates are written in the first column y. The following column is then filled by multiplying (with ZIMMERMANN'S tables) each value of y by the number written above it. The following columns are likewise filled. The result is a set of figures written in squares. The transparent paper is now placed over the diagram a_1. The numbers seen over the white

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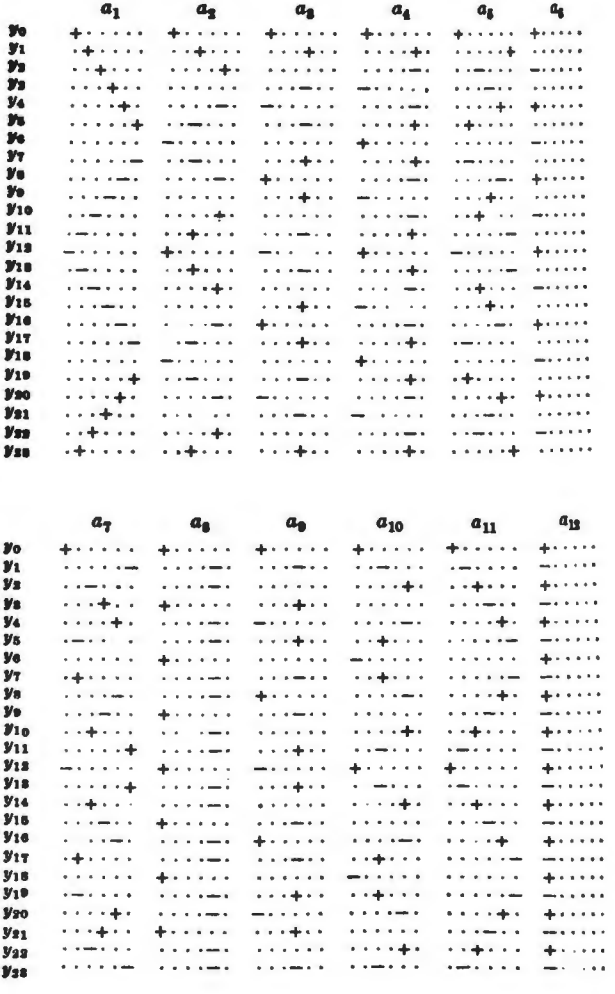
squares are to be added, with careful regard to the signs + and −. The paper is then placed over the diagrams a_0 a_0 . . . in

SCHEDULE FOR 24 ORDINATES

(Multipliers: 1, 0.97, 0.87, 0.71, 0.50, 0.26.)



succession; the numbers over the white squares are likewise to be added in each case. The values for a_1, a_2, a_3, . . . are written

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on the margin of the paper. In like manner the values for b_1, b_2, b_3, . . . are obtained.

SCHEDULE FOR 24 ORDINATES

(Multipliers: 1, 0.97, 0.87, 0.71, 0.50, 0.26.)

	b_1	b_2	b_3	b_4	b_5	b_6
y_0	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·
y_1	· · · · · +	· · · · + ·	· · · + · ·	· · + · · ·	· + · · · ·	+ · · · · ·
y_2	· · · · + ·	· · + · · ·	+ · · · · ·	· · + · · ·	· · · · + ·	· · · · · ·
y_3	· · · + · ·	+ · · · · ·	• · · · · ·	· · · · · ·	· · · — · ·	— · · · · ·
y_4	· · + · · ·	· · + · · ·	· · · · · ·	· · — · · ·	· · — · · ·	· · · · · ·
y_5	· + · · · ·	· · · · + ·	· · · — · ·	· · — · · ·	· · · · · +	+ · · · · ·
y_6	+ · · · · ·	· · · · · ·	— · · · · ·	· · · · · ·	+ · · · · ·	· · · · · ·
y_7	· + · · · ·	· · · — · ·	· · · — · ·	· · + · · ·	· · · · · +	— · · · · ·
y_8	· · + · · ·	· · — · · ·	· · · · · ·	· · + · · ·	· · — · · ·	· · · · · ·
y_9	· · · + · ·	— · · · · ·	· · · + · ·	· · · · · ·	· · · — · ·	+ · · · · ·
y_{10}	· · · · + ·	· · — · · ·	+ · · · · ·	· · — · · ·	· · · · + ·	· · · · · ·
y_{11}	· · · · · +	· · · · — ·	· · · + · ·	· · — · · ·	· + · · · ·	— · · · · ·
y_{12}	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·
y_{13}	· · · · · —	· · · · + ·	· · · — · ·	· · + · · ·	· · — · · ·	+ · · · · ·
y_{14}	· · · · — ·	· · + · · ·	— · · · · ·	· · + · · ·	· · · · — ·	· · · · · ·
y_{15}	· · · — · ·	+ · · · · ·	· · · — · ·	· · · · · ·	· · + · · ·	— · · · · ·
y_{16}	· · — · · ·	· · + · · ·	· · · · · ·	· · — · · ·	· · + · · ·	· · · · · ·
y_{17}	· — · · · ·	· · · · + ·	· · · + · ·	· · — · · ·	· · · · · —	+ · · · · ·
y_{18}	— · · · · ·	· · · · · ·	+ · · · · ·	· · · · · ·	— · · · · ·	· · · · · ·
y_{19}	· — · · · ·	· · · · — ·	· · · + · ·	· · + · · ·	· · · · · —	— · · · · ·
y_{20}	· · — · · ·	· · — · · ·	· · · · · ·	· · + · · ·	· · · + · ·	· · · · · ·
y_{21}	· · · — · ·	— · · · · ·	· · · — · ·	· · · · · ·	· · · · + ·	+ · · · · ·
y_{22}	· · · · — ·	· · — · · ·	— · · · · ·	· · — · · ·	· · · · · —	· · · · · ·
y_{23}	· · · · · —	· · · · — ·	· · · — · ·	· · — · · ·	· — · · · ·	— · · · · ·

	b_7	b_8	b_9	b_{10}	b_{11}	b_{12}
y_0	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·
y_1	· + · · · ·	· · + · · ·	· · · + · ·	· · · · + ·	· · · · · +	· · · · · ·
y_2	· · · · — ·	· · — · · ·	— · · · · ·	· · — · · ·	· · · · — ·	· · · · · ·
y_3	· · · — · ·	· · · · · ·	· · · + · ·	+ · · · · ·	· · · + · ·	· · · · · ·
y_4	· · + · · ·	· · + · · ·	· · · · · ·	· · — · · ·	· · — · · ·	· · · · · ·
y_5	· · · · · +	· · — · · ·	· · · — · ·	· · · · + ·	· · + · · ·	· · · · · ·
y_6	— · · · · ·	· · · · · ·	+ · · · · ·	· · · · · ·	— · · · · ·	· · · · · ·
y_7	· · · · · +	· · + · · ·	· · · — · ·	· · · · — ·	· + · · · ·	· · · · · ·
y_8	· · + · · ·	· · — · · ·	· · · · · ·	· · + · · ·	· · — · · ·	· · · · · ·
y_9	· · · — · ·	· · · · · ·	· · · + · ·	— · · · · ·	· · · + · ·	· · · · · ·
y_{10}	· · · — · ·	· · + · · ·	— · · · · ·	· · + · · ·	· · · · — ·	· · · · · ·
y_{11}	+ · · · · ·	· · — · · ·	· · · + · ·	· · · · — ·	· · · · · +	· · · · · ·
y_{12}	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·	· · · · · ·
y_{13}	· — · · · ·	· · + · · ·	· · · — · ·	· · · · + ·	· · · · · +	· · · · · ·
y_{14}	· · · · + ·	· · — · · ·	+ · · · · ·	· · — · · ·	· · · · — ·	· · · · · ·
y_{15}	· · · + · ·	· · · · · ·	· · · — · ·	+ · · · · ·	· · · + · ·	· · · · · ·
y_{16}	· · — · · ·	· · + · · ·	· · · · · ·	· · — · · ·	· · — · · ·	· · · · · ·
y_{17}	· · · · · —	· · — · · ·	· · · + · ·	· · · · + ·	· + · · · ·	· · · · · ·
y_{18}	+ · · · · ·	· · · · · ·	— · · · · ·	· · · · · ·	— · · · · ·	· · · · · ·
y_{19}	· · · · · —	· · + · · ·	· · · + · ·	· · · · — ·	· + · · · ·	· · · · · ·
y_{20}	· · — · · ·	· · — · · ·	· · · · · ·	· · + · · ·	· · — · · ·	· · · · · ·
y_{21}	· · · + · ·	· · · · · ·	· · · — · ·	— · · · · ·	· · · + · ·	· · · · · ·
y_{22}	· · · · + ·	· · + · · ·	+ · · · · ·	· · + · · ·	· · · · — ·	· · · · · ·
y_{23}	· — · · · ·	· · — · · ·	· · · — · ·	· · · · — ·	· · · · · +	· · · · · ·

Schedules are given here for 12 and 24 ordinates. These will probably be sufficient for most purposes.

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HERMANN writes the values for y on centimeter paper (with horizontal and vertical parallel lines dividing the surface into centimeter squares), and then cuts out squares in a similar sheet of paper so that when this is placed over the table only the numbers needed for one constant can be seen. Thus there is a pattern for a_2, another for a_3, etc.; the pattern for b_2 is obtained by turning a_2 over, likewise for b_3, b_4, . . . by turning over those for a_3, a_4 . . . No patterns are needed for a_1, b_1, a_{20}, and b_{20}.

The various additions and subtractions can be conveniently performed on the margins of the paper on which the table is written. The final sums would have to be divided by the number of ordinates used to give a_1, b_1, a_2, b_2, . . ., but this can be omitted as only the *relations* of amplitude are desired. Moreover, for a like reason the decimal points in the table itself may be omitted, as this simply multiplies all numbers by 100. After several analyses have been made it will be found that nearly every value of y with its products has occurred in some previous analysis; thus the results can be copied into the new table. With these methods a complete analysis of a curve-period with measurements of 40 ordinates and computations requires from two to three hours of work. Although the measurements are recorded with only two places of figures, the error of computation remains much smaller; the error of measurement[1] is also much smaller and the results are perfectly trustworthy to the second figure.

The results do not generally show so decided a prominence of one partial as in the case worked out above. An example is found in the following series of values for a certain period of the vowel a by HERMANN:

c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}
4.2	8.5	3.2	7.3	2.2	13.9	44.7	50.2	13.6	14.6

The 6th to 10th overtones are most strongly represented. If it were true that the vowel was composed strictly of a fundamental and its overtones, these tones would be selected as a characteristic of the vowel. It is, however, established that in general the higher partials in a vowel sound are not harmonics of the lowest partial. An analysis into a series of partials in such a case gives a series of harmonics in which those nearest the inharmonic

[1] HERMANN, *Phonophotographische Untersuchungen, IV.*, Arch. f. d. ges. Physiol. (Pflüger), 1893 LIII 44.

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partial appear of greater amplitude, while those further away are less influenced. To find this inharmonic the weighted mean (or centroid) of the neighboring overtones is obtained by multiplying each amplitude by its ordinal number and dividing by the sum of the amplitudes:

$$\frac{(6 \times 13.9) + (7 \times 44.7) + (8 \times 50.2) + (9 \times 13.6)}{13.9 + 44.7 + 50.2 + 13.6} = 7.53,$$

The number 7.53 gives the relation of frequency between the inharmonic and the fundamental. The frequency of the fundamental in this case, 98, multiplied by the number 7.53 gives the frequency of the inharmonic, 737.

In using the centroid of a set of harmonics to indicate the inharmonic partial several rules should be observed:[1] 1. when a harmonic of large amplitude appears with neighboring harmonics of very small amplitude, it may be considered alone as indicating approximately the partial; 2. when the strong harmonic is accompanied by two neighboring strong harmonics, all three should be considered; 3. when one of the neighboring harmonics is more than twice as great as the other, only the former should be considered with the strong harmonic.

It may occur that a harmonic partial of very small amplitude may lie between two of very large amplitude. The centroid method is applicable here also and the inharmonic partial may even coincide with an overtone of small amplitude.[2] Attempts at improving HERMANN's formula for averaging the harmonics do not seem to give any advantage.[3] LLOYD's criticisms[4] of the FOURIER analysis I am unable to understand; they seem to rest on mistaken views of the nature of vowels, and of the analysis.

The results of a FOURIER analysis may be graphically expressed by laying off the distances 1, 2, 3, . . . on the X axis to represent the series of harmonics, and erecting at each point an ordinate proportional to the calculated amplitude of that harmonic. The curve of Fig. 49 analyzed into a series of harmonics gave the

[1] HERMANN, as before, 50.

[2] HERMANN, as before, 276.

[3] PIPPING, *Zur Lehre v. d. Vokalklängen*, Zt. f. Biol., 1895 XXXI 564; LLOYD, *Interpretation of phonograms of vowels*, Jour. Anat. and Physiol., 1897 XXXI 240; HERMANN, *Weitere Untersuchungen über d. Wesen d. Vokale*, Arch. f. d. ges. Physiol. (Pflüger), 1895 LXI 169, 181, 182.

[4] LLOYD, *On the Fourierian analysis of phonographic tracings of vowels*, Proc. Roy. Soc. Edinb., 1897-99 XXII 97.

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resulting amplitudes as indicated by the values for c on p. 567. The resulting plot is shown in Fig. 348.

ROUDET[1] has devised a computing machine for determining the values of the coefficients a and b. It consists of a cardboard rectangle $ABCD$ (Fig. 349) covered with millimeter divisions on which the axis OO' is traced parallel to the sides. The side AB is graduated in each direction from O'. Points are marked on OO' in such a way that each divides it into two parts whose ratio gives the cosine of an angle of the first quadrant; thus, $OE : OO' = \sin 30° = \cos 60°$, $OK : OO' = \sin 60° = \cos 30°$, etc. Perpendiculars erected at these points are divided like the line AB. On the edge AB a small runner of metal or cardboard is placed; a thread is attached to a pivot at O. The use of the instrument may be readily explained. Suppose, for example, 12 ordinates to have been measured and the coefficient a_4 is to be

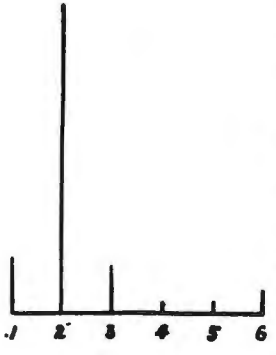

FIG. 348.

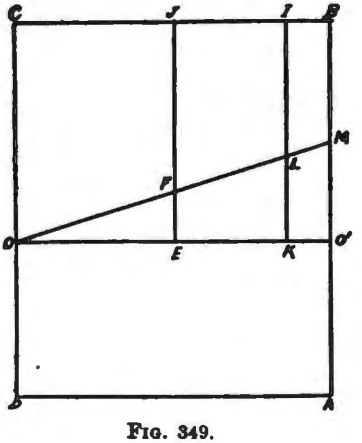

FIG. 349.

computed. The number of divisions is $n = 12$; the whole period considered as 2π (p. 562) and divided into n parts gives $h = 30°$

[1] ROUDET, *Abaque pour l'analyse des courbes périodiques*, La Parole, 1900 II 17.

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as the difference between successive angles. Thus, remembering that $\cos 120° = \cos 240° = -\cos 60°$, $\cos 360° = 1$, etc., we have from the general formula for a_i on p. 563, when $i = 4$,

$$6a_4 = y_0 - y_1 \cdot \cos 60° - y_2 \cdot \cos 60° + y_3 - y_4 \cdot \cos 60° - y_5 \cdot \cos 60° + y_6 - y_7 \cdot \cos. 60° - y_8 \cdot \cos 60° + y_9 - y_{10} \cdot \cos 60° - y_{11} \cdot$$

Let $y_0 = 8$, $y_1 = 23$, etc., for a given curve. The rider is moved upward 8 divisions from O' toward B. To obtain $y_1 \cdot \cos 60°$ the thread is stretched from O to the point 23 above O'; the distance above OO' of the point where it cuts the EF gives the value of $y_1 \cdot \cos 60°$, which is found to be 12. Since this is a negative value, the rider is moved back 12 divisions, reaching -4. The succeeding values are found and added in like manner.

A FOURIER analysis of a curve may be executed automatically by the harmonic analyzer of THOMSON [1] or of HENRICI.[2] By moving the point of the instrument over a period of the curve the indicators of the machine will show the amplitudes and phases of the partials contained in it. STRACHEY'S slide rule aids in ordinary computation.

The FOURIER analysis furnishes a convenient and trustworthy method of determining the harmonic sinusoid components of a curve. When the curve is the product of vibratory movements of this kind, the results give a proper analysis. The method gives only approximate results when the component vibratory movements are inharmonic or non-sinusoid.

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[1] THOMSON, *Harmonic analyzer*, Proc. Roy. Soc. Lond., 1878 XXVII 371; also in THOMSON AND TAIT, Treatise on Natural Philosophy, I 505, Cambridge, 1896.

[2] HENRICI, *Ueber Instrumente zur harmonischen Analyse*, Dyck's Katalog math. u. math.-phys. Modelle, Apparate u. Instrumente, 125, 213; Nachtrag, 34, München, 1892-93

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MANN, *Die Bedeutung d. Fehlerrechnung bei d. harmon. Analyse von Kurven*, Arch. f. d. ges. Physiol. (Pflüger), 1901 LXXXVI 92; *Kurvenanalyse u. Fehlerrechnung*, Arch. f. d. ges. Physiol. (Pflüger), 1902 LXXXIX 600.

For pantographs and harmonic analyzers: CORADI, Zürich. For a set of computing pätterns for 40 ordinates and a supply of centimeter paper: Prof. L. HERMANN, Physiologisches Institut, Königsberg. For a set of schedules for 12, 20, 24, 36, and 40 ordinates: E. W. SCRIPTURE, New Haven, Conn.

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APPENDIX II

STUDIES OF SPEECH CURVES

THE following is a condensed account of some work on the speech curves obtained as described in Ch. IV and analyzed as indicated in Ch. V.

The words first studied[1] were those of William F. HOOLEY, a trained speaker, reciting the nursery-rhyme entitled *The Sad Story of the Death and the Burial of Poor Cock Robin.* The record is contained on the disc numbered 6015 made by the National Gramophone Company of New York.

The record on the gramophone disc reads as follows:

Now, children, draw your little chairs nearer so that you can see the pretty pictures, and Uncle Will will read to you the sad story of the death and the burial of poor Cock Robin.

Who killed Cock Robin?
I, said the sparrow,
With my bow and arrow.
I killed Cock Robin.

Who saw him die?
I, said the fly,
With my little eye
I saw him die.

Who caught his blood?
I, said the fish,
With my little dish
I caught his blood.

Who 'll make his shroud?
I, said the beetle,
With my thread and needle
I 'll make his shroud.

Who 'll be the parson?
I, said the rook.
With my little book
I 'll be the parson.

Who 'll dig his grave?
I, said the owl,
With my spade and trowel
I 'll dig his grave.

Who 'll carry the link?
I, said the linnet,
I 'll fetch it in a minute.
I 'll carry the link.

[1] SCRIPTURE, *Researches in experimental phonetics (first series)*, Stud. Yale Psych. Lab., 1899 VII 14.

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To extend the treatment to prose some cases of 'I' were studied in another record by William F. HOOLEY, entitled *Gladstone's Advice on Self-Help and Thrift*, being disc number 6014 of the gramophone series. The speech begins as follows:

Ladies and gentlemen, the purpose of the meeting on the 14th instant may, I can say, be summed up in a very few words: self-help and thrift.

Two examples of this diphthong were also studied in the word 'thy,' as it appears in a disc numbered 668Z (name of speaker not given), which begins as follows:

Our Father which art in Heaven, hallowed be Thy name, Thy kingdom come . . .

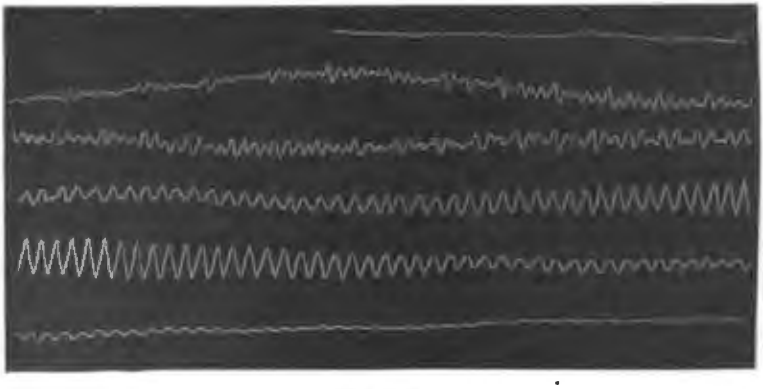

FIG. 350.

These are the three records referred to on p. 58 as *Cock Robin, Series I; Self-Help, Series I; Lord's Prayer, Series I.*

The first occurrence of ai is in the verse 'I, said the sparrow.' A reproduction of the curve for this word is given in Fig. 350. Some of the details were lost by the engraver in making the figure, and others were not quite correctly reproduced; the original curve is much sharper and clearer. The

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with a period of 6.3$^{\sigma}$ in the u at 39$^{\sigma}$ after the beginning of the word; it rises steadily to 4.2$^{\sigma}$ and then falls to a constant pitch of 4.6$^{\sigma}$ for the latter part of the u; suddenly it rises to 2.1$^{\sigma}$ for the l and remains practically constant for 71$^{\sigma}$.

On speaking the words ' who 'll ' I perceive apparently *continuous* movements of the lips and tongue; they do not assume fixed positions at any moment. This would agree with the changes just described.

There are thus at least three distinct but cooperating continuous processes following different courses throughout the words, namely, the force of expiration, the cavity tone and the cord tone.

It seems therefore somewhat artificial to divide the words ' who 'll ' into 3 or 5 sounds; we may preferably say that for the sake of discussion 5 stages in the changing sound may be picked out as typical of the whole process. To illustrate by an analogy, we might take single pictures out of a series of views of a runner made for the kinetoscope and treat the whole movement as made up of a series of positions in which the runner remains at rest. This treatment has its advantages for certain cases, but we should never lose sight of the fact that the true movement occurs otherwise.

This view is not inconsistent with the fact that some of the elements of a vocal sound may remain approximately constant for a short time. Thus, the pitch of the h-u glide is nearly constant — as far as our methods can discover — though the intensity is changing, and the pitch of the u is fairly constant for a while.

The sound l apparently does not begin suddenly but arises from a modification of the u. The u itself has been steadily changing in character from the very beginning; during its last five or more cord vibrations it gradually approaches the form of curve that characterizes the l. After this point the curve takes the l form which differs completely from that of the u at the start (Fig. 357, line 4). As stated above, the explanation is presumably (1) that the cord tone remains

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on the u pitch until a certain moment at which it suddenly rises to the l pitch, whereas (2) the mouth cavity begins to modify itself from the u form to the l form before the cord tone changes.

The l occupies a total time of 71$^{\sigma}$. It shows 34 cavity vibrations with a fairly constant period of 2.1$^{\sigma}$ or 576 frequency. There seems to be a grouping by twos that indicates a cord tone an octave lower, that is, of 4.2$^{\sigma}$ period, or 238 frequency. The form of the vibration steadily changes as shown in the figure; there is a change either in the tone of the mouth cavity or in that of the cords.

The changes in pitch in these words 'who'll' follow the same general course as in ai, namely, that in a succession of sonants (speech elements with tones) the cord tone of a sonant tends to be a multiple or a sub-multiple of the cord tone or the mouth tone of the preceding sonant. The relations are not exact but only approximate. The mouth tone 2.5$^{\sigma}$ of the h is followed by a cord tone for the u having a general average of 5.0$^{\sigma}$ or an octave below the former. The mouth tone of the u, 1.9$^{\sigma}$, is followed by a cord tone for the l of pretty nearly the same period 2.1$^{\sigma}$. Such relations are what would be expected in a voice — at any rate in one that was not unpleasant; for the human ear finds pleasure in a succession of tones whose periods stand in certain relations. Possibly some of the explanation of disagreeable voices may be found in the violation of this law.

In the spoken words on the gramophone disc the sound b follows immediately upon the l without pause. The speech curve at this point (Fig. 357, line 5) shows no measurable vibrations, the enlargement not being great enough to reveal the details of the weak tone of the b. The interval occupied is 96$^{\sigma}$.

The cavity vibrations of i (lines 6 and 7) have a constant period of 2.8$^{\sigma}$, or a frequency of 357. They start with an amplitude of 0 and rise steadily to an amplitude of 0.2^{mm}; at the end they fall to 0 suddenly in four vibrations (line 8). They are grouped in twos, indicating a cord tone an octave

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below with a period of 5.6^{σ}, or a frequency of 179; the relation is like that often found in i of ai. The glide to ð is seen in the first part of line 8.

The scale of enlargement is not sufficient to give definite information concerning the waves of the ð ; it occupies a time of 56^{σ}.

The indefinite vowel ə of ' the ' rises somewhat rapidly to its maximum, remains at an even amplitude (line 9), and drops suddenly to 0 in the last 4 vibrations. It has a pitch of 6.7^{σ} on an average and a maximum amplitude of 0.4^{mm}. The entire vowel contains 12 cord vibrations and occupies a total time of 84^{σ}.

The unstressed vowel ə of ' the ' is cut short by the closing of the lips for p. This suddenly reduces the amplitude of the vibrations till they are very faint (line 9), yet the cords



FIG. 358.



FIG. 359.

continue to vibrate after the closure as may be seen from the faint vibrations (lines 9 and 10). The sound can no longer be considered to be the vowel ə and cannot in the usual sense be called a p. It may be treated as a glide although it occupies fully two-thirds of the interval of 112^{σ} between the ə in ' the ' and the a in ' parson.' If the period of sonancy after ' the ' is to be considered as a glide, the remaining third of the 112^{σ} may be assigned to the p (line 10).

The word ' parson ' appears to the ear to have an inflectional force of the form indicated in Fig. 357, as often appears at the end of questions; the circumflexion appears to lie in the a and the deep fall to be in the n. The word seems to contain a brief r. The word differs from the same word three lines later (p. 575) which appears to the ear to have a deep inflectional tone, at first level and then falling as in deciding a matter; this is indicated in Fig. 359. The latter word seems to contain no r. The word ' parson ' is in

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both cases apparently continuous with the word 'the' and would be phonetically written ðəparsn.

The vowel a in this case occupies a period of 180$^{\sigma}$. It is preceded by the interval of 112$^{\sigma}$ belonging to the p and is followed by a glide of 12.3$^{\sigma}$.

The a shows 36 cord vibrations. The pitch rises gradually as shown by the following measurements of the successive periods: 6.7, 7.0, 6.7, 6.0, 6.0, 6.3, 5.3, 5.3, 5.3, 5.3, 5.3, 5.3, 4.9, 4.9, 4.6, 4.6, 4.6, 4.6, 4.6, 4.2, 4.2, 4.2, 3.9, 3.9, 3.9, 3.9, 3.9, 3.9, 3.9, 3.9, 3.9, 3.9, 3.9, 3.9, 3.9, 4.0, 4.2. It contains a constant lower cavity tone with a period of 2.8$^{\sigma}$ or a frequency of 357. The upper cavity tone is one of about 714 vibrations per second.

The amplitude rises through the first four vibrations from zero to 0.3^{mm} and is maintained at this to the end.

The vowel a in 'parson' has undoubtedly a diphthongal character. The first portion resembles the a sound discussed above (p. 577) in the rising cord tone but differs radically in the falling cavity tone, in which respect it is somewhat like the a in 'die' (Figs. 353 and 355). The latter portion (Fig. 357, line 13) is related to the earlier portion much as the i is related to the a in ai in respect to amplitude, the lowering of the cavity tone and the maintenance of the cord tone. Although this latter portion is not so long as in most cases of ai, the resemblance is sufficient to justify the statement with which this paragraph begins. The sound might be written a†, where the sign † indicates a brief vowel not yet determined. It may be suggested that this brief vowel may arise from the weakening of the r, whereby a vowel sound partially or completely replaces the full r. It seems, however, to be a general rule, that in English the long vowels have a diphthongal character.

The sudden fall in amplitude and the change in pitch of the vowel indicated by † is continued through an interval of 8.8$^{\sigma}$ in which 3 vibrations with a period of 2.4$^{\sigma}$ appear (line 13, middle). During this time the tongue is presumably passing to the r position. This portion might be called the a-r glide.

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The very brief r is distinctly heard in the word 'parson;' it occupies a time of 63$^{\sigma}$ (line 13 middle to line 14 beginning). The r shows clearly 3 'pseudobeats' (p. 19) with a period of 19$^{\sigma}$ or a frequency of 53. The vibrations within the beats are grouped in pairs indicating a cord tone acting upon a cavity. The period of the cord tone is at first constant at 3.5$^{\sigma}$ (frequency 286) but falls slightly in the third beat. The cavity tone has a period apparently constant at 1.4$^{\sigma}$ (frequency 714). Still higher cavity tones are probably present. The explanation of this curve of r seems clear. The r consists of a cord tone with a frequency of 286 acting upon a resonating cavity adjusted to a frequency of 714. The tongue is adjusted to vibrate with a frequency of 53; this vibration of the tongue closes and opens the air passage so that the intensity of the sound escaping from the mouth is regularly varied from zero to a maximum and again to zero at the rate of 53 times a second.

The pseudobeats with the cord and resonance vibrations are shown in the curves of WENDELER[1] and in those of NICHOLS and MERRITT (p. 28). The German rolled r of WENDELER has a much longer beat period, in general over 250$^{\sigma}$ or $\frac{1}{4}$ sec.; the Finnish r of PIPPING has a beat of $\frac{1}{3}$ to $\frac{1}{2}$ sec.[2] The American rolled r of NICHOLS and MERRITT has also apparently a long beat-period as far as can be judged from the pictures. The brief r in three examples given by these last observers seems to have a shorter beat-period than that of 'parson.' The cord period in WENDELER'S examples varies apparently from 2.8$^{\sigma}$ to 3.3$^{\sigma}$ (WENDELER'S own computation of a frequency of 200, or a period of 5$^{\sigma}$, can hardly be correct); the cavity tone has a period in the neighborhood of 1.7$^{\sigma}$, according to my calculation from his records. The later observations of HERMANN on r have been given on pages 44 and 337.

[1] WENDELER, *Ein Versuch, die Schallbewegung einiger Konsonanten und anderer Geräusche mit dem Hensen'schen Sprachzeichner graphisch darzustellen*, Zt. f. Biol., 1887 XXIII 303, Tafel II, B.

[2] PIPPING, *Zur Phonetik d. finn. Sprache, Unters. mit Hensen's Sprachzeichner*, Mém. de la Soc. finno-ougrienne, XIV Helsingfors, 1899.

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The s follows directly upon the r. The vibrations in the curve are hardly distinguishable and no very definite limit can be set to them.

The n follows immediately on s (Fig. 357, line 14 to end). It occupies an interval of 197$^{\sigma}$. The successive vibrations occupy periods of 4.2, 3.5, 5.1, 3.7, 5.3, 4.1, 4.1, 5.3, 4.2, 4.9, 4.9, 5.3, 5.3, 5.3, 5.3, 5.3, 5.6, 5.3, 5.3, 5.6, 5.6, 5.3, 6.7, 6.3, 6.7, 6.7, 7.0, 7.0, 7.0, 7.0, 7.0, 8.4, 8.8, 8.8, 9.1, 8.8. The maximum amplitude is 0.1^{mm}.

The tracings on Plate I were made with the double recording lever described on p. 59; they belong to *Cock Robin, Series II.* They comprise ɔhi of sɔhim 'saw him' (analyzed and discussed above, pp. 63, 276), o of bow 'bow' (see also pp. 66, 433), au of šraud 'shroud,' o of 'sparrow,' ɔju of 'draw your.' A preliminary study[1] of these curves is here condensed and continued.[2]

The word 'bow' in 'with my bow and arrow' appeared to the ear to be melodious and prolonged; it might even be called mellifluous. The tracing (Plate I) gives the curve of ow. It begins with three faint vibrations that presumably occur as the mouth begins to open. Thereafter the vibrations follow in groups of four, beginning with a length of 5.5^{mm} and decreasing slowly to 4.8^{mm} in the middle of the line; this indicates a cord tone of rising pitch. The cavity tone remains practically constant at 1.5^{mm} for each vibration, or a period of 0.0024$^{\sigma}$ and a frequency of 417.

The amplitude rises steadily to a degree that indicates considerable loudness; it then falls rather suddenly (middle of second line). The vibrations beyond this point show so many peculiarities that their difficulties can best be attacked by working backwards from a later point where the grouping is more regular. About one-third of the distance from the middle in the second line the vibrations fall into groups having two main crests with two subordinate ones. The entire group arises presumably from one cord vibration. This con-

[1] Scripture, *Speech Curves, I.*, Mod. Lang. Notes, 1901 XVI 72.

[2] In this I have been assisted by Miss E. Jelliffe, of Mt. Holyoke Seminary.

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clusion is drawn because further on to the right the group gradually changes to two main crests only, a typical form for a cord tone accompanied by a cavity tone nearly an octave higher. Starting from the strong vibrations (third quarter of line 2), we mark off backward the alternate higher vibrations as the points of maximum for each cord puff. We thus have the vibrations in pairs; the period of the cord tone at any moment will be given by the distance between two such marked vibrations.

As we go towards the left, we see that each of the vibrations of the pair shows a tendency to split up into two minor vibrations; this indicates the presence of higher cavity tones. Measurements of the periods of the cord tone show that it steadily rises in pitch from the middle to the third quarter of the line. They also show that the smaller cavity vibration keeps very closely at the middle of the cord period, though in the first portion it is generally a little behind the middle point. This indicates a cavity tone in general an octave higher than the cord tone, but a little lower in the first portion. The condition of a cord tone with an octave cavity tone is modified in the first part by higher tones that do not form an exact harmonic interval with either of the other tones; these give rise to the minor fluctuations. The higher tones are of changing pitch, as can be seen by the steadily changing form.

The puffs of air from the cords are not generally of the even nature found in sinusoid vibrations; they rather resemble more or less sharp explosions. In this sound they are not so sharply explosive as in au of 'shroud' or æ of 'sparrow,' yet the puff has its greatest intensity in the first part of the interval of time it occupies.

A third maximum is found in the latter portion of 'bow' (third line). This vowel sound is to be considered as a triphthong; careful listening to the gramophone plate enables the ear to hear two maxima clearly and the third faintly. The maxima are due to coincidence of the cavity period with a sub-multiple of the cord period (p. 13). As a triphthong the sound might be writen **oow** or **ouw**.

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The word 'shroud' occurs in 'Who'll make his shroud?' The portion of the record on line 3 and the first quarter of line 4 gives the curve of the r with one pseudobeat (p. 19) at the flat place in line 4. The r-a glide after this is followed by the long record for **au** reaching to the middle of line 5. The latter half of line 5 contains the faint vibrations of the u-d glide, the still fainter ones of the d-occlusion and the strong ones of the d-explosion. After the occlusion of the pseudobeat the tongue again allows the cord-and-cavity vibrations to appear. The form of the vibration is different, indicating a changing adjustment of the mouth from the r-position to the a-position; this portion is to be considered as the r-a glide. There is no possibility of definitely limiting the r from the **a**, or of marking off a distinct **r-a** glide; the change is gradual throughout (p. 451). The **r** shows a rise and fall of amplitude. The occlusion during the one pseudobeat is complete, as indicated by the entire cessation of vibrations near the beginning of line 4. During **au** the cord tone rises from the frequency 120 to 111 and then falls steadily to 92. The diphthong **au** is of circumflex pitch. It is of crescendo-diminuendo intensity, the crescendo being gradual and diminuendo rather sudden. In the **d** the cord tone rises to 109.

The word 'sparrow' occurs in 'I, said the sparrow.' The æ of 'sparrow' begins at the first quarter of the sixth line; it ends in **r** just beyond the third quarter of the same line. The **o** extends over the remainder of this line and the whole of the next. This **o** is quite different from that in 'bow' above. The vowel is a crescendo-diminuendo sound; its amplitude rises slowly to a maximum and then falls to zero. The vowel-sound in 'bow' has three maxima; the fall from the maximum is in two cases very sudden. In general the curve of the **o** of 'sparrow' differs greatly from that of the **o** of 'bow,' although there is some resemblance of the former to the middle portion of the latter.

The cord tone of 'sparrow' has at the beginning a frequency of 125. This frequency increases to 202 and then falls by degrees as low as 136. The amplitude increases slowly, then

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descends suddenly and almost reaches zero at the r; after this the amplitude increases again quite rapidly and continuously during o to a maximum, and then gradually decreases.

The words 'draw your' occur in the introduction 'Now, children, draw your little chairs nearer.' The last five lines of Plate I give the curve for the sounds ɔju, omitting a piece at the end. The recording-surface was run at about three times the speed used for the previous curves. Measurements of the groups of vibrations show that the cord tone rises from about the frequency 75 at the beginning of ɔ (line 8) to about 189 (line 10, first quarter), after which it remains practically constant until it begins to fall in the ɔj glide (line 10, last part). During the j and u the tone seems to fall steadily.

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APPENDIX III

FREE RHYTHMIC ACTION

As a measure of the irregularity in a voluntary act we may use the probable error.[1] When a series of measurable acts are performed they will differ from one another, if the unit of measurement is fine enough. Thus, let $x_1, x_2, \ldots, x_n$ be successive intervals of time marked off by a subject beating time, or walking, or running, at the rate he instinctively takes. The average of the measurements,

$$a = \frac{x_1 + x_2 + \cdots + x_n}{n},$$

can be considered to give the period of natural rhythm under the circumstances. The amount of irregularity in the measurements is to be computed according to the well-known formula

$$p = \tfrac{2}{3}\sqrt{\frac{v_1^2 + v_2^2 + \cdots + v_n^2}{n-1}}$$

where $v_1 = x_1 - a$, $v_2 = x_2 - a$, $\ldots$, $v_n = x_n - a$ The quantity p is known as the 'immediate absolute probable error.' The quantity

$$r = \frac{p}{a},$$

the 'immediate relative probable error,' expresses the probable error as a fraction of the average. Both p and r are

[1] SCRIPTURE, *Observations on rhythmic action*, Science, 1899 X 807; also in Stud. Yale Psych. Lab., 1899 VII 102.

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called 'immediate' in order to distinguish them from the 'final' ones,

$$P = \frac{p}{\sqrt{n}}$$

and

$$R = \frac{r}{\sqrt{n}},$$

used to indicate the precision of the average.

If all errors in the apparatus and the external surroundings have been made negligible, the 'probable error' is a personal quantity, a characteristic of the irregularity of the subject in action. If, as may be readily done, the fluctuations in the action of the limbs of the subject are reduced to a negligible amount, this probable error becomes a central, or subjective, or psychological, quantity. Strange as it may appear, psychologists have never understood the nature and the possibilities of the probable error (or of the related quantities, 'average deviation,' 'mean error,' etc.). In psychological measurements it is — when external sources of fluctuation are rendered negligible — an expression for the irregularity of the subject's mental processes. Nervous or excitable people invariably have large relative probable errors; phlegmatic people have small ones. Thus a person with a probable error of 25% in simple reaction time will invariably have a large error in tapping on a telegraph key, in squeezing a dynamometer, and so on. I have repeatedly verified this in groups of students passing through a series of exercises in psychological measurements. I do not believe it going too far to use the probable error as a *measure* of a person's irregularity. This is equivalent to asserting that a person with a probable error twice as large as another's is twice as irregular, or that, if a person's probable error in beating time at one interval is r_1 and at another interval r_2, his irregularity is r_2/r_1 times as great in the second case as in the first. This concept is analogous to that of precision in measurements. We might use the reciprocal of the probable error as a measure of

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regularity. The positive concept, however, is in most minds the deviation, variation or irregularity, and not the lack of deviation, the non-variability, or the regularity. In the case of the word 'irregularity' the negative word is applied to a concept that is naturally positive in the average mind.

The irregularity in an act is a good expression of its difficulty. Thus, if a person beating time at the interval T has an irregularity measured by the relative probable error R and at the interval t by the relative probable error r, it seems justifiable to say that the interval t is $\frac{r}{R}$ times as difficult as T. If T is the natural interval selected by the subject, then the artificial interval t would be more difficult than T, and we should measure the difficulty by comparing probable errors.

It is now possible to state with some definiteness the law of difficulty for free rhythmic action. Let T be the natural period and let its relative probable error — that is, its difficulty — be r. It has already been observed [1] that any other larger or smaller period (slower or faster beating) will be more difficult than the natural one and will have a larger probable error. Thus any interval t will have a relative probable error r' which is greater than r, regardless of whether t is larger or smaller than T.

Continued observations during several years enable me to give an idea of the general relation. The results observed can be fairly well expressed by the law

$$r' = r\left(1 + c\frac{[t - T]^2}{t}\right),$$

in which T is the natural period, r the relative probable error for T, t any arbitrary period, r' the relative probable error for t, and c a personal constant.

This may be called the law of difficulty in free rhythmic action. A curve expressing the equation for $T = 1.0^s$, $r =$

[1] SCRIPTURE, *The law of rhythmic action*, Science, 1896 IV 535.

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0.02^s and $c = 1$ is given in Fig. 360. It will be noticed that periods differing but little from the natural one are not much more difficult and that the difficulty increases more rapidly for smaller than for larger periods. In plotting this curve I have assumed unity as the value for all personal constants. These personal constants will undoubtedly vary for different persons, for different occasions and for different forms of action.

In case it is desired to know what periods are of a difficulty 2, 3, . . ., n times that of T, a table of values for p may

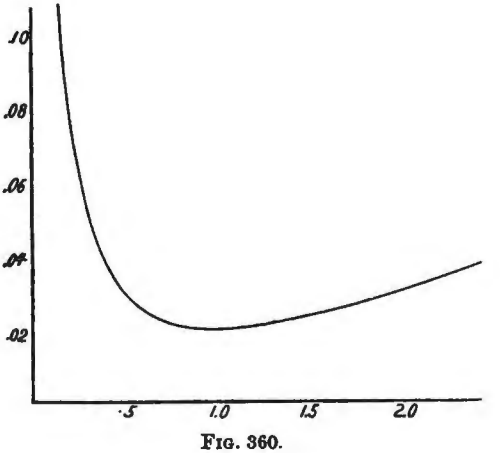

FIG. 360.

be drawn up in the usual way and tha value for t sought for (with interpolation) which gives for r' a value 2, 3, . . . , n times as great. Thus, in a table for the above example it is found that the periods 0.38^s and 2.6^s are twice as difficult.

This law can be stated in another form which is of special interest to the psychologist. To the person beating time a period of 0 is just as far removed from his natural period as one of ∞; both are infinitely impossible. The scale of seconds does not express this fact; objectively a period of 0 is as different from a period of 1^s as a period of 2^s would be. Similar considerations hold good for the lesser periods; the scale by which the mind estimates periods is different from

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their objective scale. This difference may be expressed by asserting that the following relations exist between the two:

$$x = c\frac{(t-T)^2}{t},$$

where x is the measure on the mental scale, T the natural period, t any other period, and c a personal constant. By this formula the various periods may be laid off according to their mental differences from the natural period. Every difference from the natural period is mentally a positive matter. With the mental scale the law of difficulty becomes

$$r' = r(1 + cx),$$

where r' and r are the relative probable errors for t and T respectively, x the measure on the mental scale, and c a personal constant. This is the equation of a straight line. The law states that the difficulty of any arbitrary period is directly proportional to its mental difference from the natural period.

This law of difficulty as depending on the period is, of course, only one of the laws of free rhythmic action. It is quite desirable that other laws of difficulty and of frequency should be determined. For example, observations on ergograph experiments tend to show that the irregularity and the natural period both change with the weight moved; they also change with the extent of the movement.

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ADDITIONS AND CORRECTIONS

Page 24. — HERMANN's earlier records were made by a beam of light reflected from a mirror attached to a diaphragm ; see first four references in note 1 on page 38.

Page 32. — A simpler and better form of recorder has lately been devised for the phonograph. The sapphire knife is fastened to a mica diaphragm with no intervening link.

Page 36. — The earliest reference to the use of large cylinders for the phonograph seems to be DUSSAUD, *De l'amplification des sons dans les phonographes*, C. r. Acad. Sci. Paris, 1899 CXXVIII 552.

Page 37. — To note 3 add BOEKE, *On the derivation of the curves of vowel sounds by means of microscopical research of their phonograms*, Proc. Roy. Soc. Edin., 1897-98 XXII 88.

Page 42. — The record for χ shows pseudobeats resembling those of uvula r ; see also p. 461.

Page 61. — Gramophone (or zonophone) discs are now made of large diameter ; the records are remarkably clear and truthful. Discs containing typical English sounds are now being traced off.

Page 63. — The statement concerning **sohim** should be corrected as indicated on page 277.

Page 75. — The results of the analysis of the curve in Fig. 49 are not correctly given ; see pp. 567, 572.

Page 248. — The pull on the tongue must modify to some extent the adjustments of the larynx.

Page 313. — In Figs. 192 and 193, ca, ɟa should be ca, ɟa.

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PHONETIC SYMBOLS

Some of the less frequently used symbols are not included in this list; their meanings are explained in the text.

The following language-names are abbreviated to their initial letters: American English, British English, English, French, German.

a — A. '*y*acht, *a*h.'
æ — E. '*p*at,' A. '*p*ass.'
b — E. b.
β — Dutch w.
c — surd palatal occlusive.
ç — G. 'rec*h*t, bü*ch*er.'
č — E. ch.
d — E. d, F. d.
δ — mouillé d.
ð — E. sonant th.
e — F. é, è, G. eh, ä.
ə — E. 'h*e*r, f*u*ngus,' F. 'pre*e*mier,' G. 'geb*i*rge.'
f — E. f, F. f.
g — E. "hard" g.
ɣ — mouillé g.
γ — sonant fricative in G. 'sa*g*e.'
h — E. h, G. h.
i — E. 'p*i*ck, p*i*que,' F. 'p*i*que.'
ɟ — sonant palatal occlusive.
j — North G. '*j*äger.'
ȷ — E. '*y*et,' F. 'l*i*eu.'
ʝ — E. j.
k — E. k.
ĸ — a k-sound (k, ĸ, c).
ĸ — mouillé k.
χ — G. 'ac*h*t, bu*ch*.'
ξ — mouillé χ.
l — E. l, F. l.
ʎ — mouillé l.
m — E. m.
n — E. n, F. n.
ñ — mouillé n.
ŋ — E. 'si*ng*er, fi*n*ger, si*nk*.'
ɲ — mouillé ŋ.
o — F. o, G. o.
ɔ — E. 'gn*aw*ed,' B. 'n*o*d.'
œ — F. eu, G. ö.
p — E. p.
ɸ — Japanese f.
r — flapped r.
ɹ — unflapped r.
s — E. surd s.
σ — mouillé s.
š — E. sh, F. ch, G. sch.
ǒ — mouillé š.
t — E. t, F. t.
ᴛ — a t-sound (t, τ).
τ — mouillé t.
θ — E. surd th.
u — F. ou, G. u.
v — E. v, F. v.
w — E. '*w*ay,' F. 'l*oi*, l*ou*is.'

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beginning of the record appears under the magnifying glass like the drawing in Fig. 351. The dots indicate intervals of 1^{σ} ($^{\sigma} = 0.001^{s}$).

This word 'I' occupies an interval of 452^{σ}. It is preceded by a silent interval of 770^{σ}, or about $\frac{3}{4}$ of a second; this is the full stop in the stanza after the question is asked and before the answer is given. It is followed by a silent interval of 210^{σ}.

The beginning of the a is apparently clear, that is, it is not preceded by any breathing. The vocal cords are apparently adjusted for voice production before the expiration begins; the vowel starts with a light vibration of the cords. There is no explosive sound, or glottal catch, before the vowel.

The vowel a begins with a movement of the vocal cords by which an extremely weak puff of air is emitted. This puff



FIG. 351.

of air passing through the cavity of the mouth arouses three or four oscillations of the air contained in it. There is first a half-oscillation of weak amplitude, then a comparatively strong oscillation, followed by very weak ones. Even the strongest is, however, very weak; the following oscillations are so weak as to be hardly perceptible. The cavity vibrations disappear and there is an interval of silence before the second puff appears. Then the cords emit another puff of air a trifle stronger than the first, the time from puff to puff being 18^{σ}. The six cavity vibrations are slightly stronger than before. The period of silence is shorter than before. The third puff occurs 11^{σ} after the second one. The cavity vibrations are a trifle stronger still; there are seven of them with a brief interval of silence. The fourth puff begins at 10^{σ} after the beginning of the third one. The fourth puff contains eight cavity vibrations, all slightly stronger than before; there is no interval of silence because the fifth puff

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begins just as the last cavity vibration of the fourth puff ends. The interval occupied by the fourth puff is 9^{σ}.

It is a characteristic trait of this particular a that each group of cavity vibrations is strongest at the start; this indicates a sudden and complete opening of the cords (p. 260). The quickest opening requires, however, a little time and there must be a measurable change from no passage of air to full passage; this is shown by the weak half of the first cavity vibration preceding the large half. The form of vibration probably indicates a complete closure of the cords whereby they actually touch each other after the puff is emitted.

The cavity vibration in the first part of the word has a period of 1^{σ} or a frequency of 1000.



FIG. 352.

As the period of the cord tone becomes shorter, the number of cavity vibrations to each period becomes smaller. Beyond the 30th puff of the cord tone the cavity vibrations show a lengthening of period. In the 39th cord vibration the cavity tone reaches a period of 2.2^{σ} or a frequency of about 450; it thus falls more than an octave in the time of nine cord puffs, or, in this case, in 33^{σ}. Here the cavity tone is nearly but not quite of the same period as the octave, 2^{σ}, of the cord tone, 4^{σ}. This change is shown in the hand-drawing, Fig. 352, which begins with the 31st vibration. This relation between cavity tone and cord tone is maintained to the end of the word; the rest of the curve shows the peculiar alternation of waves seen in the last two vibrations in Fig. 352.

The vibrations up to the 31st unquestionably belong to the a. In the vibrations beyond the 39th both the cord tone and the cavity tone are constant, except for a slight fall at the

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end. They unquestionably belong to the i. The vibrations from the 31st to the 39th show a constant cord tone and a falling cavity tone. They are presumably to be considered as belonging to the 'glide.' During the a the cords have been stretched more and more, until at the 31st vibration they reach the tension required for the i; the only further change necessary is the lowering of the cavity tone.

Beyond the portion shown in Fig. 352 the curve shows strong vibrations so nearly alike that one is naturally induced to consider each one a cord vibration. This would not be proper because close inspection of Fig. 350 shows that succeeding vibrations differ slightly, while alternate ones are alike. This likeness of all the cavity vibrations in the i as contrasted with the a is probably due also to a difference in the action of the cords; this difference appears more clearly in the word 'eye' analyzed below.

With the understanding that no definite limit can properly be made between one sound and the neighboring one in this case, we may, in view of the facts just mentioned, consider the a to have occupied the time 203^{σ} ending with the 30th puff, the glide to have occupied 33^{σ} ending with the 38th puff, and the i to have occupied the remaining 216^{σ}.

The cavity tone of the i is one of about 450 frequency. This cavity tone is much lower than the very high tone assigned to i by HERMANN and others, but is not so low as those assigned by some other observers. There is, however, the possibility of different tones in the vowels from different speakers, and also that of several cavity tones in the same vowel. By careful examination of the curves I find them often marked by small additional vibrations. These are frequently quite prominent in the i of ai. Their fineness rendered it impossible to settle on any definite period for them.

Beginning with a period of 18^{σ}, the cord tone changes slowly through 11, 10, 9, 8, 7^{σ}, reaching 6^{σ} at the 11th vibration, 5^{σ} at the 15th, 4^{σ} at the 30th; the period of 4^{σ} is maintained to about the 100th vibration, after which it falls

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slightly to 4.2^{v} during the last seven vibrations. In other words, the pitch glides slowly upward from a tone of 56 complete vibrations per second to one of 200 a second, then more slowly to one of 250 a second, at which it remains constant except for a slight drop as the diphthong ends.

The changes of pitch in the cord tone and the cavity tones are indicated in a general way in Plate XV.

The amplitude of a vibration is the distance from the position of equilibrium to the extreme position on either side; it is thus one-half the difference in altitude between the crest and the trough of a wave. The initial cavity vibration of the first puff of this a has an amplitude of less than 0.1^{mm}. This slowly increases to 0.3^{mm} at the 20th vibration, after which it sinks only a little to the 38th. Beyond the 38th, that is, from the beginning of the i, the amplitude rapidly increases from 0.3^{mm} to 0.7^{mm} at the 50th vibration; thereafter it slowly sinks, becoming 0.3^{mm} at the 60th vibration and 0.2^{mm} at the 80th, 0.1^{mm} at the 88th and 0 at the 96th. The maximum for the i is 2$\frac{1}{3}$ times that for the a. The course of change in amplitude is given in Plate XVI. The horizontal scale is greater than that for the pitch curve in Plate XV.

The word ai ends by a gradual cessation of the expiratory impulse with hardly a noticeable change in the tension of the vocal cords; this is the clear ending usual in English. The slight fall in pitch of the i toward the end indicates a change that may be apparent in the auditory effect of the word, although it cannot be distinguished separately. It is probably due to a relaxation of the cords.

To the ear the sound of this word 'I' appears from the record 'colorless, without emotion, without inflectional rise or fall within the word, a monotone'; 'a mild statement.' The mildness of this word seems related to its length and its gradual changes in pitch and intensity.

In the original monograph the details of several other examples of ai are given as for this first one. The curves of pitch for all of them are given in Plate XV, those of am-

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plitude in Plate XVI; the horizontal scale for all except the last two figures on Plate XVI is twice that used in Plate XV.

Thirteen cases of 'I' from the *Cock Robin* record were studied. In general the fundamental characteristics already considered were found in all. Some peculiarities, however, are to be noted.

For convenience the term 'primary' will be applied to the strongest one in a group of cavity vibrations, and 'secondary' to the others. In the first ai the primary is the first of the group.

In the 4th 'I,' of 'I saw him die,' one of the secondaries appears almost as strong as the primary. This large secondary keeps at the same distance behind the primary. As the pitch of the cord tone rises, the primaries come closer together; the large secondary, being at a constant interval behind the preceding primary, thus comes steadily closer to the following primary until it disappears in it.

I do not believe that this larger secondary is due to an overtone-vibration of the cords. The curves in such a case would show the first overtone-vibration always half-way between the two primaries. In the curve for this vowel the strong secondary keeps at the same distance after the preceding primary, while the distance to the following primary steadily decreases.

It might be suggested that the primary and the strong secondary may represent two waves of a lower cavity tone, while the primary and the other secondaries represent the waves of a higher one; the lower tone would have a period of $3\frac{1}{2}^{\sigma}$ or a frequency of about 286. There would then be at least three tones present in the a: the rising cord tone; the lower cavity tone of 286, which finally coincides with the cord tone; and the higher cavity tone of 1000.

This large secondary appears strongly in most cases of ai in the *Cock Robin* records, but also sometimes weakly (Fig. 350 above; also 'I' in Plate II) and sometimes not at all (see table of tones, p. 587; also 'my' in Plate II).

Sometimes the first period of the cord tone is shorter than the

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following one. This occurs, for example, in ' I 'll make his shroud,' and ' I 'll be the parson.' In the former case the periods are 9.8^{σ}, 11.6^{σ}, 10.9^{σ}, 9.8^{σ}, etc., and in the latter 8.1^{σ}, 10.5^{σ}, 9.8^{σ}, 8.8^{σ}, 8.8^{σ}, 8.1^{σ}, etc. The cords seem to receive an excess of tension before the breath begins, and to be then relaxed to the tension desired.

In one case the fall of the upper cavity tone appears to take place from the very beginning of the word; the cavity tone is thus steadily falling, while the cord tone is steadily rising.

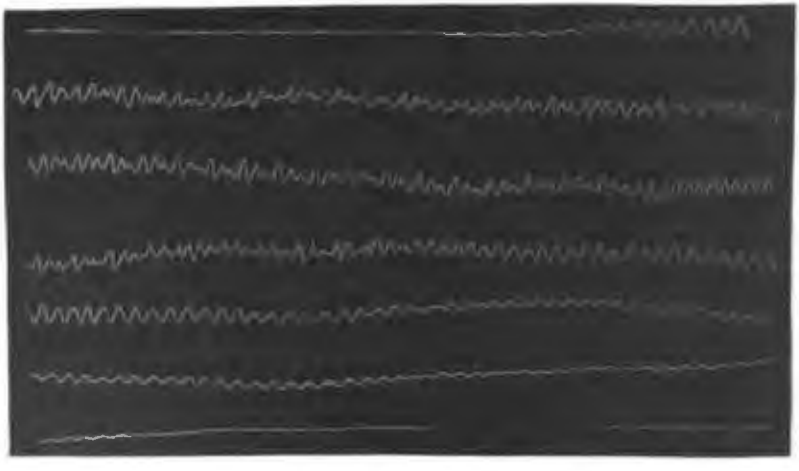

FIG. 353.

This occurs in the a of ' I ' in ' I, said the fish.' The period of the cavity tone begins with 1.4^{σ}, reaches 1.5^{σ} at about the 10th vibration, 1.8^{σ} at the 40th vibration and then remains constant to the end of the word. The cord tone, however, starts low and rises.

The curve for ai of ' eye ' in the phrase ' with my little eye ' follows immediately on the last vibration of the final l in the word ' little.' The three words ' my little eye ' are here spoken with no separation. It is interesting, in passing, to consider the possibility that this fusion of the three words goes parallel to a fusion of thought. It is evident

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from the very tone of the speaker that he is thinking of one thing, a certain ' eye,' and that the facts of ' being mine ' and ' smallness ' are not of any particular account to him (p. 126).

The curve for dai in ' Who saw him die? ' is given in Fig. 353. The word begins with 20 vibrations belonging to the d. These vibrations have a period of 2.0^{σ} or a frequency of 500. The a begins promptly and loudly, as might be expected from the fact that the expiration is already in progress and the cords are in vibration. The cord tone of the a in the first vibration is higher than in the subsequent vibrations, as might be expected on the assumption that the cords are already stretched to give a period of 2.0^{σ} for the d, and must



FIG. 354.

be relaxed to produce the lower tone of the a. While this relaxation is going on, the cords must pass through all intermediate positions between that for a period of 2.0^{σ} and that for one of 3.2^{σ}. This occurs to a large extent apparently within the time required for one vibration of the d. At the same time the mouth is changing from the d position to the a position. These facts seem sufficient to explain the curve at the change from d to a, shown in the drawing, Fig. 354; the three vibrations on the left are the last of the d, the strong one on the right is the primary cavity vibration of the first puff of the a, and the connecting line shows the curve during the glide.

The curve of dai in ' I saw him die ' is given in Fig. 355. The word begins with 11 vibrations rapidly increasing in amplitude from 0 to 0.4^{m} and having a constant period of 2.5^{σ}, or frequency of 400. These are the vibrations for the

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d; they resemble those of dai in the first example. The sudden fall in pitch after the d is quite marked. The d curve is lost at once. The following interval of 7$^{\sigma}$ can hardly be said to be the first vibration of a, as its secondaries are very irregular in form; during this interval the mouth is changing from the d shape to the a shape. The peculiar form of the vibrations of this glide is well shown in the figure.

The a curve differs from that of most cases of ai, in having less difference between the primary cavity vibration and the rest; the first and second in a group are, in fact, of almost equal intensity. The curve changes from the a form to the

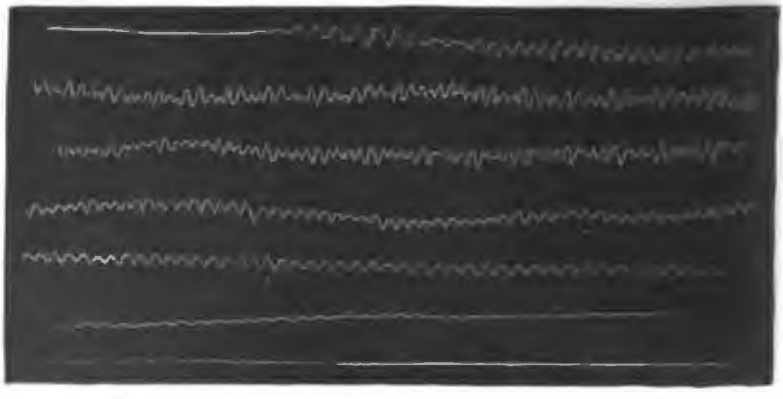

FIG. 355.

i form so gradually that it is quite impossible to place any dividing line; each element of the diphthong may be said roughly to occupy half the total time.

The curve for lai of 'fly' in 'I, said the fly' is shown in Fig. 356. No specific details concerning the f can be derived from the curve. The strong vibrations just preceding those of the a are presumably from the l sound. They rise rapidly in intensity and greatly resemble those of the d in the two cases of dai above; their period is 1.9$^{\sigma}$ and their frequency 526. Immediately after the last vibration of the l there follows a short a puff with the primary cavity vibration not so strong as in the following puffs. The cord ad-

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justment seems not to be perfected for the a till the second characteristic a puff occurs.

The curve of 'thy' in 'hallowed be thy name' begins with 7 vibrations belonging to ð having a period of 2.5$^{\sigma}$ or a frequency of 400. The beginning of the a is prompt and loud.

The curve of 'thy' in 'Thy kingdom come' shows 6 faint vibrations at the beginning belonging to the ð and having a period of 2.8$^{\sigma}$. The curve of the a suggests a more gradual



FIG. 356.

opening of the cords and a less explosive effect. There is no strong secondary of the kind described on p. 581.

A comparison among the curves of pitch given in Plate XV shows that general resemblances occur among most of the curves of pitch for the cord tone in the cases of 'I.' In 'eye' the curve differs radically from all the other examples; it starts with a moderately high pitch and falls continuously. There is the possibility that the fall in pitch in this word may have something to do with its position at the end of a phrase. If the word had been followed by a long pause, it would naturally have fallen on account of its position at the end of a sentence; the pause, however, was extremely short

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and we cannot very well assume a short pause as the equivalent of a full stop unless we give up entirely the theory of relation between punctuation and time. It is, nevertheless, possible that this theory may have to be modified, as later researches have shown that comma pauses may be long and semi-colon and colon pauses may be very short. The upper cavity tone is to some degree stable in the two end portions of all cases in Plate XV, but undergoes a more or less rapid change within the various words. The lower cavity tone is constant when it is present.

Both the ear and the curves indicate that the first part of the diphthong in the cases just studied is to be considered a form of a as in 'parson.' The second part is probably i as in 'kin' in all cases except the second 'thy.' In this last case the cavity tone differs greatly from all the others; the sound may be e as in 'let.' The difference between the two cases of 'thy' may arise from the following sound; the forward contact of n favors an i while the backward one of k favors an e.

Various words like 'ein,' 'weisser,' 'Eis,' 'Zeiten,' 'Schein,' etc., were closely studied in the tracings from disc number 1500, *Die Lorelei und Der Fichtenbaum*, by W. L. ELTERICH. When examined under the magnifying glass, the a portion of the record showed in most cases curves analogous to those in the cases of 'I,' whereas the i portion was extremely weak. This peculiarity of the weak i in the German ai and the very strong i in most cases of the American ai gives the former the effect of containing a longer a. It must be noted, however, that many sounds usually treated as the same are really different. Thus the vowel of 'weiss' in 'Ich weiss nicht was soll es bedeuten' gave a curve differing greatly in character from that of 'weisser' and the other words mentioned above. Again, some of the cases of the American ai described above showed a weakening of the i that indicates a tendency toward the German form.

The analyses show that ai is not the sum of the two vowels a and i, but an organic union into a new sound $\bar{ai}$.

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There is no necessary pause or very sudden change of intensity or change in pitch or even change in character. This is what would be expected on psychological grounds. The speaker does not think of and speak two sounds separately but only one; the execution of this one impulse by two distinct processes would be unusual. The various degrees of perfection of the synthesis of the two elements would correspond to various expressive characters of the resulting sounds.

In so far as they can be considered to be constant, the cavity tones in these cases of the a and the i were found to be as in the following table.

	Tone of	*Tones of the* a.				*Tones of the* i.	
	d, l, ð.	Cord, start.	Cord, end.	Lower cavity.	Upper cavity.	Cord.	Cavity.
I, 1st example		56	250	286	1000	250	450
I, 2d "		83	250	286	1000	250	555
I, 3d "		131	250	286	1000	250	500
I, 4th "		111	286	286	1000	286	400
I, prose "		102	180	360	1000	180	360
Eye,		400	160	435	1000	160	476
Die, 1st example	500	179	200		1000	200	473
Die, 2d "	400	217	133		1000	133	473
Fly,	526	160	204	256	625	256	500
Thy, 1st example	400	143	149		588	149	416
Thy, 2d "	417	84	143		416	143	288

The following view of the physiological action of the vocal cavities in producing ai in the cases studied above may be proposed tentatively. The depressed position of the tongue for the a (Plate XXV) leaves open a large cavity reaching from the teeth to the vocal cords; the uvula offers no great interruption. The lower cavity tone of the a may be considered to arise from the vibration in this cavity. The upper cavity tone of the a may be supposed to arise from the rear cavity, that is, the throat cavity from the cords to the slight elevation of the tongue at the uvula. As the a changes to i (Plate XXVI) this elevation of the tongue moves forward, enlarging the rear cavity by including more and more of the mouth; this continuously lowers the upper cavity tone until the tongue comes to rest in the typical i position.

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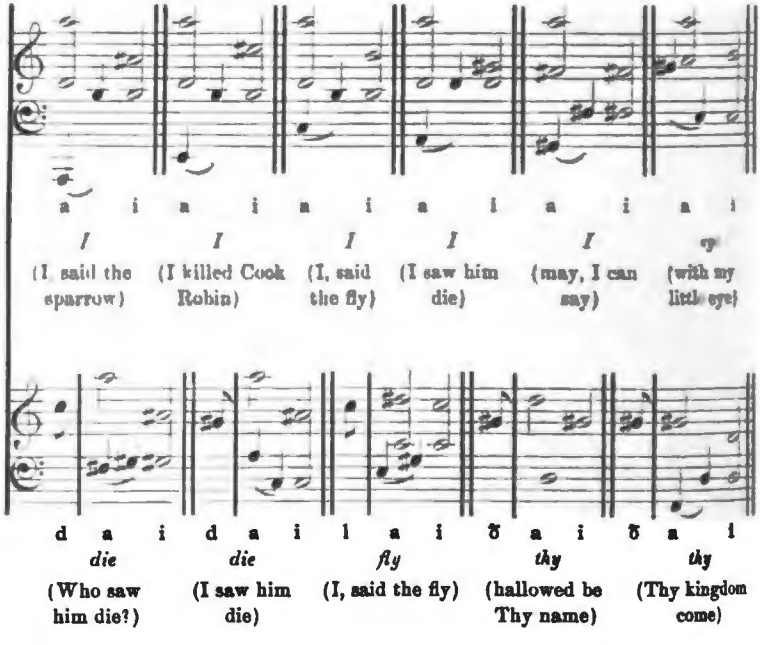
Another theory is possible. The lower cavity tone of the a may be assigned to the trachea (p. 294); the rise and fall of the larynx may explain the differences among the various cases. This view is favored by the constant character of the tone within each case (see dash-line in Plate XV). The higher cavity tone for a is then to be assigned to the mouth cavity. The resonance tone of i, as found in these records, is probably from the mouth, the effective capacity of the rear cavity being increased from a to i.



In all cases of ai there is no sudden jump of the cord tone; the i continues the cord tone of the a, forming with it the easiest musical interval, a unison. This tone is, however, different in different cases; the cord tone of the a rises to a certain point selected for that of the i. The selection of the pitch of the cord tone for the i is influenced by the preceding cavity tones of the a, as may be seen from the table. A

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study of these tones reveals some tendency toward musical relations within each ai. This probably is one of the factors of the musical character of the voice of this speaker. The musical relations are roughly indicated in the accompanying notation; the lowest notes indicate the cord tone, the others the cavity tones.

In ai of 'die,' in a manometric flame record (p. 29) sent me by NICHOLS and MERRITT, I find a cord tone rising through 7.5, 5.2, 4.8, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6^{mm}, at which point the record is cut off. In another example of ai in 'die' the cord tone rises more slowly through 6.1, 6.0, 5.8, 5.7, 5.6, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5, 5.5 (the 18th vibration), at which point the record is cut off. The beginning is thus like that in the cases studied above.

A curve of 'fly' has been sent me by Prof. BEVIER (p. 49) with the explanation that the a appears to change gradually through æ (as in 'hat') to e (as in 'let'); that the two cavity tones of a are of 600 and 1150 frequency; that those of e are of about 600 and 1700; that the entire sound lasts 0.32^s, including 0.09^s for a, 0.11^s for æ, 0.12^s for e; and that the maximum amplitude lies in the a. This example of ae resembles the diphthong of the second 'thy' above.

Some of the characteristics of fusion (Ch. XXX) may be illustrated by the following study of the phrase 'Who 'll be the parson?' of *Cock Robin, Series I.*[1] The entire curve is given in Fig. 357; an inspection of the curve shows the arbitrary nature of the divisions into vowels, glides, etc.

The breathing h probably does not appear in the record. The vibrations in line 1 may perhaps be considered as belonging to the passage from h to u, or the h-u glide. They show cavity vibrations beginning with a period of 2.8$^\sigma$ and shortening to 2.5$^\sigma$. It is impossible to say definitely whether or not they are in groups that indicate cord vibrations. The first two vibrations in line 2 have periods of 2.3$^\sigma$; they

[1] In the following phonetic analysis of a complete phrase I have been assisted by Miss E. M. COMSTOCK.

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FIG. 357.

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are also cavity vibrations. Thereafter the cavity vibrations remain practically constant at 1.9^{σ} and are found in groups clearly indicating a cord tone; they belong to the u.

The curve for the u (lines 2 and 3) closely resembles that for ai in its general character. The first part shows a rising cord tone and a nearly constant but afterwards falling cavity tone. In the latter portion the cord tone is approximately constant while the cavity tone falls. The change in the character of the action of the cords appears clearly also as in ai (p. 578). It is, in fact, very evident that this sound is somewhat diphthongal with possibly less difference between the two elements than in the case of ai. This diphthongal character of the English u is well known to phoneticians; the sound is generally indicated as uw.

The curve at the beginning of the u shows a vibration of 6.3^{σ} from the vocal cords acting on a cavity whose period 1.9^{σ} is not a sub-multiple of the cord period. As the cord period is gradually shortened, the cavity period (remaining the same) steadily modifies the form of the resultant vibration, and the curve is seen to change its form gradually. The relation between cord tone and cavity tone is closely analogous to that in the a of ai.

The successive vibrations of the u occupy the periods of 6.3, 6.1, 6.1, 5.6, 5.4, 5.4, 4.9, 4.9, 4.9, 4.9, 4.9, 4.6, 4.6, 4.6, 4.2, 4.2, 4.2, 4.2, 4.2, 4.2, 4.2, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6, 4.6^{σ}. The total time occupied by the u is 167^{σ}.

The u thus shows a tightening of the cords to the tension necessary for a tone with a period of 6.3^{σ}, and thereafter a gradual increase of tension to a maximum represented by 4.2^{σ}; after this there is a fall to 4.6^{σ}, at which the tone remains constant.

The cavity tone begins with period of 1.9^{σ}, or a frequency of 526, or at approximately c^2. It is, however, not constant throughout the u in this case. This is especially evident during the last part where the cord tone is constant. In this region the curve steadily changes its form from the

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earlier u form toward the l form; during the last eight or ten cord vibrations it is difficult to say whether the curve belongs to the u or the l. The cord vibrations of the u persist in their own constant period, however, to a point which can be detected. We are thus justified in attributing these vibrations to the u although the mouth cavity has been presumably steadily shaping itself for another sound. The cavity tone thus rises toward the end.

Repeatedly observed facts of this kind have forced upon me the belief that the view of a word as composed of a set of fixed sounds with glides between them is a somewhat inadequate one. It is derived from the attempt to get away from the artificial character of spelling, but it still largely retains that character. The usual view of the words ' who 'll ' would represent them as composed of h—glide—u—glide—l. The vocal organs are supposed to occupy three distinct positions, the glides representing the intermediate positions during the moments of change.

A somewhat different view seems better fitted to the actual curves. The unit of speech is sometimes a phrase, sometimes a word, and never a vowel or a consonant unless this is at the same time a word. In speaking a word the vocal organs pass through a series of positions of a special character without stopping in any one position. Thus the words ' who 'll ' represent a continuous change in the force of expiration following a definite plan, also a continuous change in the tension of the vocal cords, likewise continuous movements of the parts of the mouth. The force of expiration rises to a maximum of 35$^{\sigma}$ in the h-u glide, continues with slight fluctuation during 171$^{\sigma}$ in the glide and u, and finally dies away at 277$^{\sigma}$ at the end of the l. Before the breath begins the mouth has adjusted itself to a tone of a period of 2.8$^{\sigma}$; this position changes very slightly during the 35$^{\sigma}$ of h; then it makes a rapid change through 2.3, 2.1 to 1.9$^{\sigma}$ in the u, remains constant during 167$^{\sigma}$, and rises suddenly to the mouth tone of the l (not determinable here).

The cord tone has a somewhat similar course. It begins

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ʍ — surd w.
y — F. u, G. ü.
ɥ — F. 'lui.'
z — E. z, F. z.

ʒ — mouillé z.
ž — E. 'vision,' F. j.
ǯ — mouillé ž.
ʾ — G. 'be()enden.'

Smaller letters on the line indicate weak sounds.

ʰ — aspiration, as in G. 't()at().'

ⁿ — nasal modification of preceding sound.

ᵇ — labial " " " "

ʲ — palatal " " " "

ₑ — sonant " " " "

ₒ — surd " " " "

The combination ₑₒ means that the sound is partly sonant, partly surd.

₁, ₂, ₃, etc. are sometimes used to indicate different varieties of a sound, as explained in text.

Quantity is sometimes roughly indicated by the macron (long) and breve (short).

Accent is occasionally marked by an acute over the vowel.

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Followed in this book.	German.	French.	Frequency, complete vibrations (even temperament).	Frequency, half vibrations (even temperament) [French].	Frequency, complete vibrations (physical or mathematical scale).	Followed in this book.	German.	Frequency, complete vibrations (even temperament).
c^5	c''''	ut_7	4138.4	8276.5	4096	$c^{5\sharp}$	cis''''	4384.5
b^4	h''' Viergestrichene Octave	si_6	3906.2	7812.4	3840			
a^4	a'''	la_6	3480.0	7360.0	3413⅓	$a^{4\sharp}$	ais''''	3686.9
g^4	g'''	sol_6	3100.3	6200.7	3072	$g^{4\sharp}$	gis''''	3284.7
f^4 Fourth octave	f'''	fa_6	2762.1	5524.1	2730⅔	$f^{4\sharp}$	fis''''	2926.3
e^4	e'''	mi_6	2607.1	5214.1	2560			
d^4	d''''	$ré_6$	2322.6	4645.2	2304	$d^{4\sharp}$	dis''''	2460.7
c^4	c''''	ut_6	2069.2	4138.4	2048	$c^{4\sharp}$	cis''''	2192.3
b^3	h''' Dreigestrichene Octave	si_5	1953.1	3906.2	1920			
a^3	a'''	la_5	1740.0	3480.0	1706⅔	$a^{3\sharp}$	ais'''	1843.7
g^3	g'''	sol_5	1550.2	3100.3	1536	$g^{3\sharp}$	gis'''	1642.3
f^3 Third octave	f'''	fa_5	1381.0	2762.1	1365⅓	$f^{3\sharp}$	fis'''	1463.2
e^3	e'''	mi_5	1303.5	2607.1	1280			
d^3	d'''	$ré_5$	1161.3	2322.6	1152	$d^{3\sharp}$	dis'''	1230.4
c^3	c'''	ut_5	1034.6	2069.2	1024	$c^{3\sharp}$	cis'''	1096.1
b^2	h'' Zweigestrichene Octave	si_4	976.5	1953.1	960			
a^2	a''	la_4	870.0	1740.0	853⅓	$a^{2\sharp}$	ais''	921.7
g^2 Second octave	g''	sol_4	775.1	1550.2	768	$g^{2\sharp}$	gis''	821.2
f^2	f''	fa_4	690.5	1381.0	682⅔	$f^{2\sharp}$	fis''	731.6
e^2	e''	mi_4	651.8	1303.5	640			
d^2	d''	$ré_4$	580.7	1161.3	576	$d^{2\sharp}$	dis''	615.2

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First octave	Zero octave	First negative octave	Second negative octave	Eingestrichene Octave	Ungestrichene Octave	Grosse Octave	Contra Octave				
b^1	b^0	b^{-1}		h'	h	H	H_1	si_3	488.2	976.5	480
a^1	a^0	a^{-1}		a'	a	A	A_1	la_3	435.0	870.0	$426\frac{2}{3}$
g^1	g^0	g^{-1}		g'	g	G	G_1	sol_3	387.5	775.1	384
f^1	f^0	f^{-1}		f'	f	F	F_1	fa_3	345.3	690.5	$341\frac{1}{3}$
e^1	e^0	e^{-1}		e'	e	E	E_1	mi_3	325.9	651.8	320
d^1	d^0	d^{-1}	d^{-2}	d'	d	D	D_1	$ré_3$	290.3	580.7	288
c^1	c^0	c^{-1}	c^{-2}	c'	c	C	C_1	ut_3	258.7	517.3	256
								si_2	244.1	488.2	240
								la_2	217.5	435.0	$213\frac{1}{3}$
								sol_2	193.8	387.5	192
								fa_2	172.6	345.3	$170\frac{2}{3}$
								mi_2	162.9	325.9	160
								$ré_2$	145.2	290.3	144
								ut_2	129.3	258.7	128
								si_1	122.1	244.1	120
								la_1	108.8	217.5	$106\frac{2}{3}$
								sol_1	96.9	193.8	96
								fa_1	86.3	172.6	$85\frac{1}{3}$
								mi_1	81.5	162.9	80
								$ré_1$	72.6	145.2	72
								ut_1	64.7	129.3	64
								si_{-1}	61.0	122.1	60
								la_{-1}	54.4	108.8	$53\frac{1}{3}$
								sol_{-1}	48.4	96.9	48
								fa_{-1}	43.2	86.3	$42\frac{2}{3}$
								mi_{-1}	40.8	81.5	40
								$ré_{-1}$	36.3	72.6	36
								ut_{-1}	32.3	64.7	32

$a^{1\sharp}$	*ais'*		460.9
$g^{1\sharp}$	*gis'*		410.6
$f^{1\sharp}$	*fis'*		365.7
$d^{1\sharp}$	*dis'*		307.6
$c^{1\sharp}$	*cis'*		274.0
$a^{0\sharp}$	*ais*		230.4
$g^{0\sharp}$	*gis*		205.3
$f^{0\sharp}$	*fis*		182.9
$d^{0\sharp}$	*dis*		154.0
$c^{0\sharp}$	*cis*		137.0
$a^{-1\sharp}$	*Ais*		115.2
$g^{-1\sharp}$	*Gis*		102.6
$f^{-1\sharp}$	*Fis*		91.4
$d^{-1\sharp}$	*Dis*		76.0
$c^{-1\sharp}$	*Cis*		68.5
$a^{-2\sharp}$	*Ais'*		57.6
$g^{-2\sharp}$	*Gis'*		51.3
$f^{-2\sharp}$	*Fis'*		45.7
$d^{-2\sharp}$	*Dis'*		38.5
$c^{-2\sharp}$	*Cis'*		34.3

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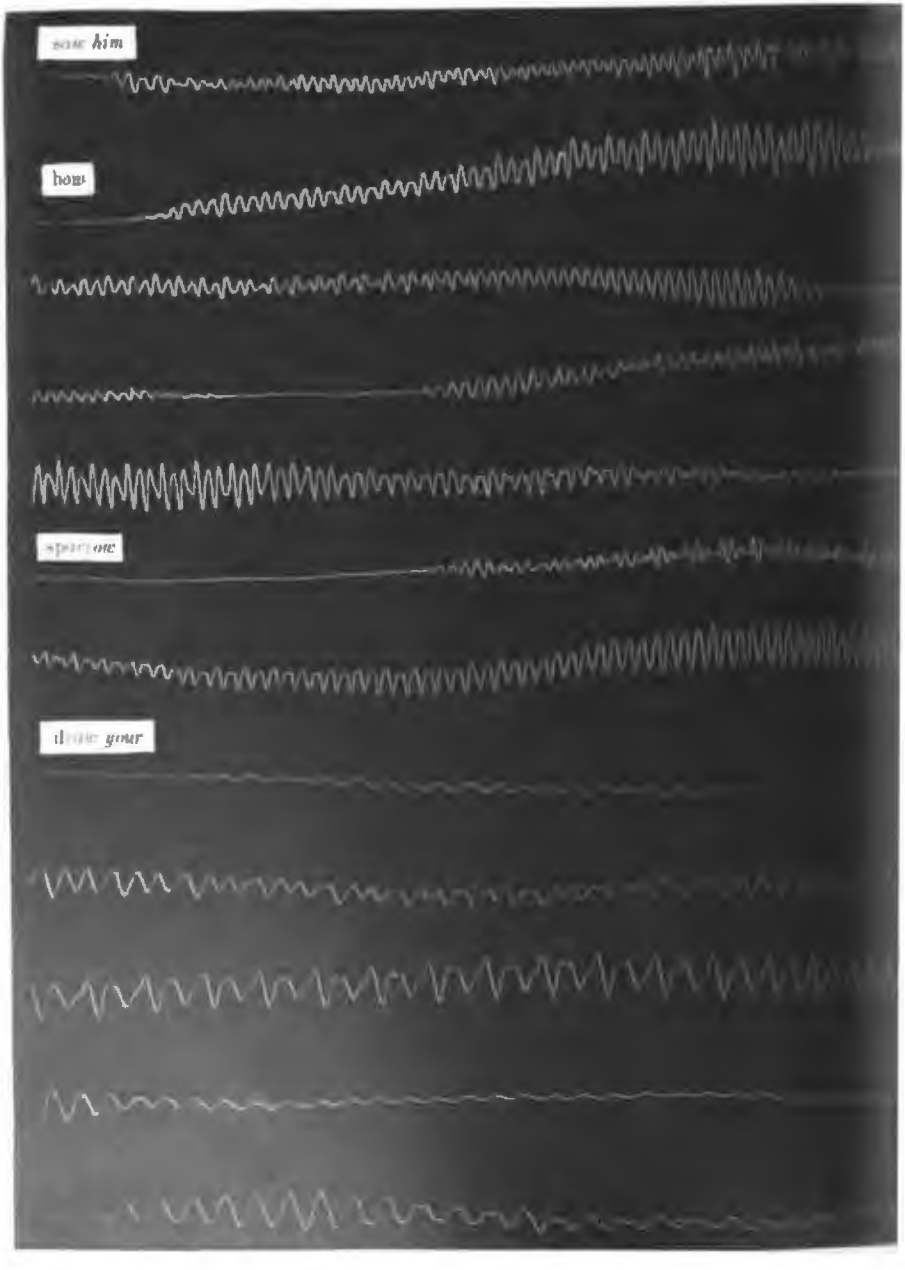

(First seven lines, 1mm = 0.0016s ; last five lines, 1mm = 0.0007s.)

PLATE I. Curves fr

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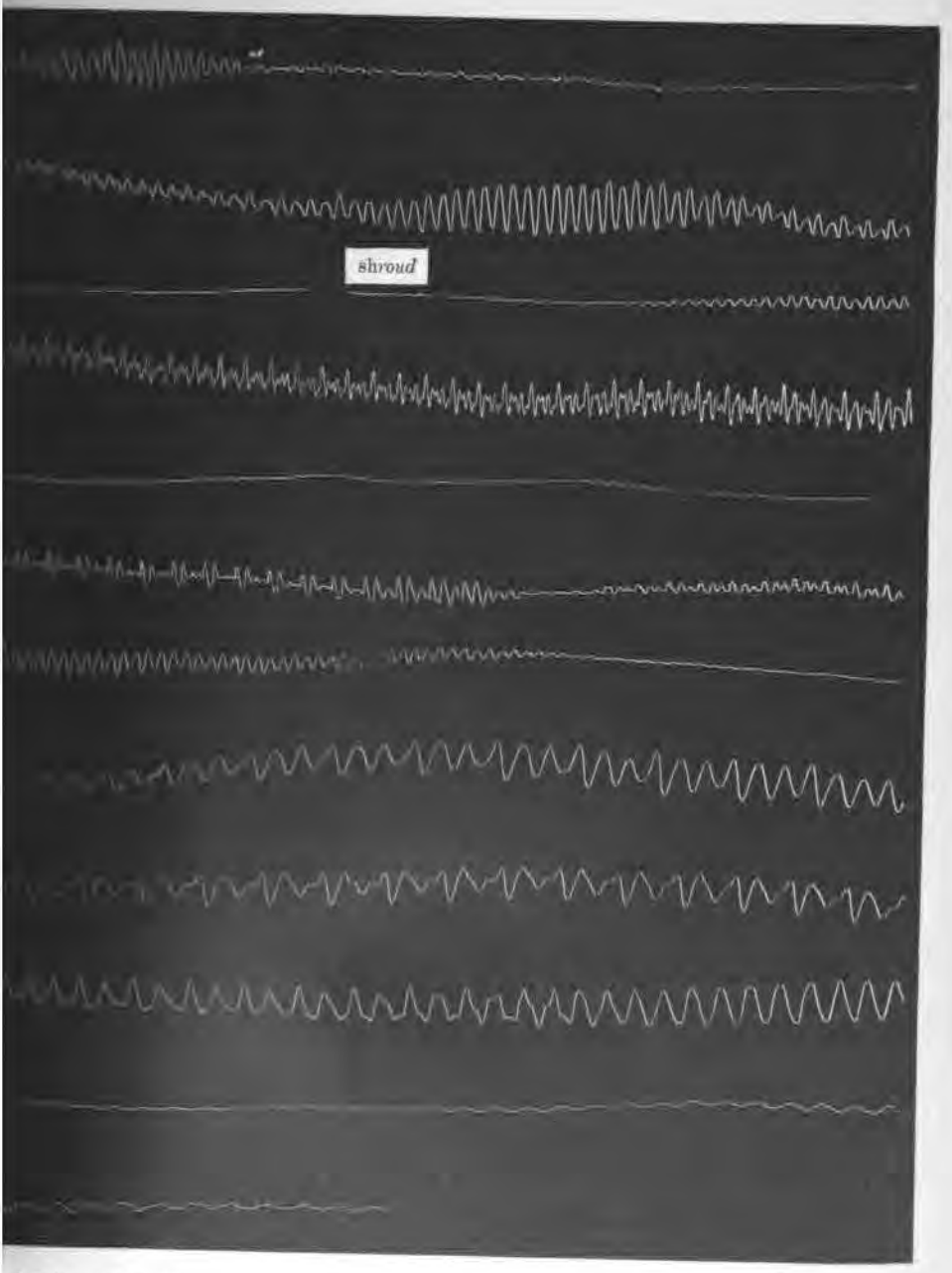

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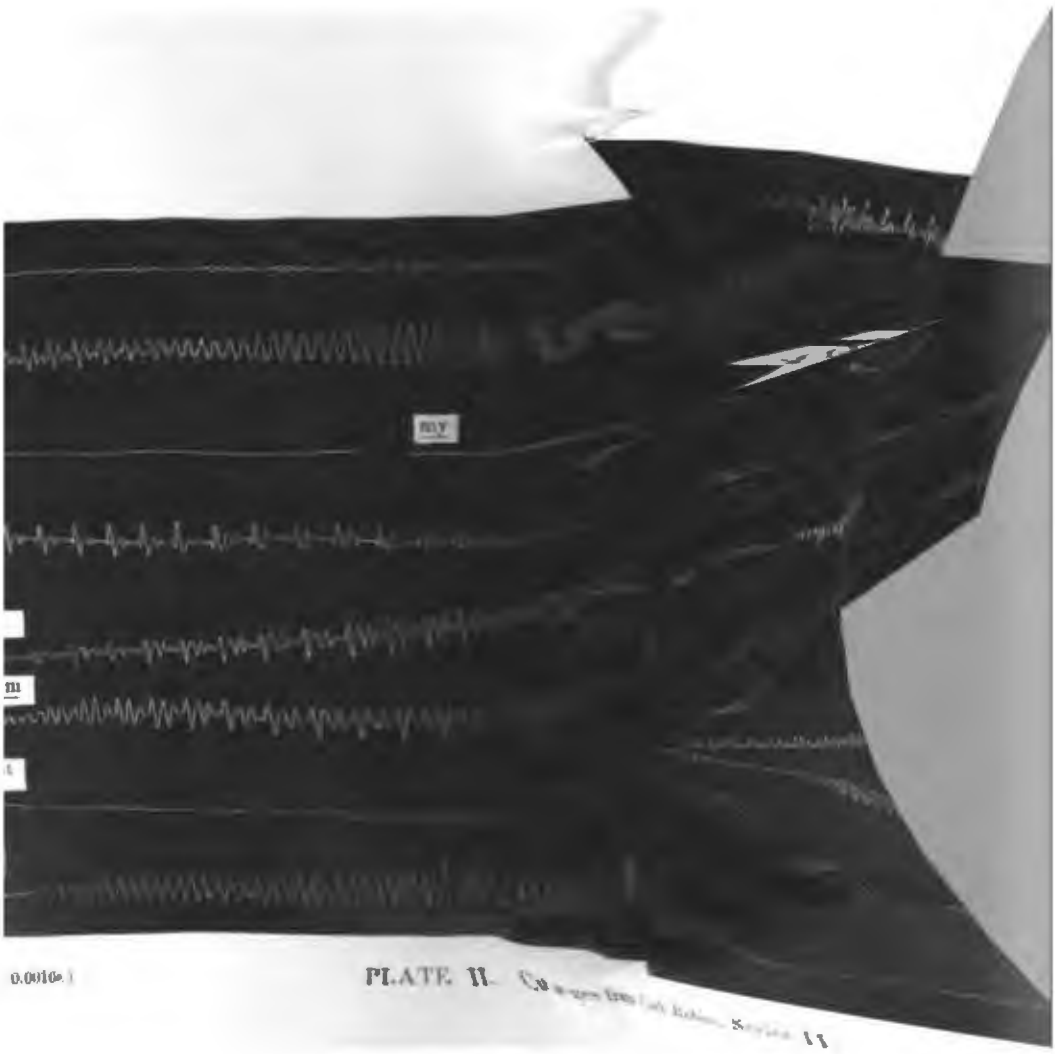

PLATE II.

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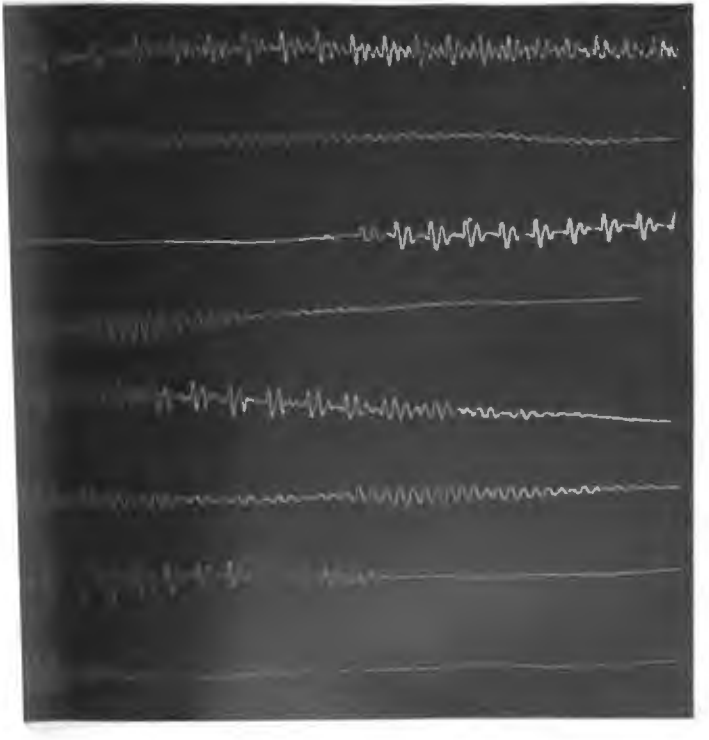

1 *Cock Robin, Series II.*

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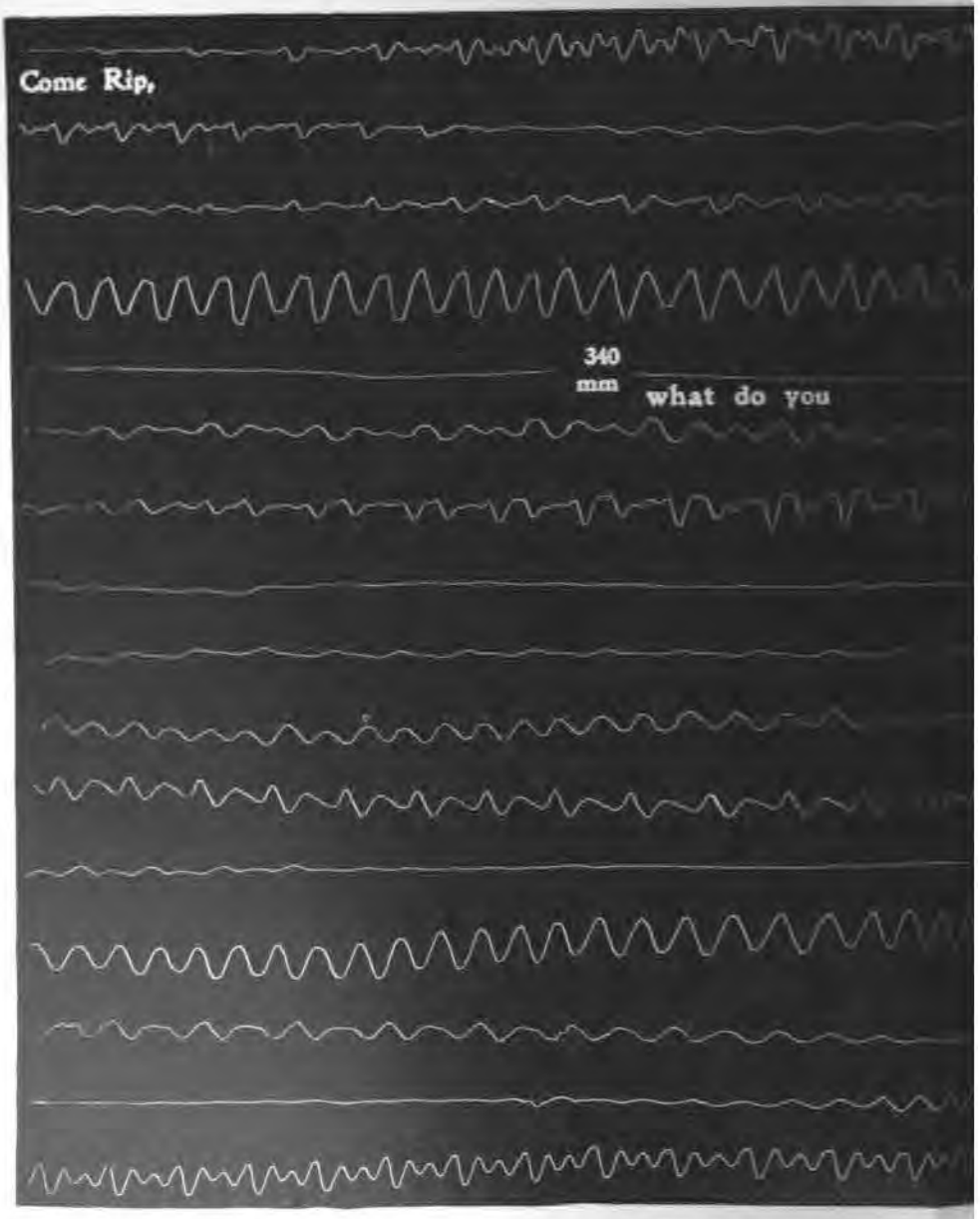

PLATE III. *Rip Van Wi*
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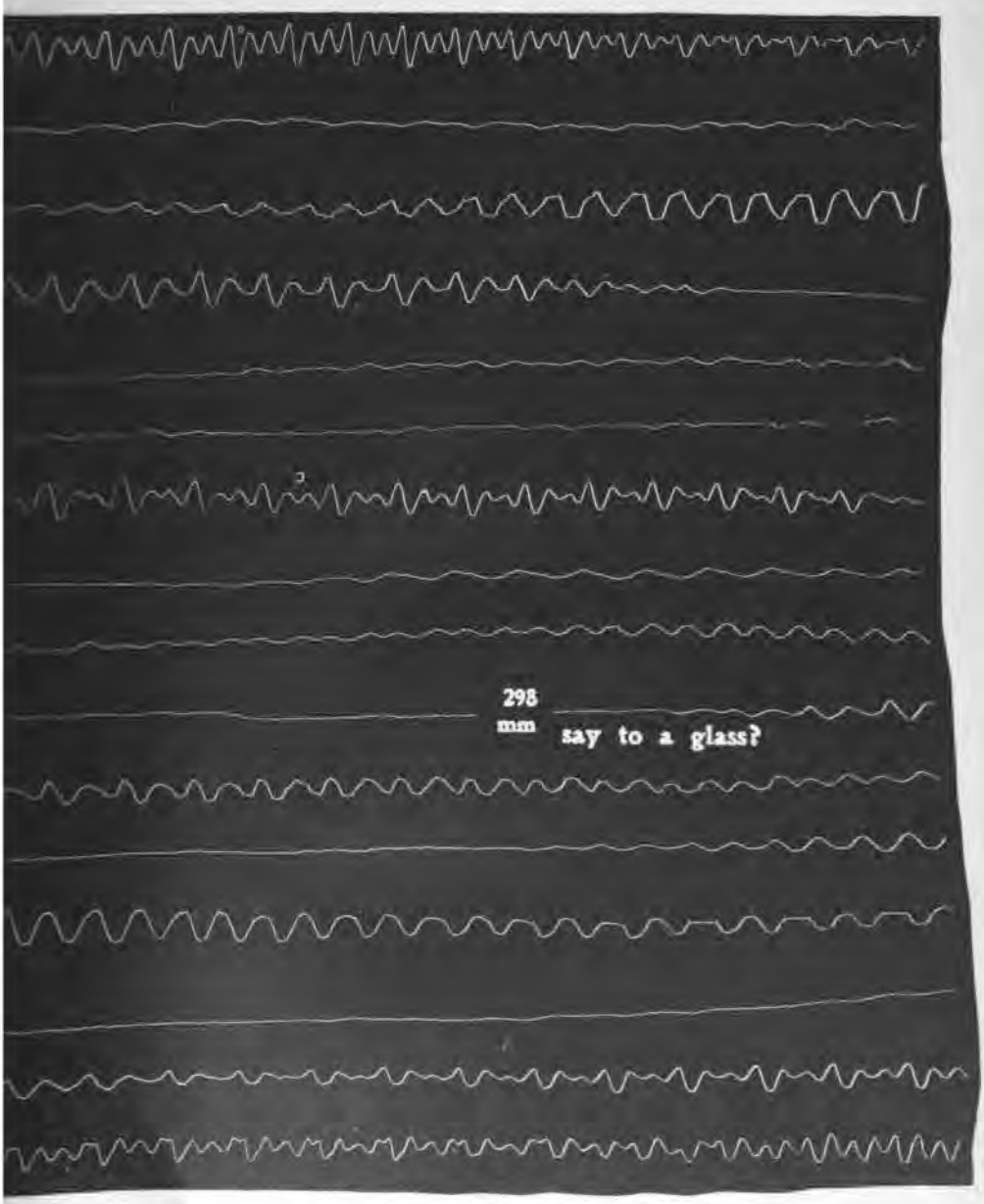

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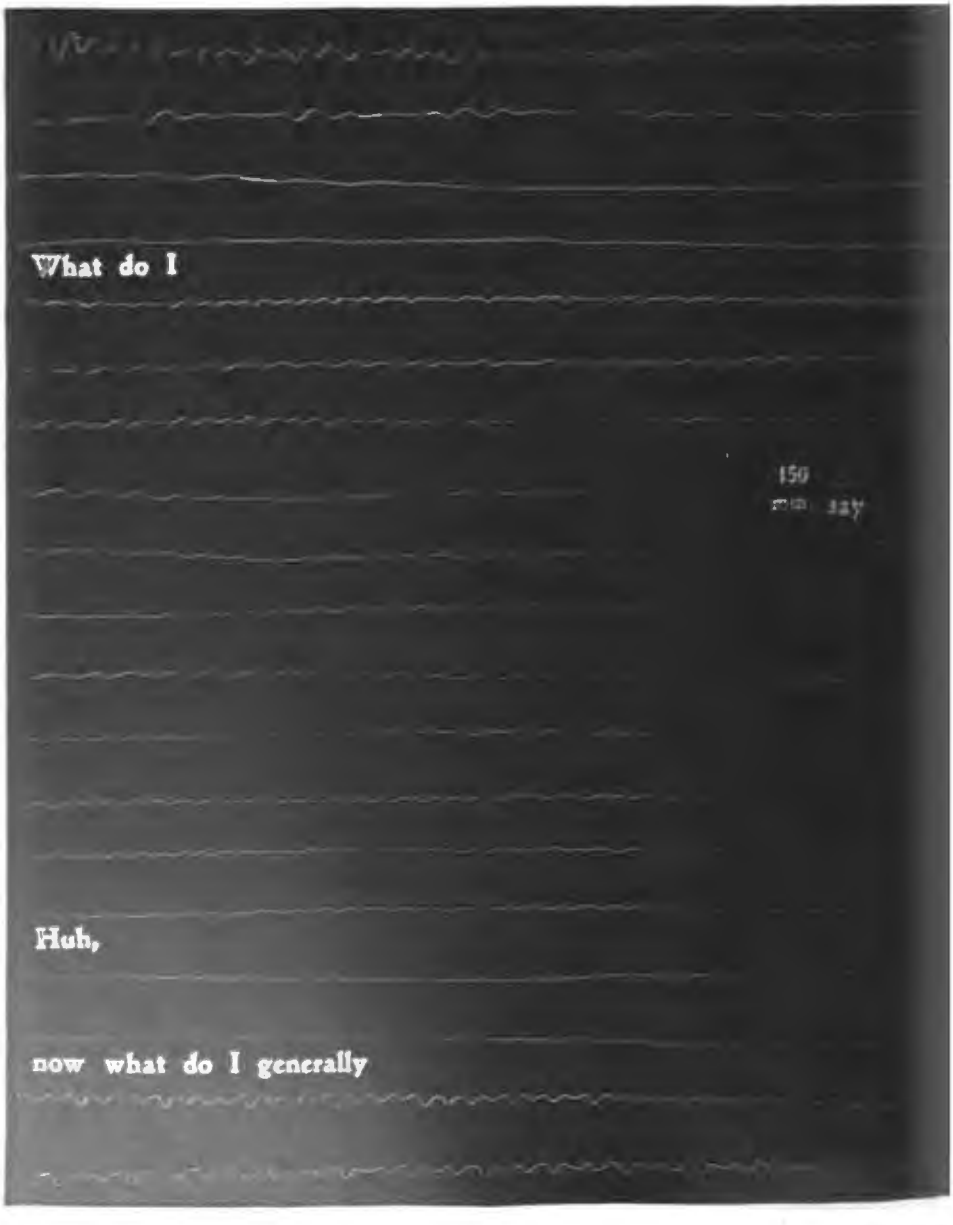

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PLATE IV. *Rip Van Winkle*
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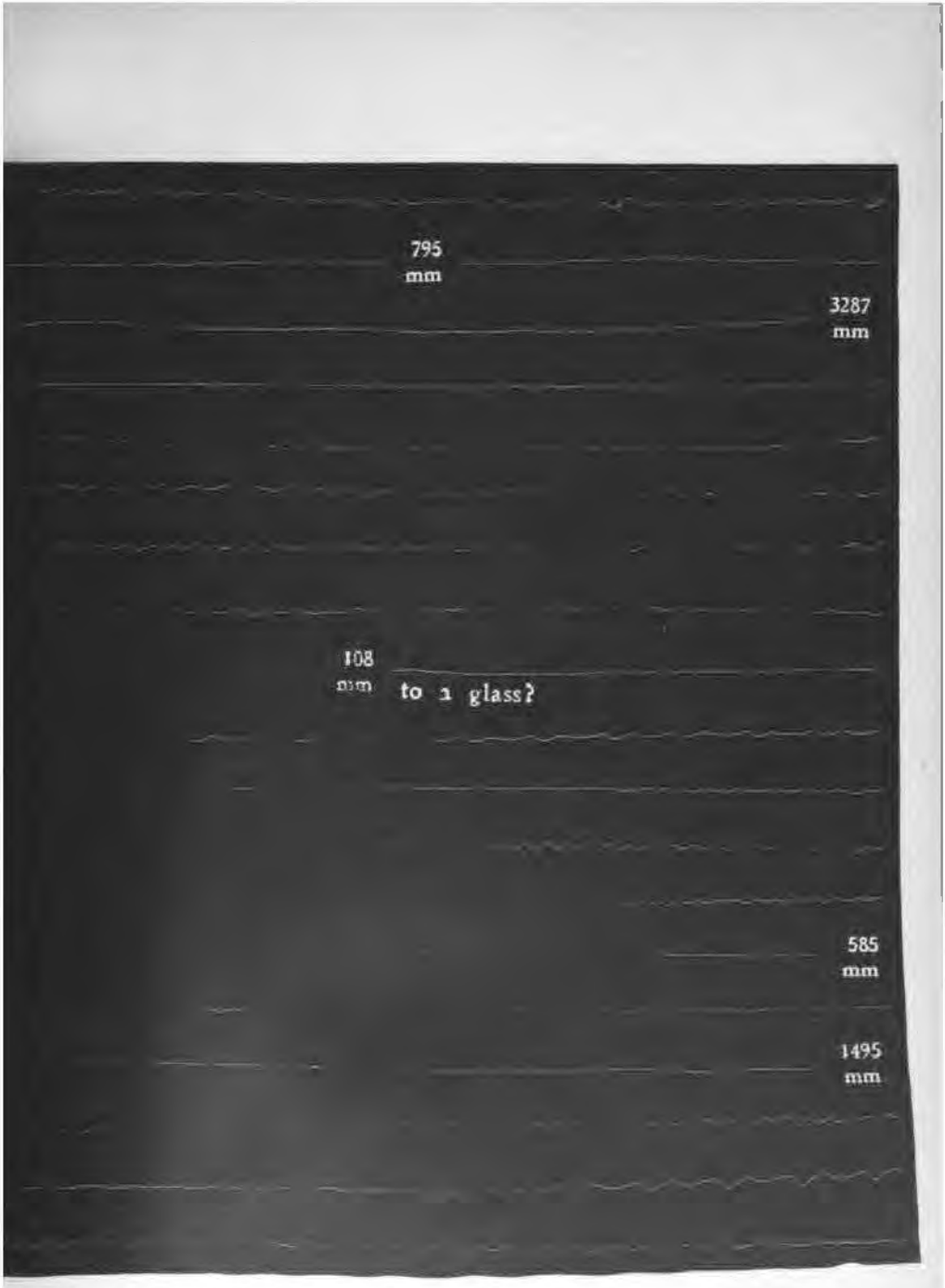

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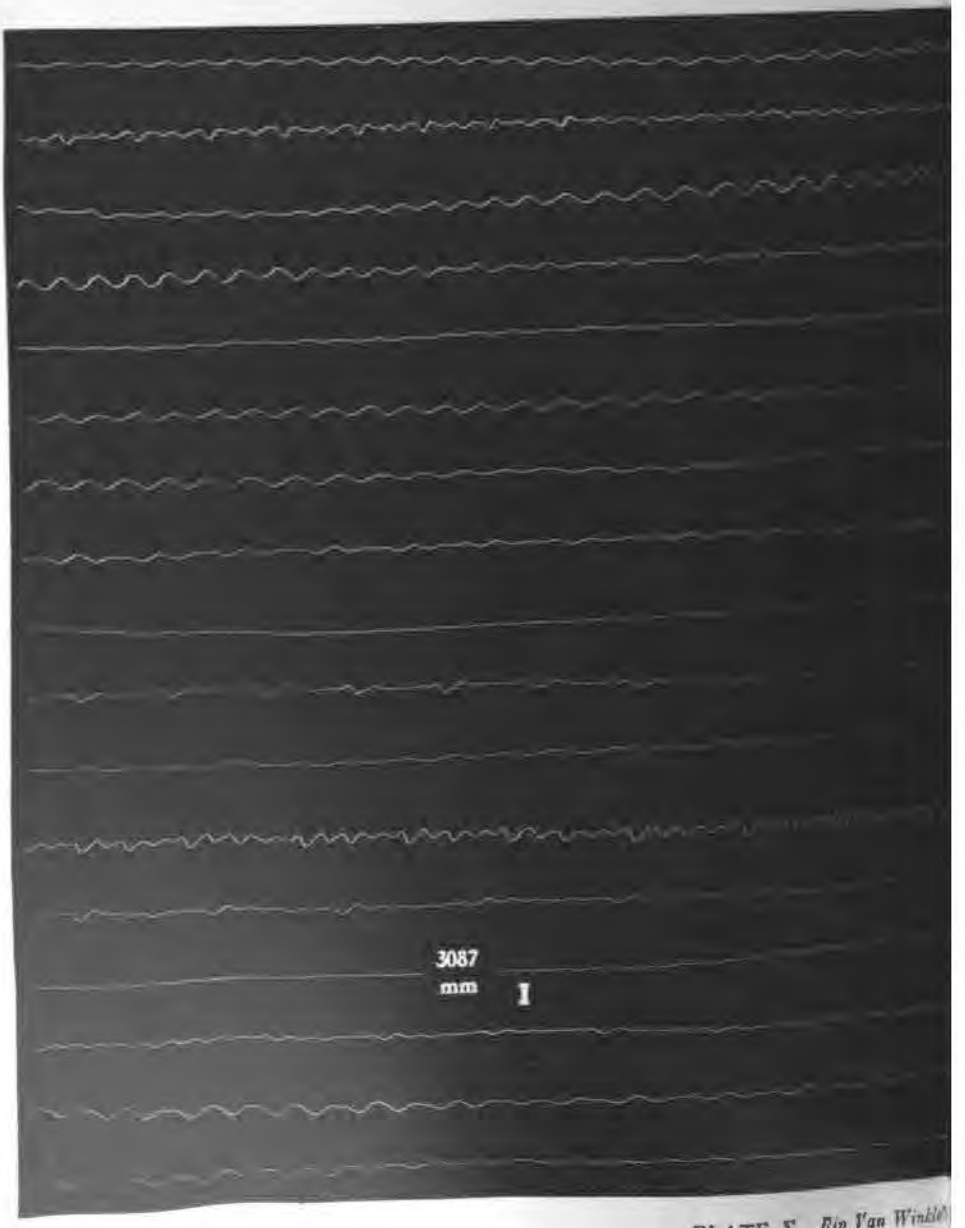

PLATE V. *Rip Van Winkle*
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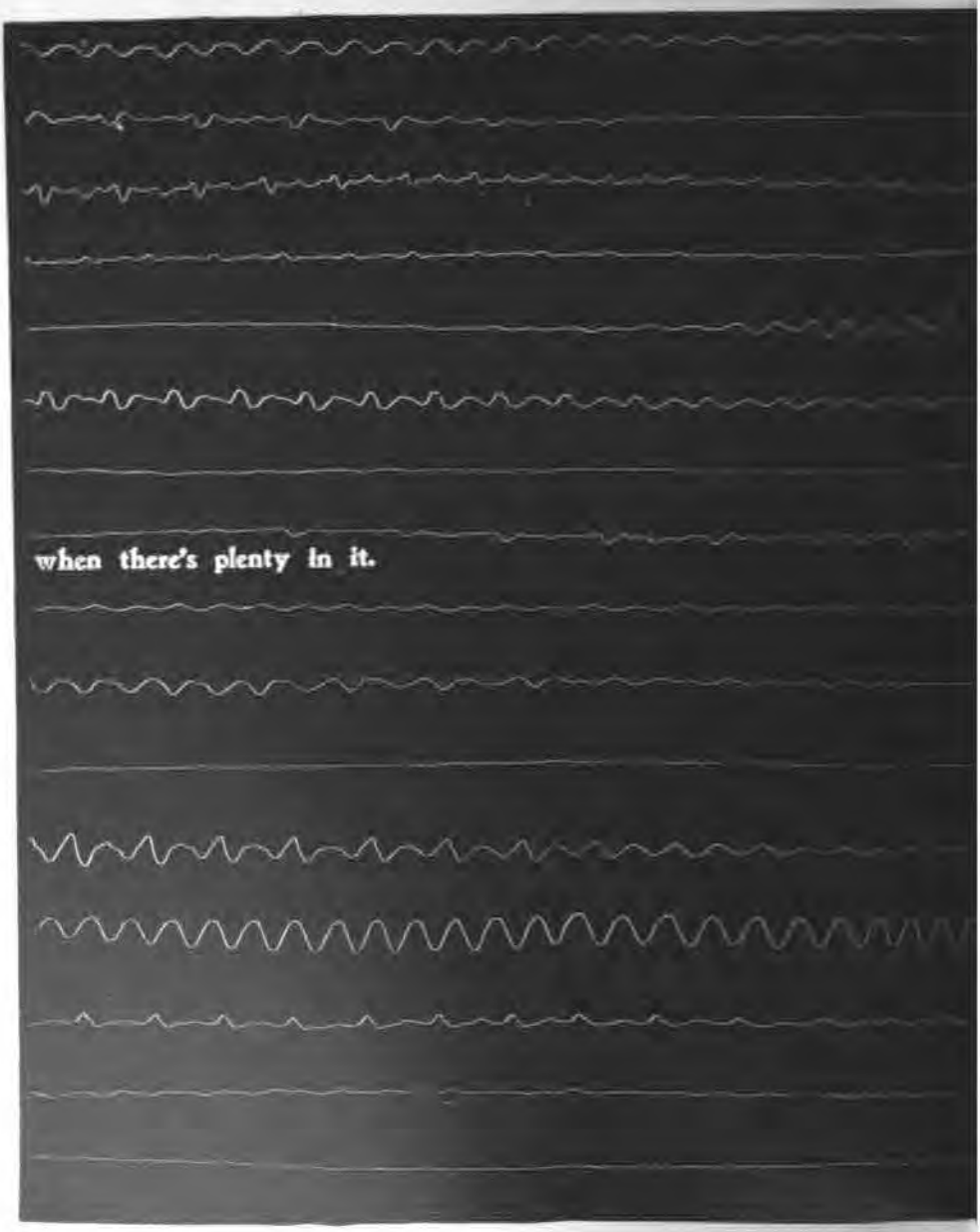

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PLATE VI. *Rip Van Wink*
(Blo

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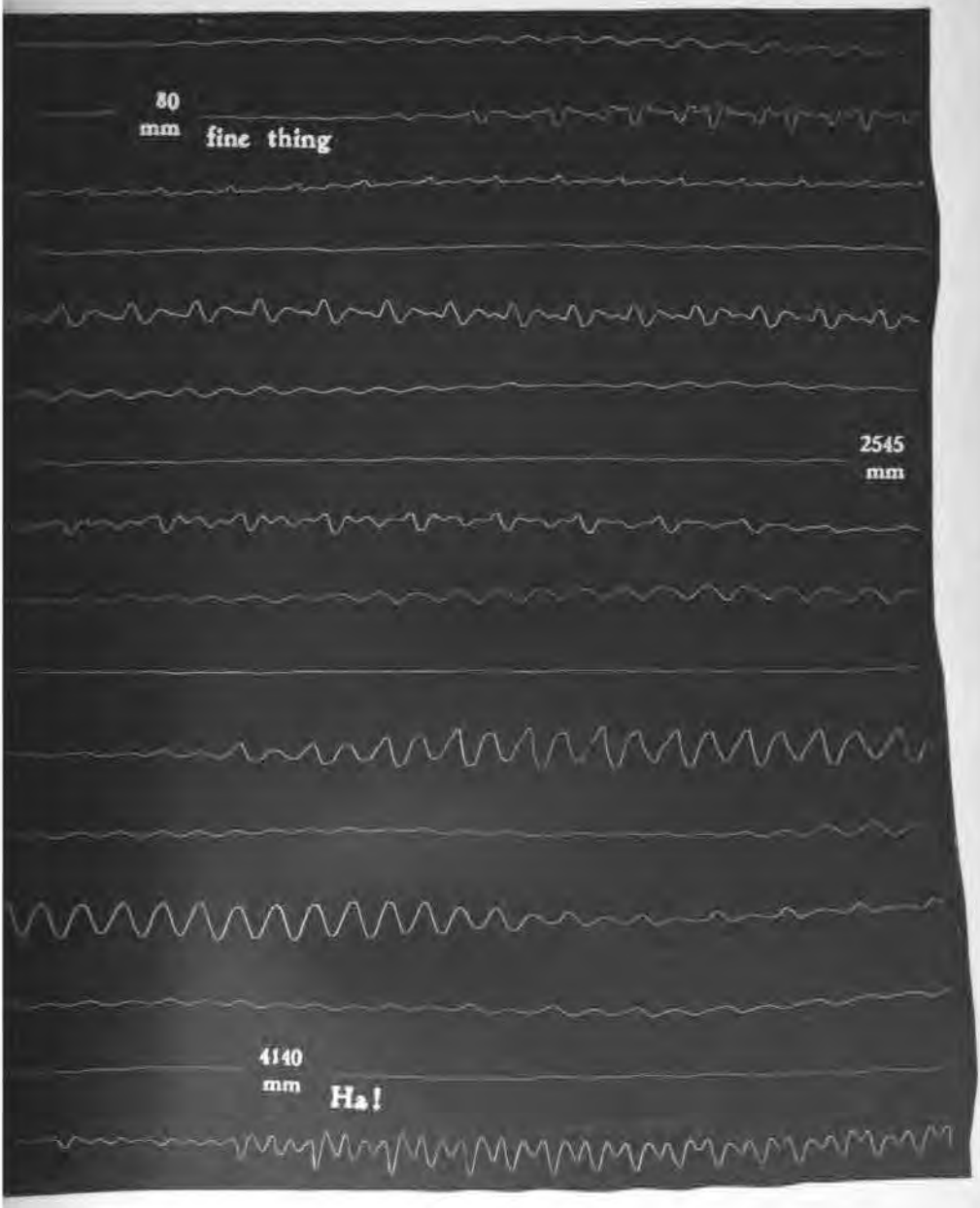

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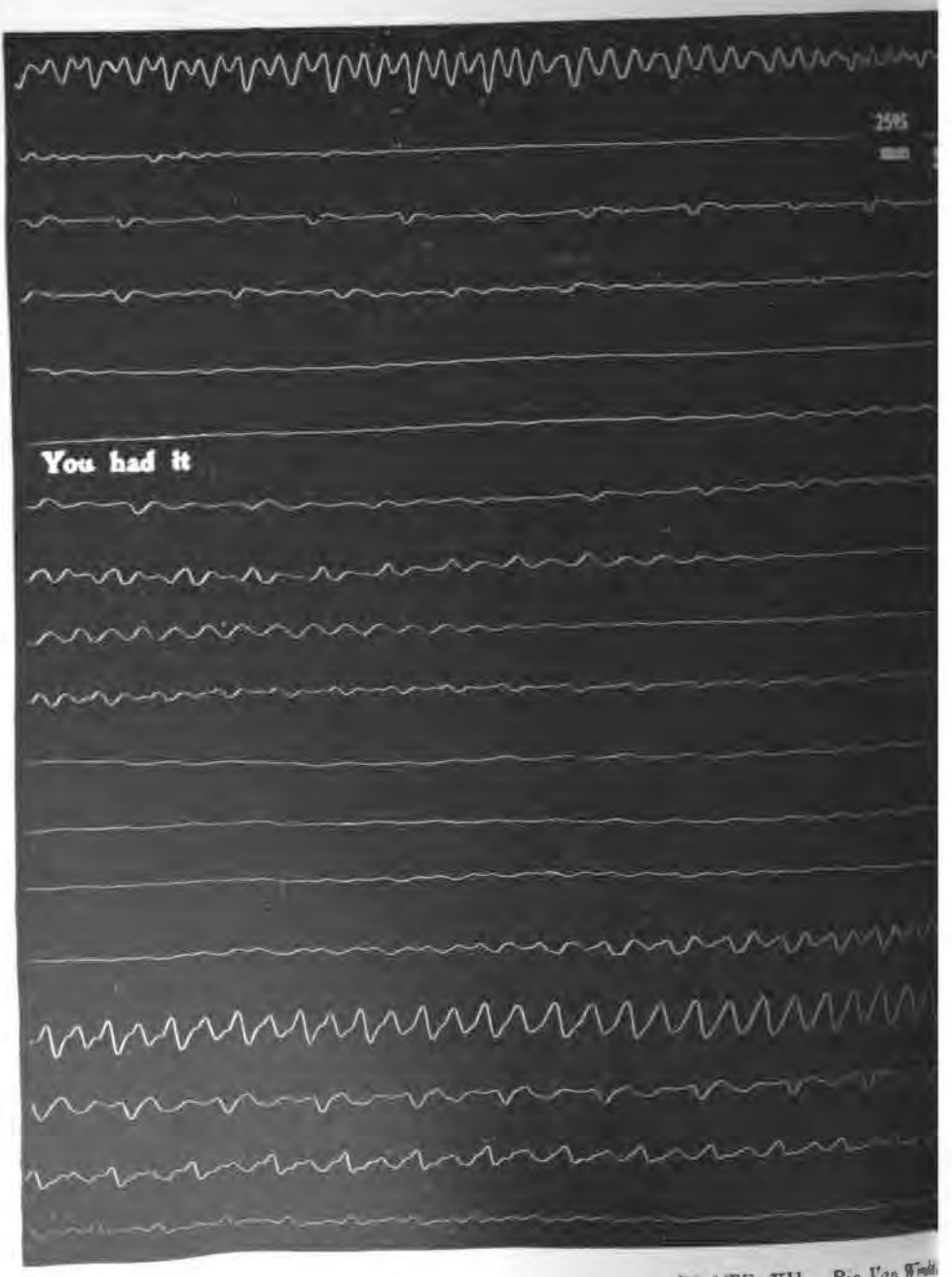

PLATE VII. Rip Van Wink

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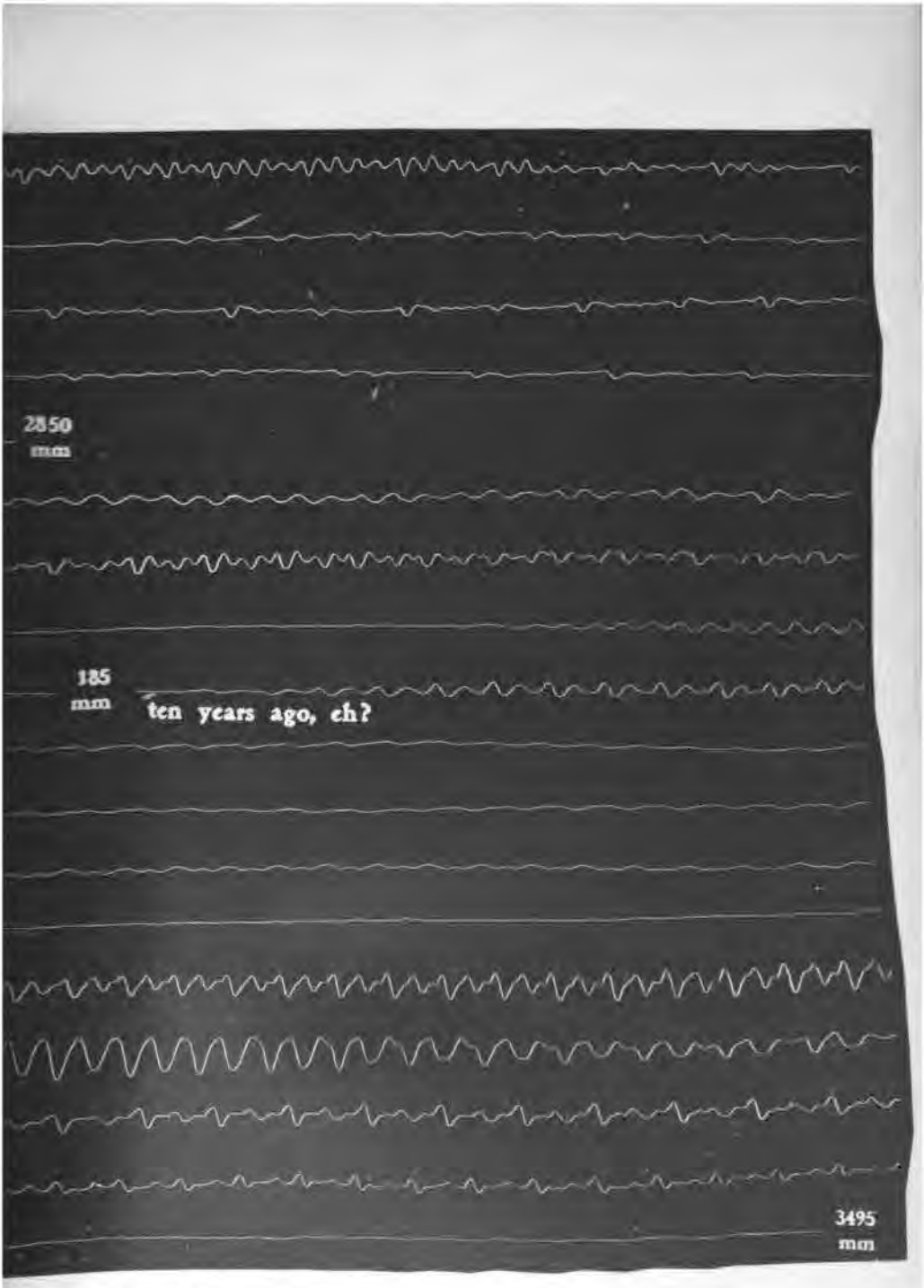

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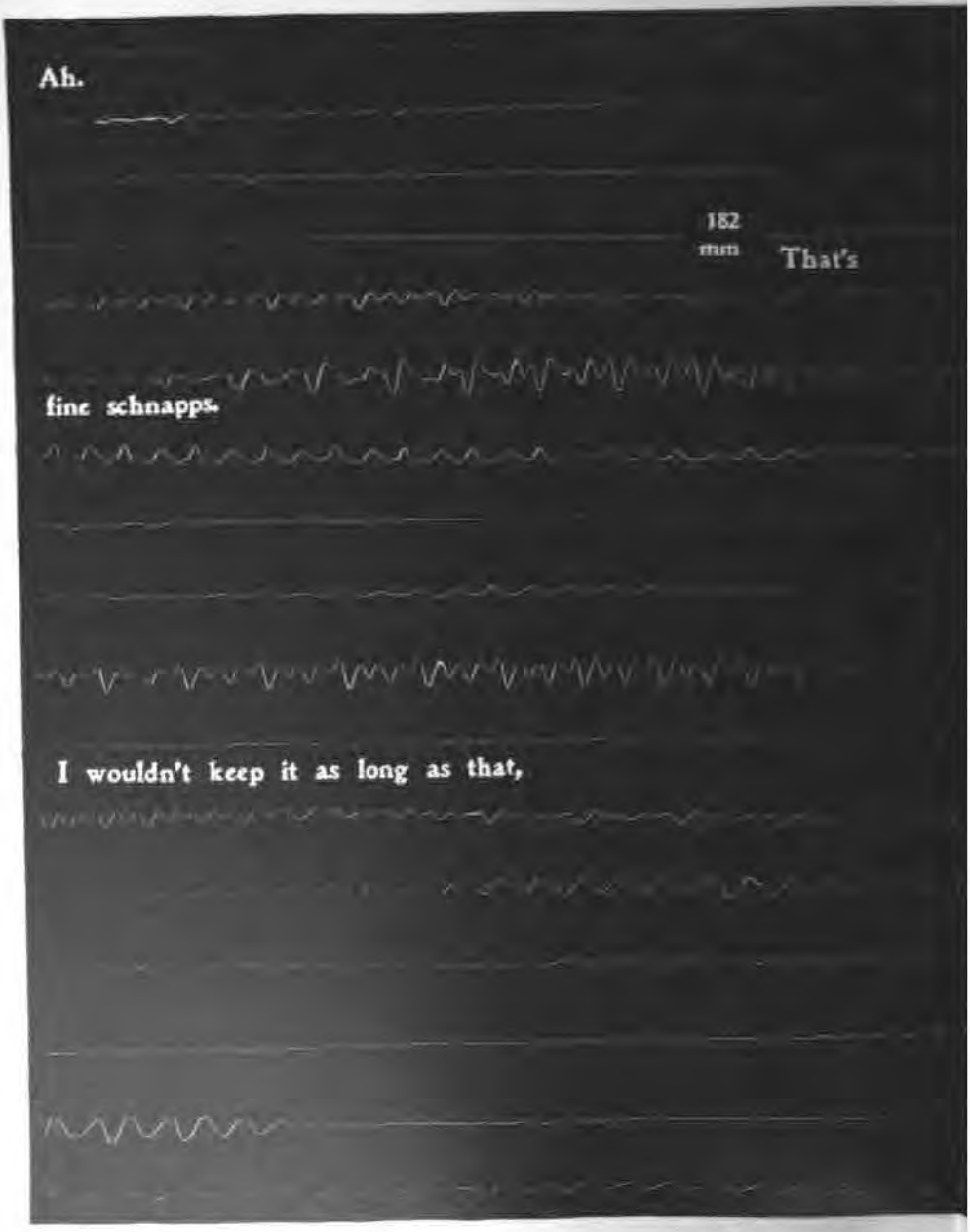

(1 mm = 0,0007".)

PLATE VIII. *Rip Van Winkle*
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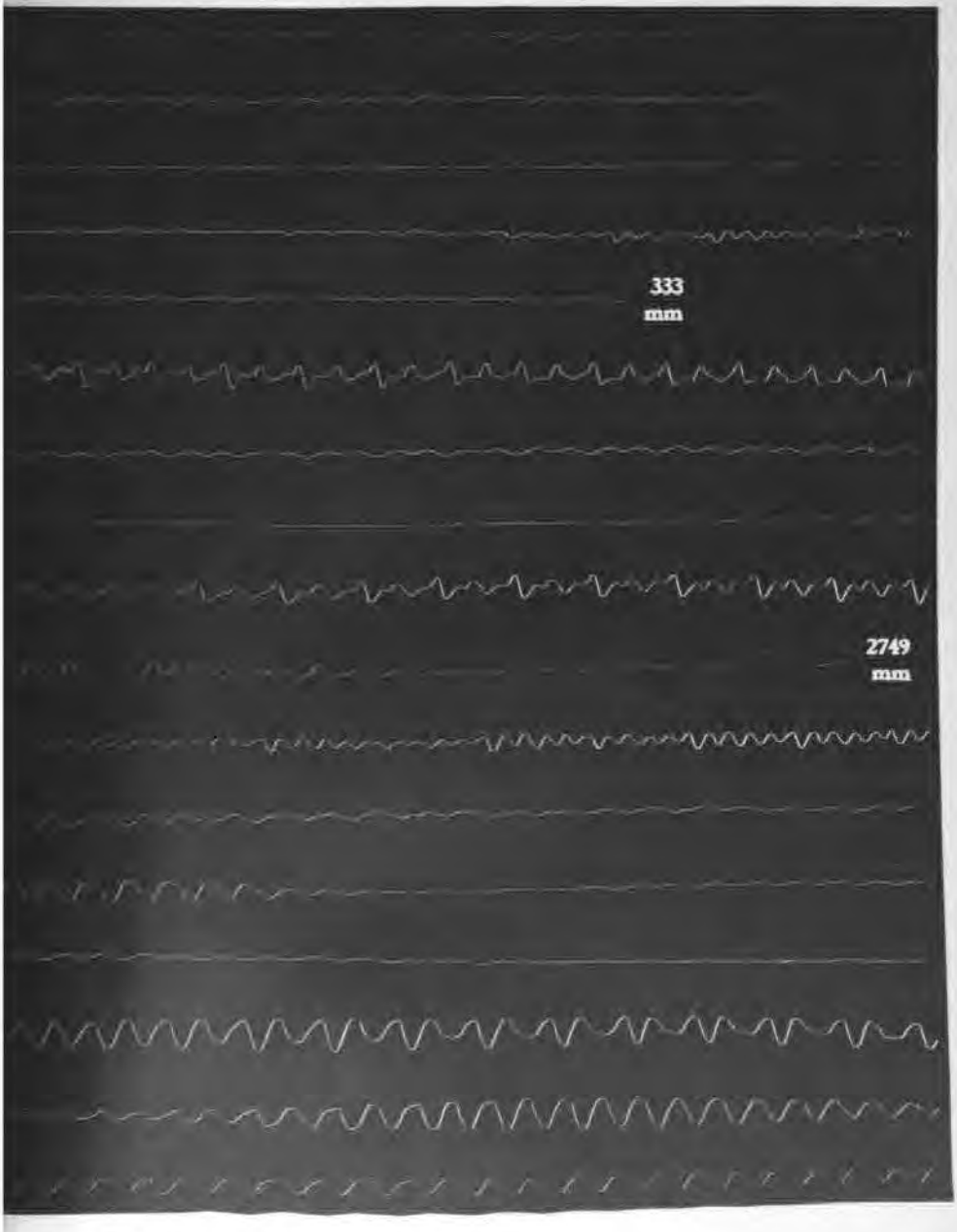

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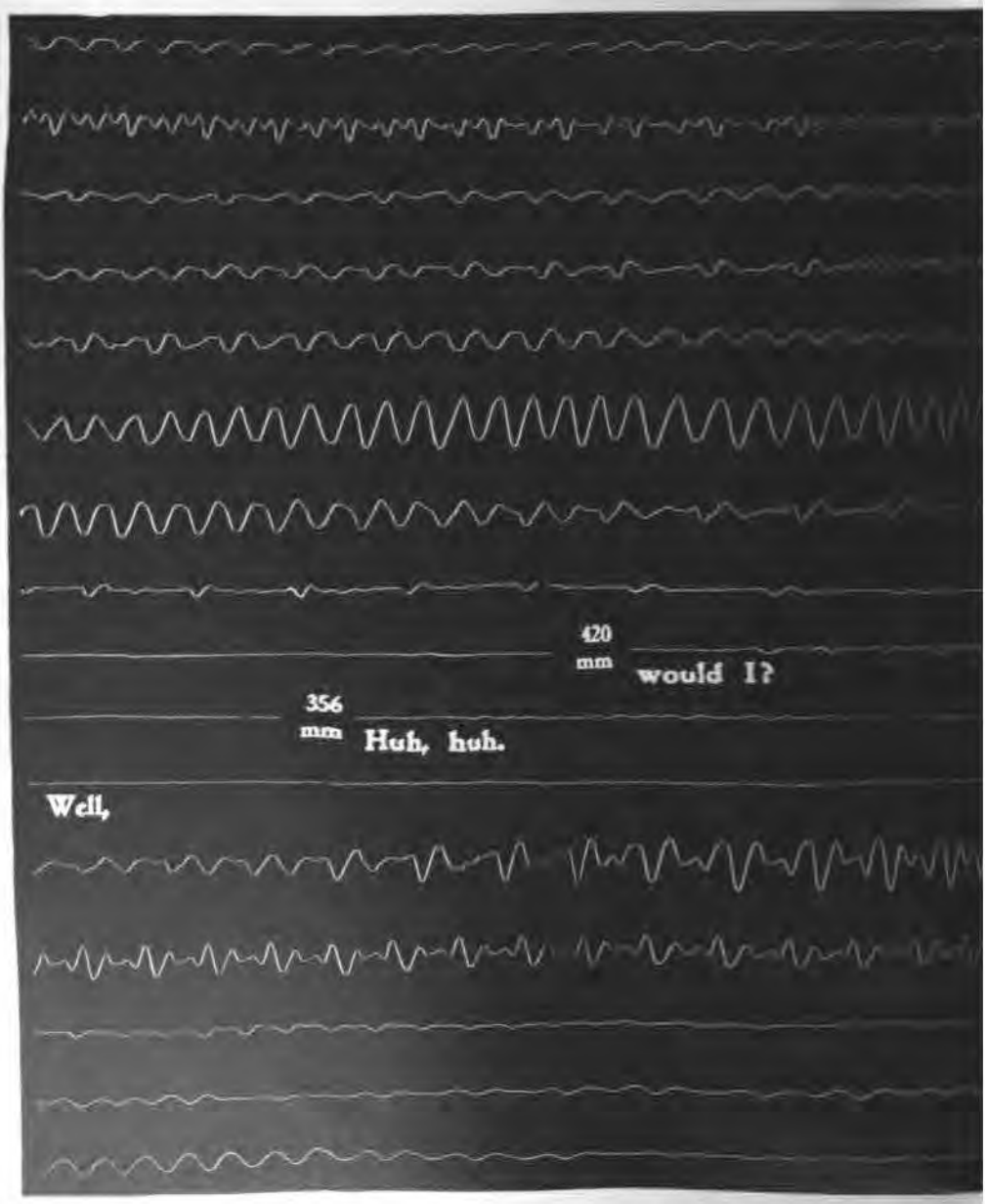

(1mm = 0.0007")

PLATE IX. *Rip Van Winkl*
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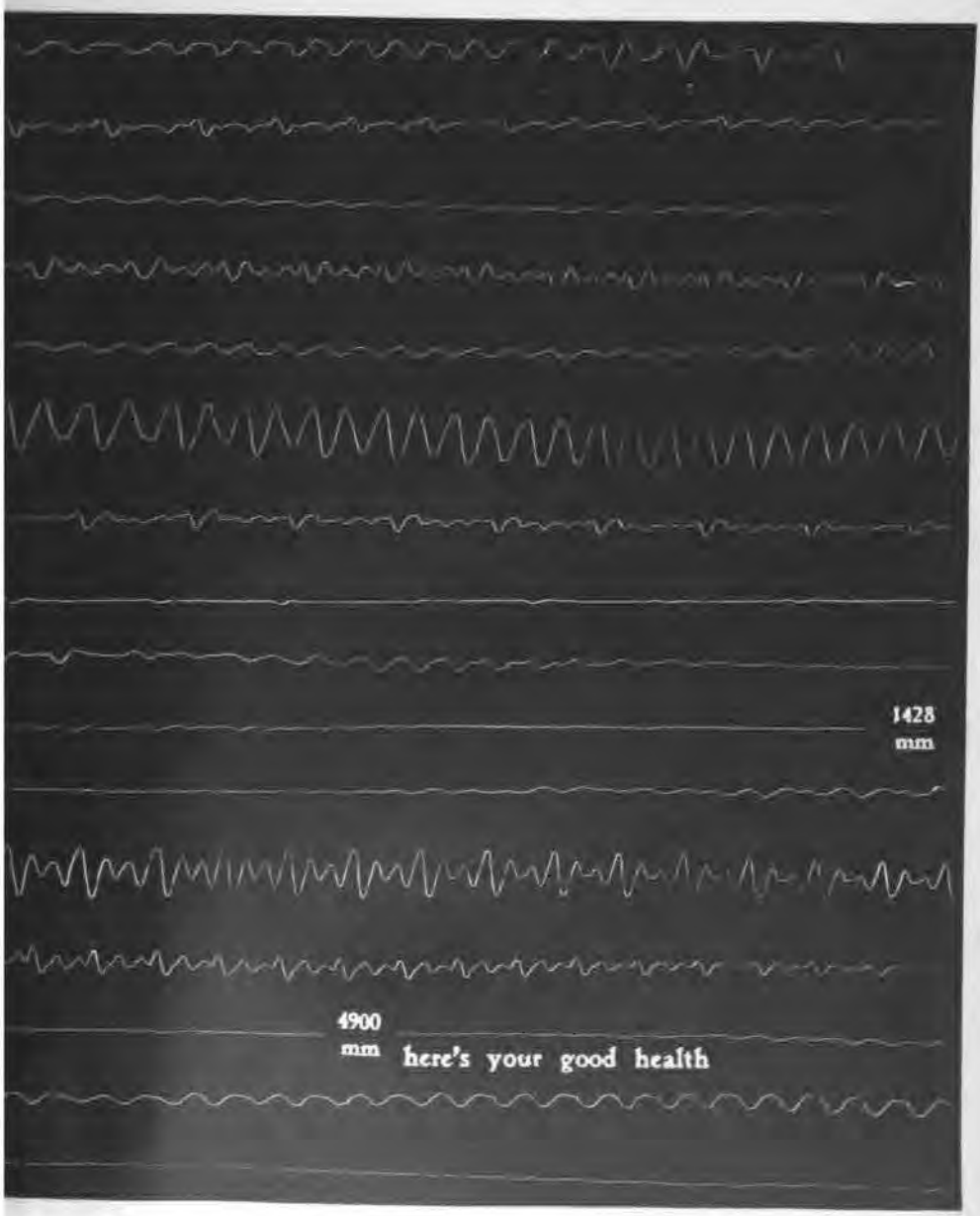

e *Toast*, by Joseph JEFFERSON.
VII.)

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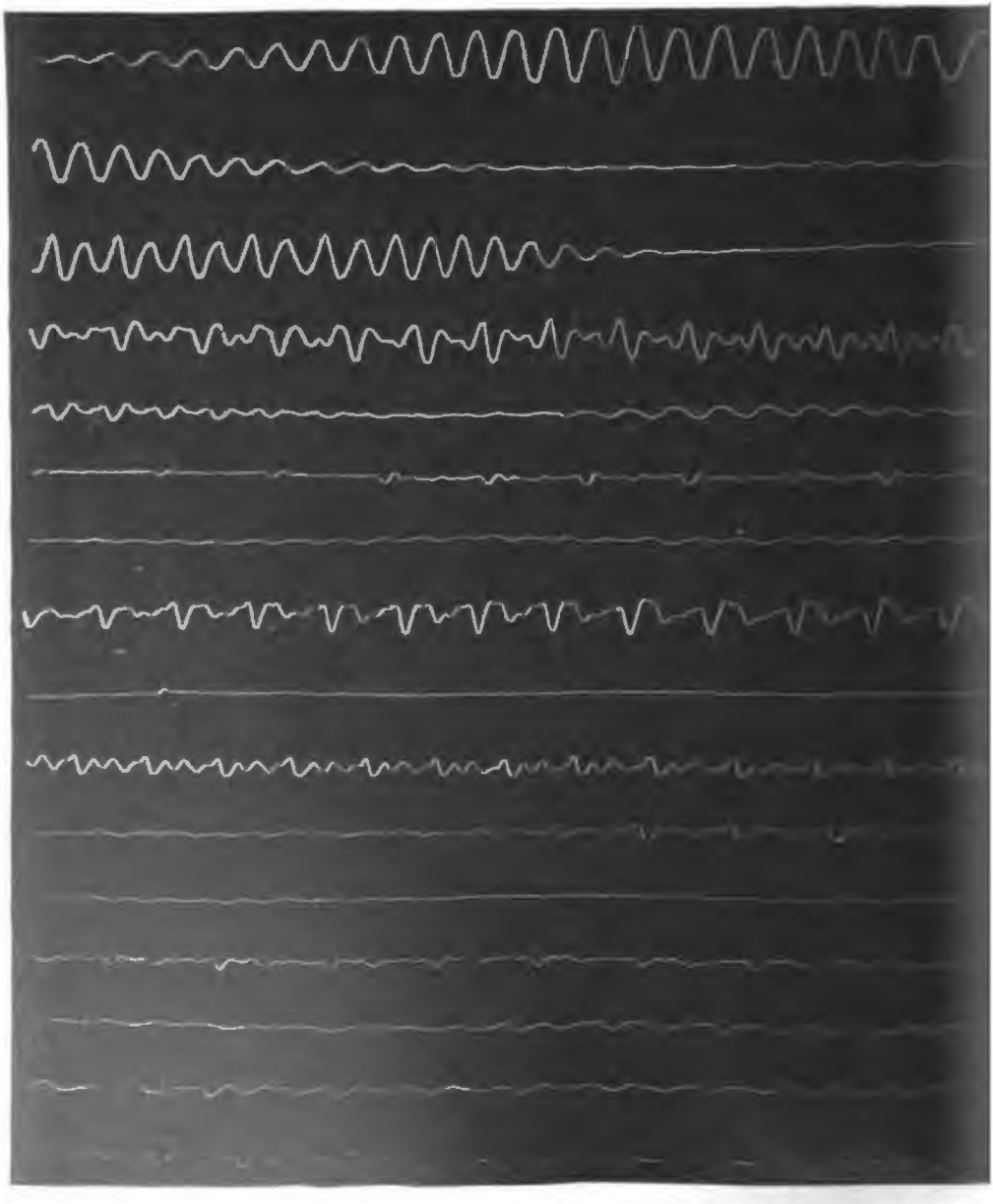

PLATE X *Rip Van Wi*
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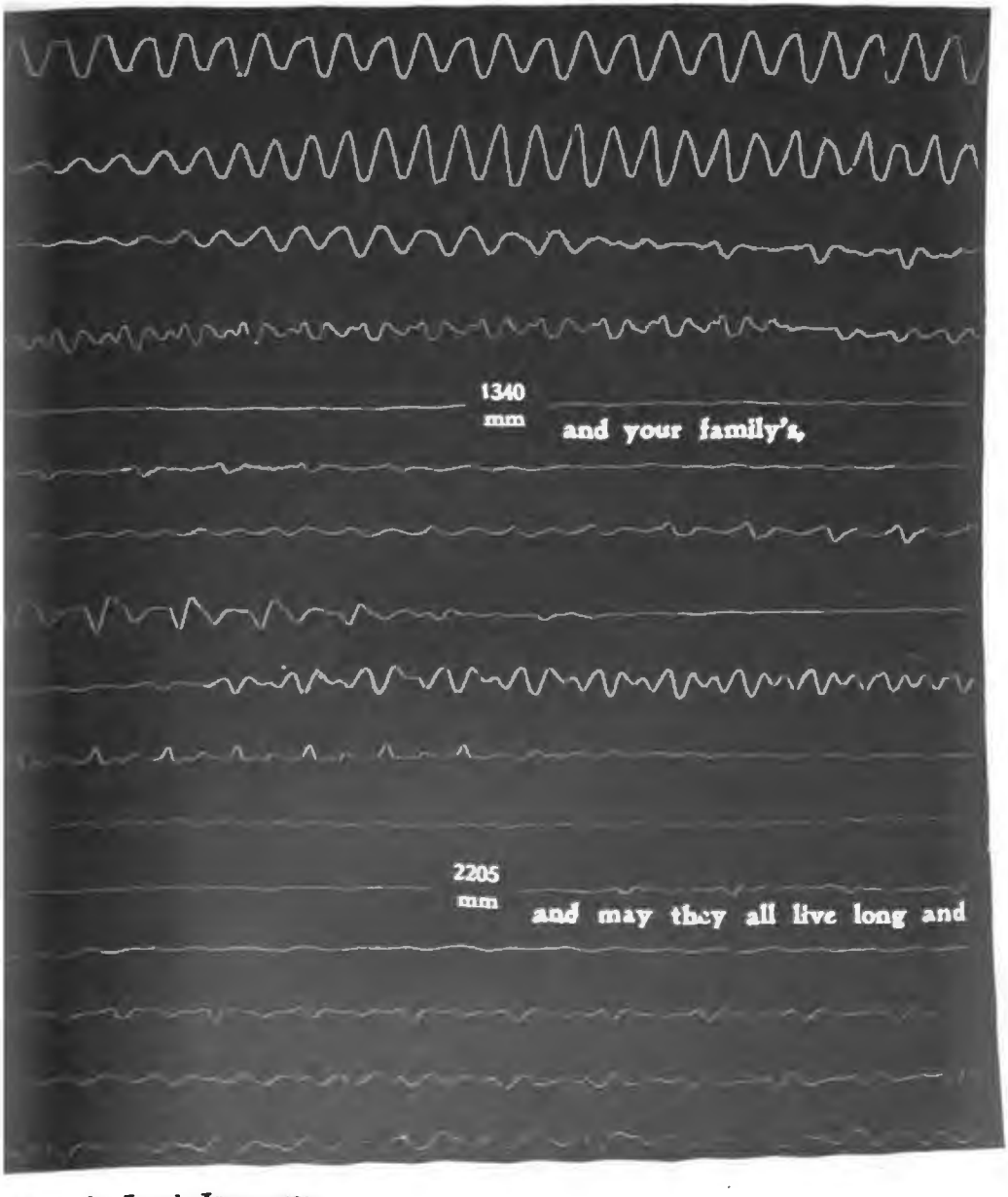

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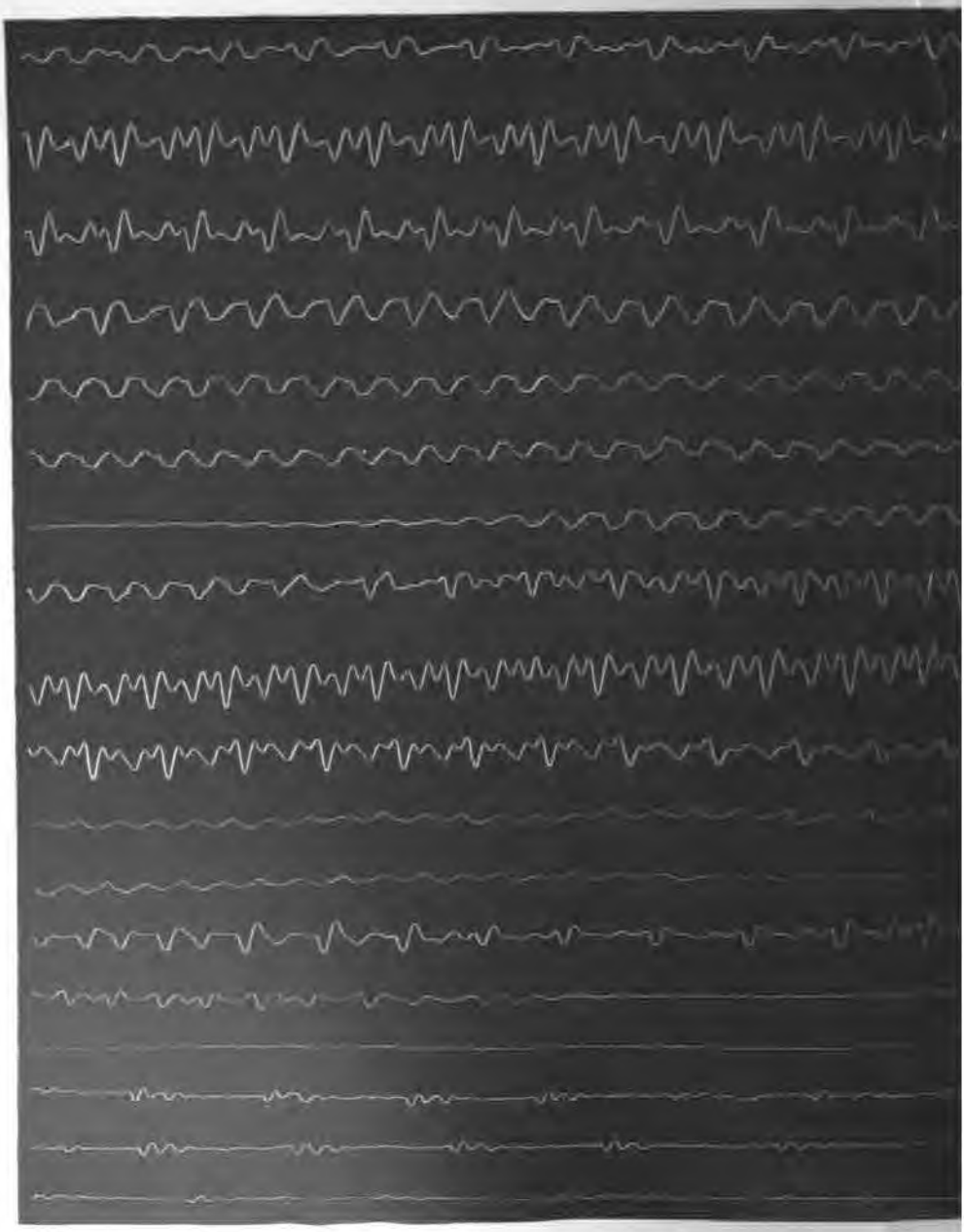

(1 mm = 0.0007 s.)

PLATE XI. *Rip Van W*

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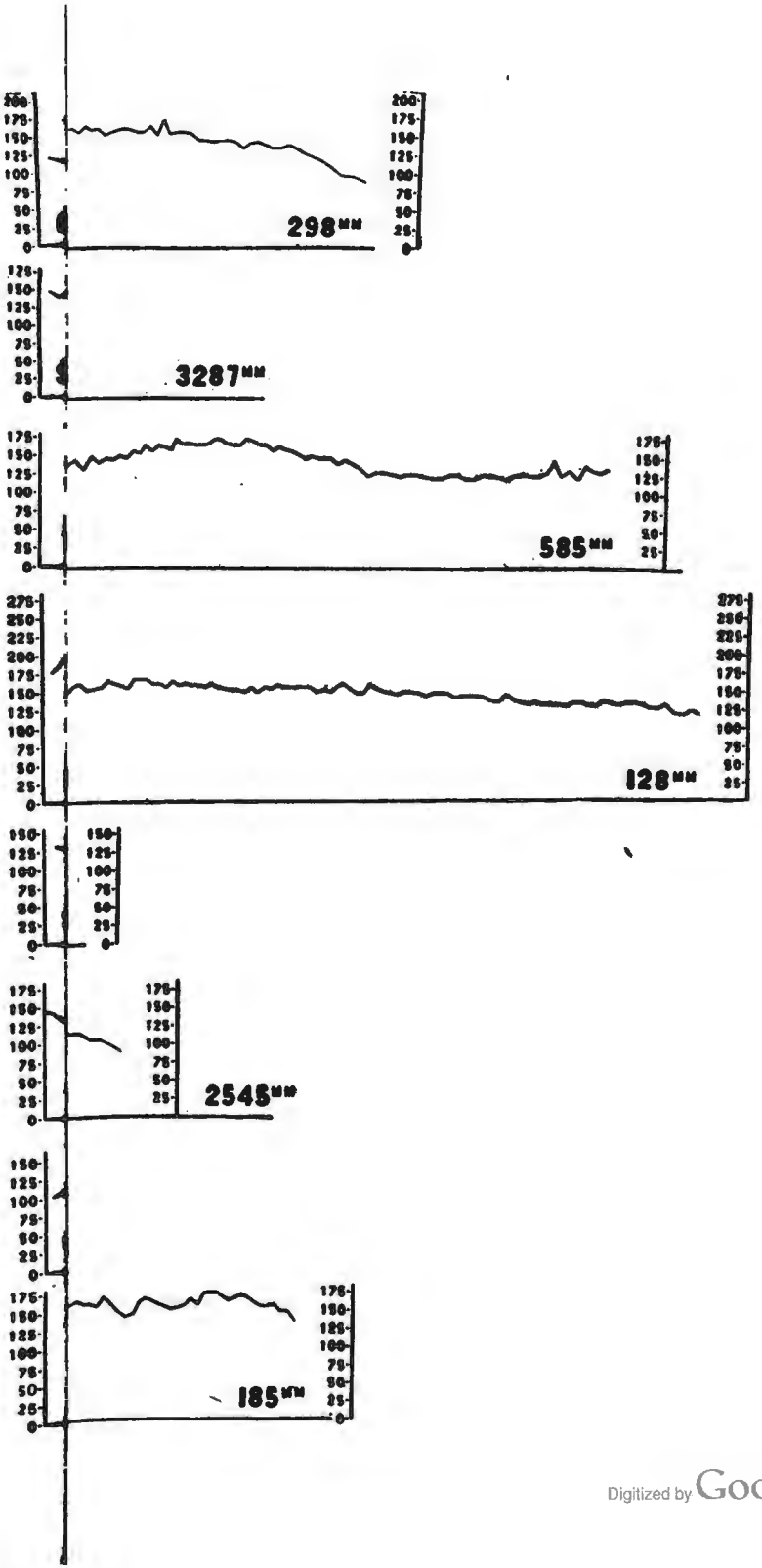

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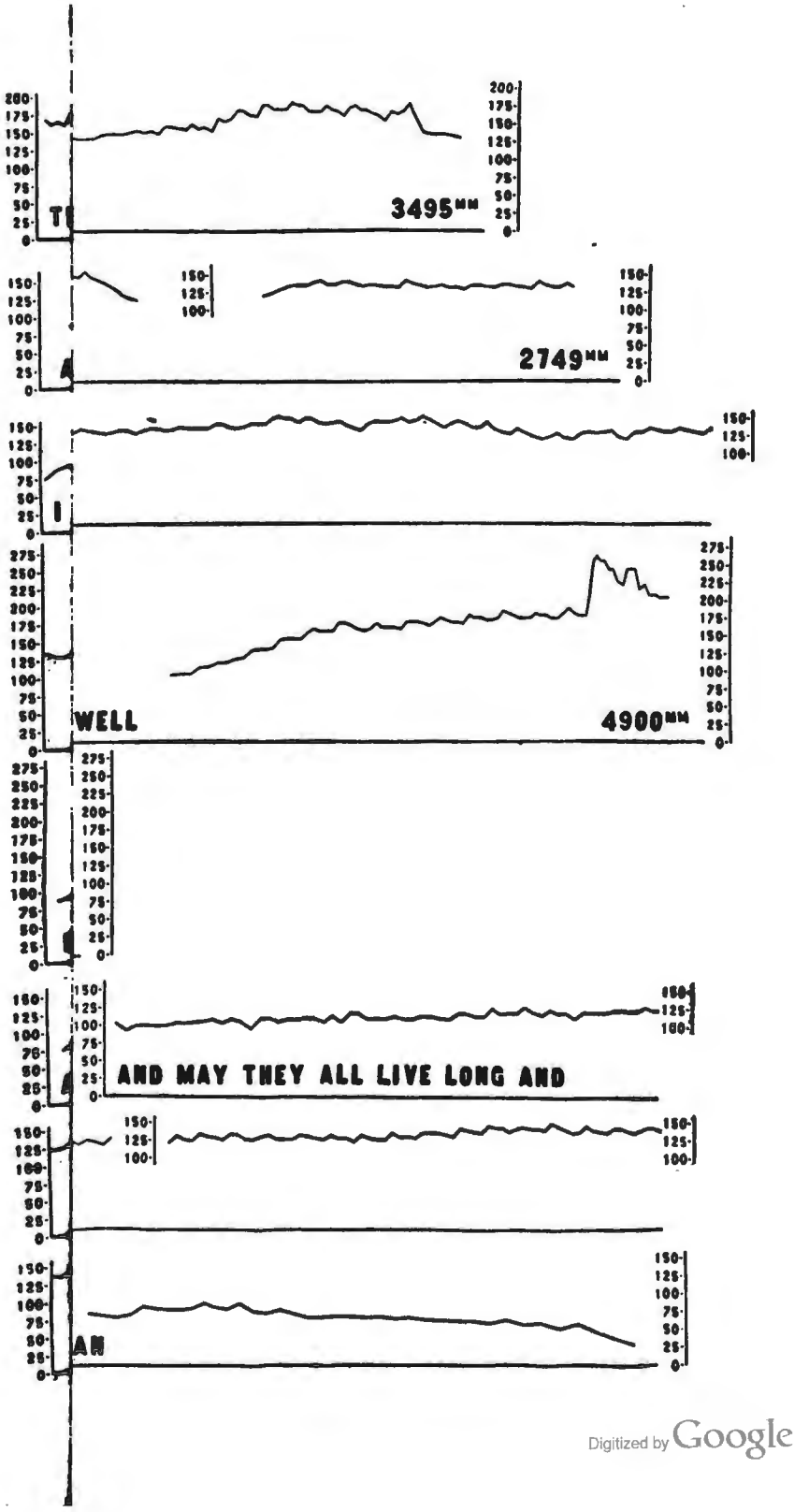

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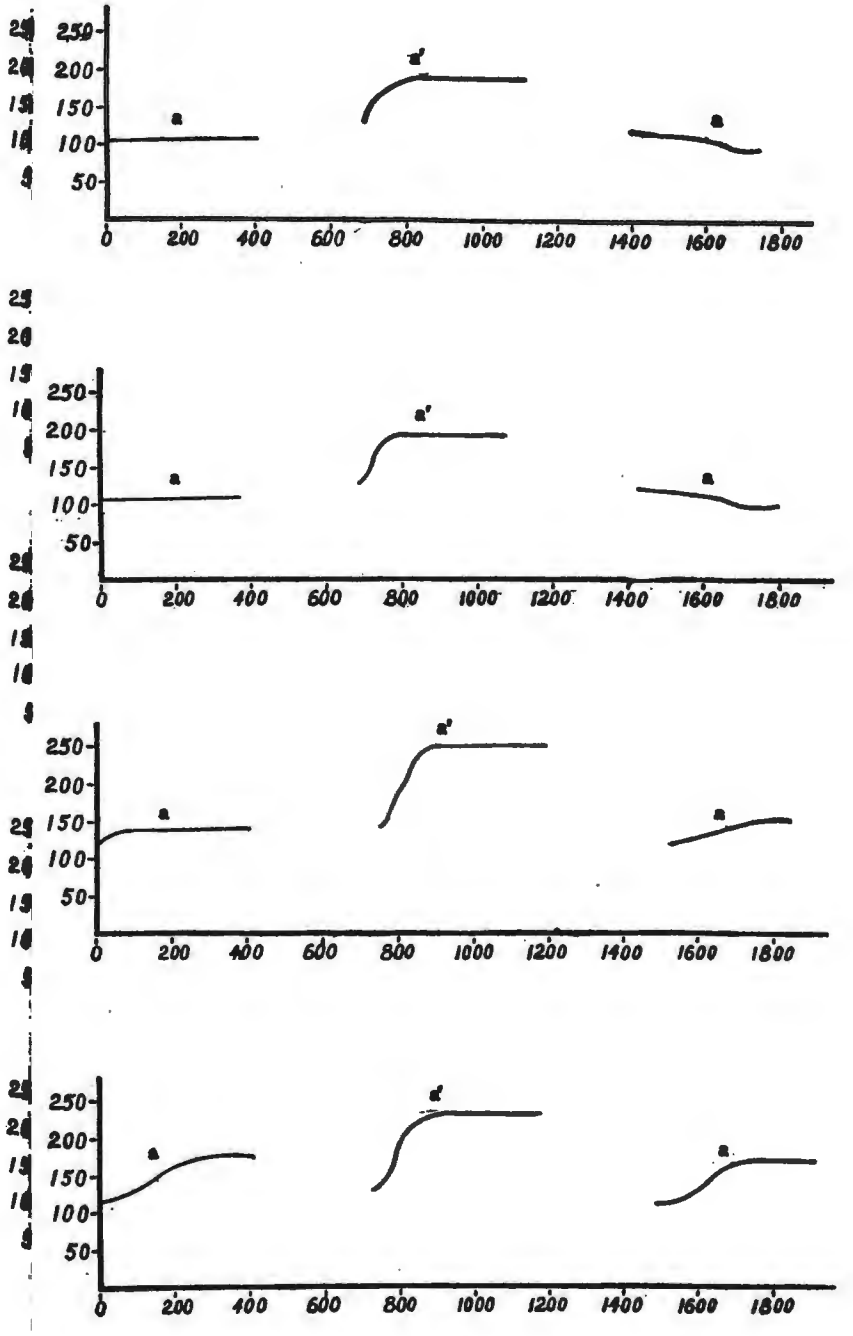

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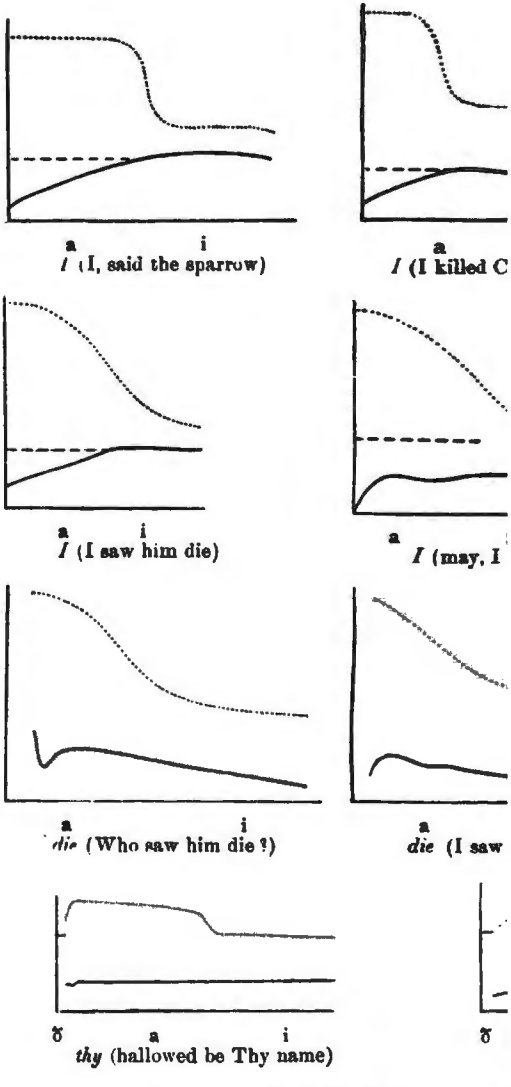

PLATE XV. *Curves*

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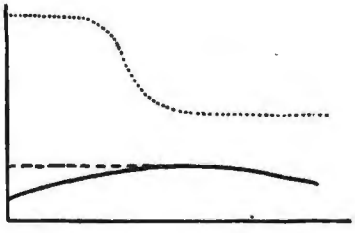
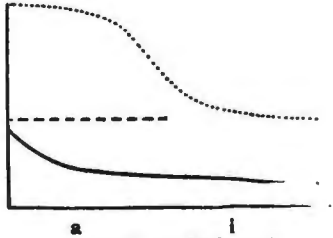
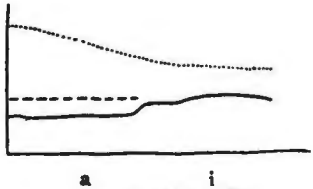


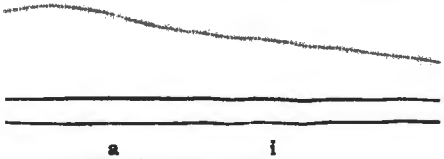
Robin) *I* (I, said the fly)



ay,) *eye* (with my little eye)



die) *fly* (I, said the fly)



thy (Thy kingdom come)

tch. (APPENDIX II.)

ıe.

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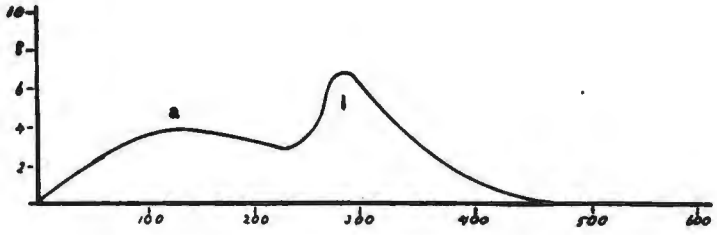
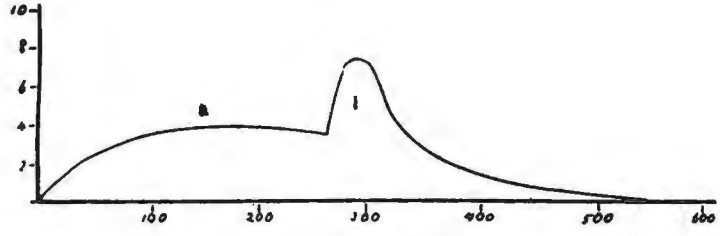
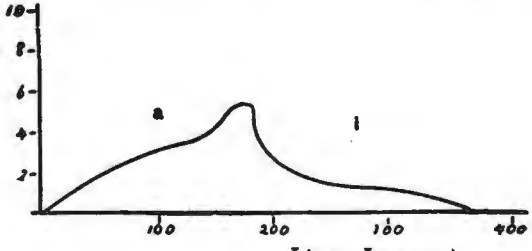


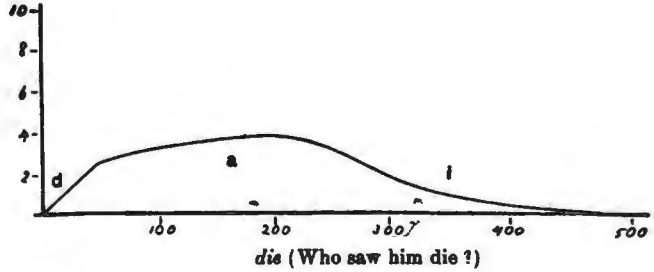
I (I, said the sparrow)



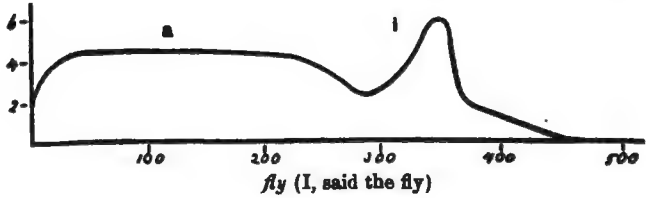
I (I, said the fly)



I (may, I can say)



die (Who saw him die?)



fly (I, said the fly)



thy (Thy

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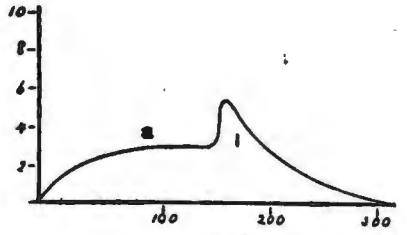
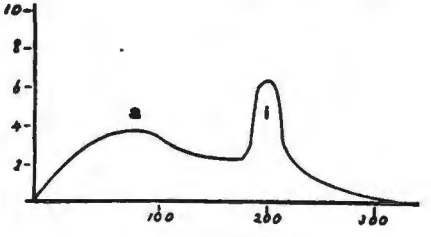
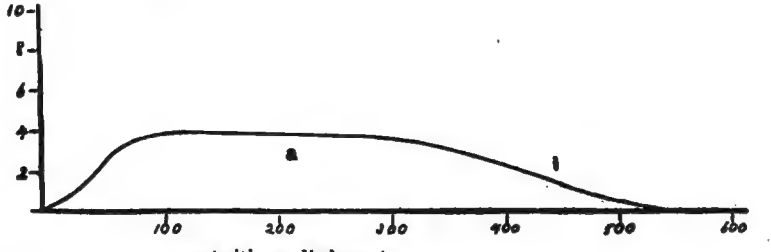
PLATE XVI. *Curves of Amp*



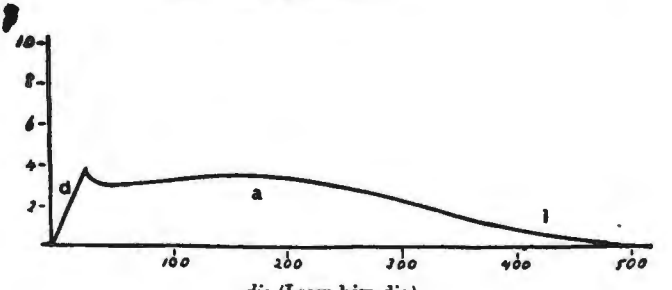
I (I killed Cock Robin)



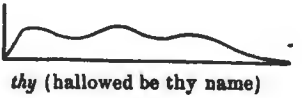
I (I saw him die)



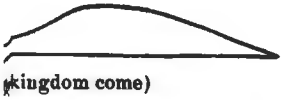
eye (with my little eye)



die (I saw him die)



thy (hallowed be thy name)



kingdom come)

titude. (APPENDIX II.)

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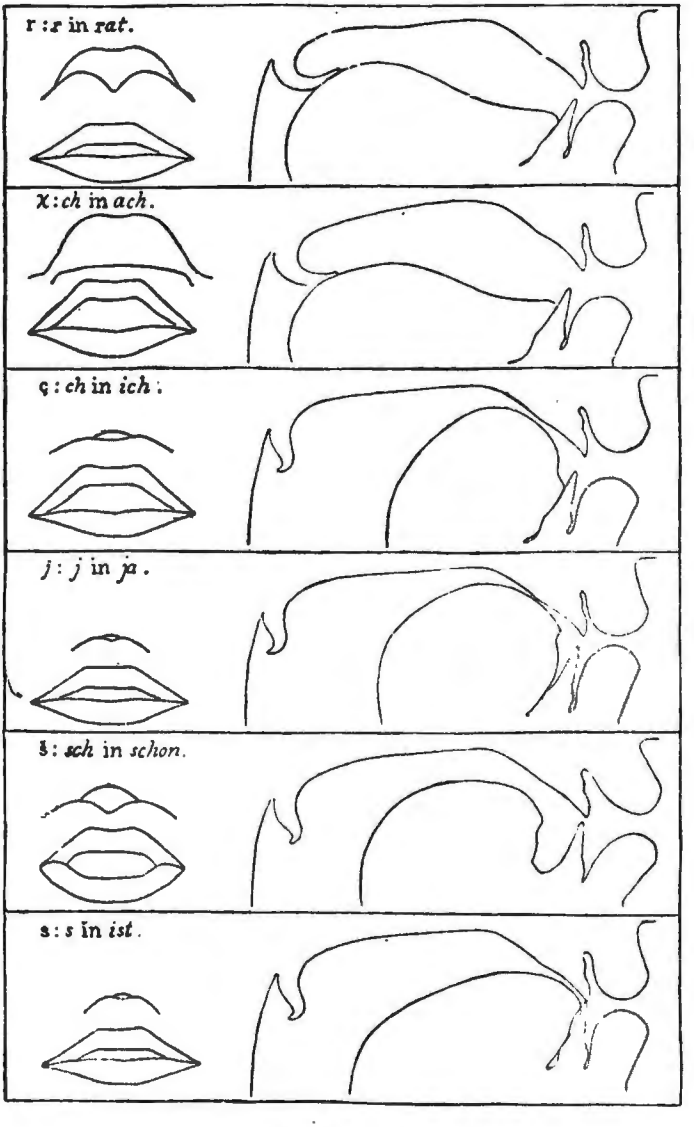

PLATE XVII.

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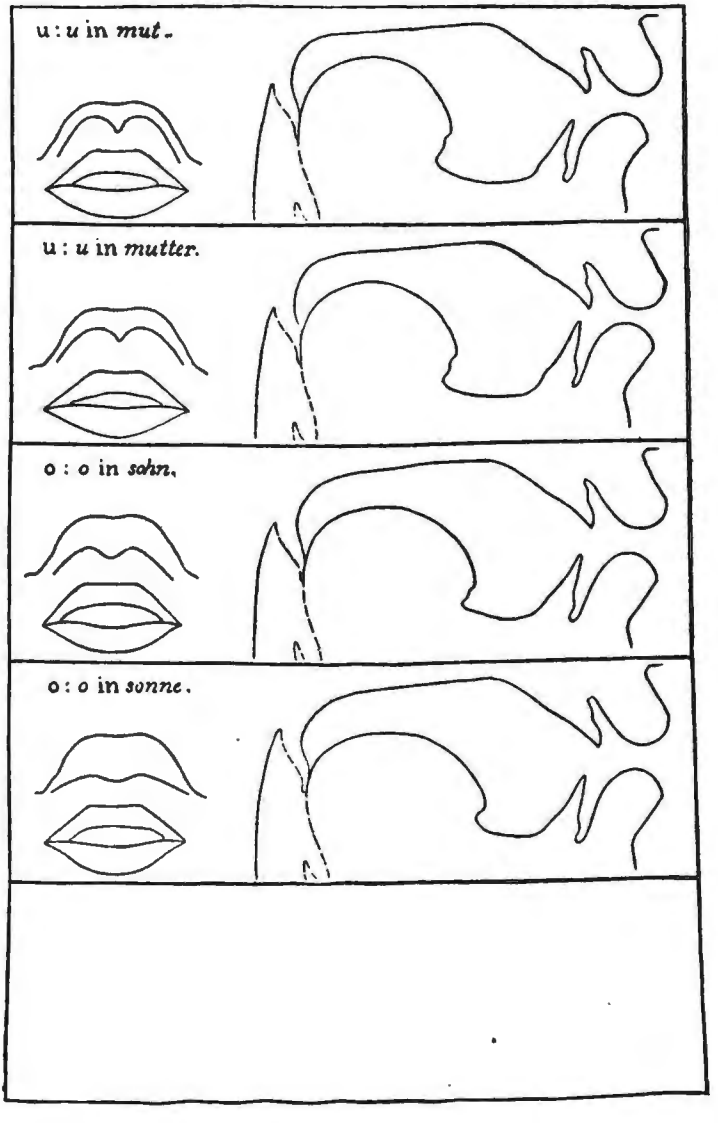

PLATE XVIII.

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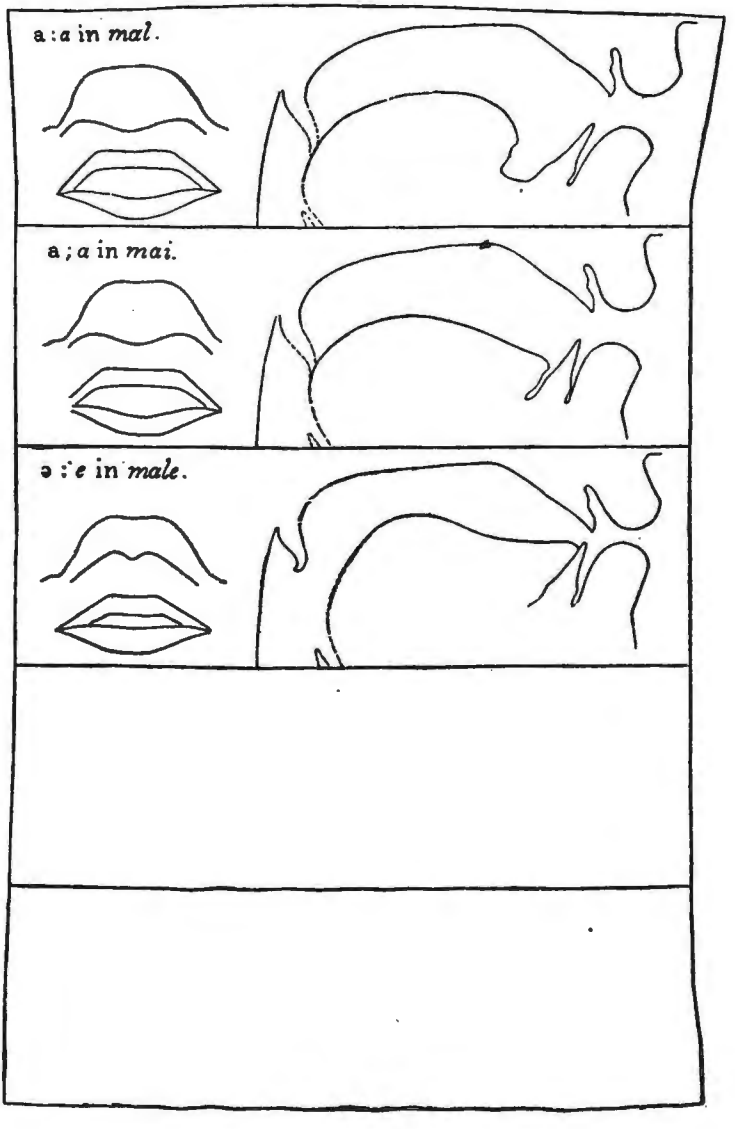

PLATE XIX.

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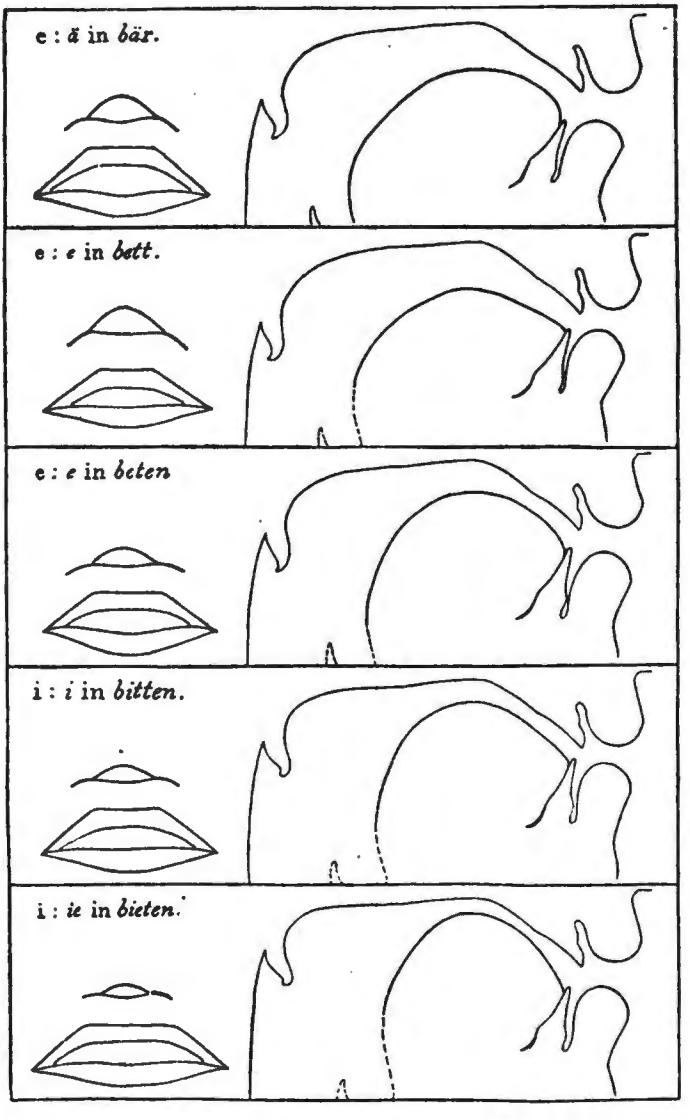

PLATE XX.

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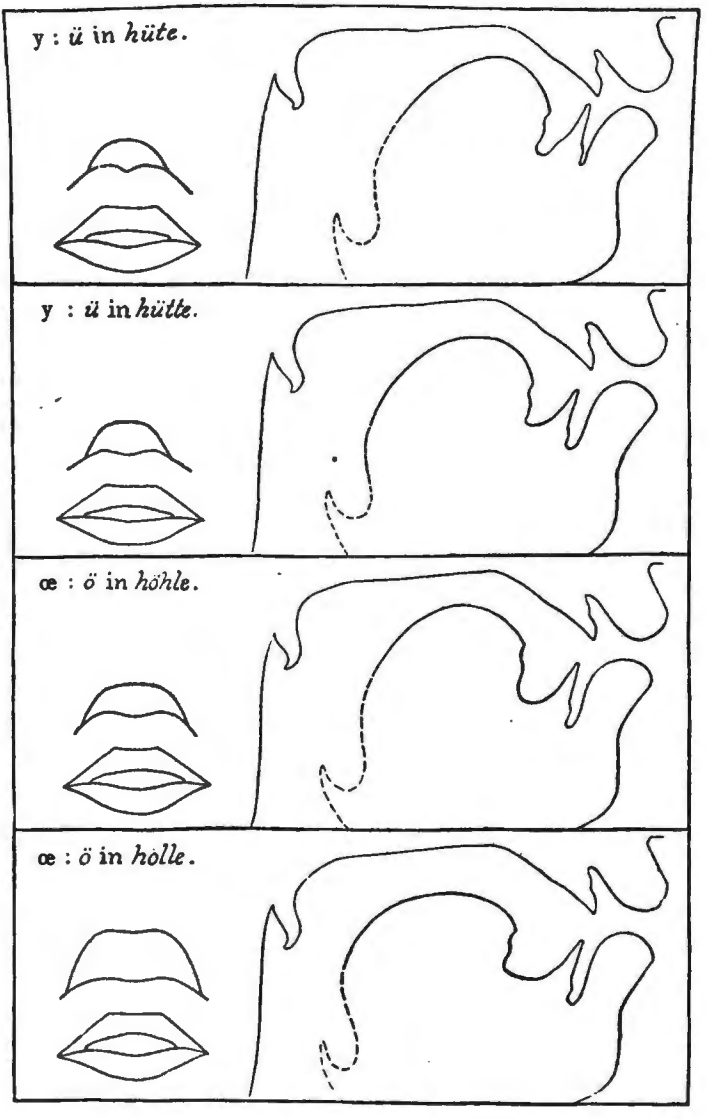

PLATE XXI.

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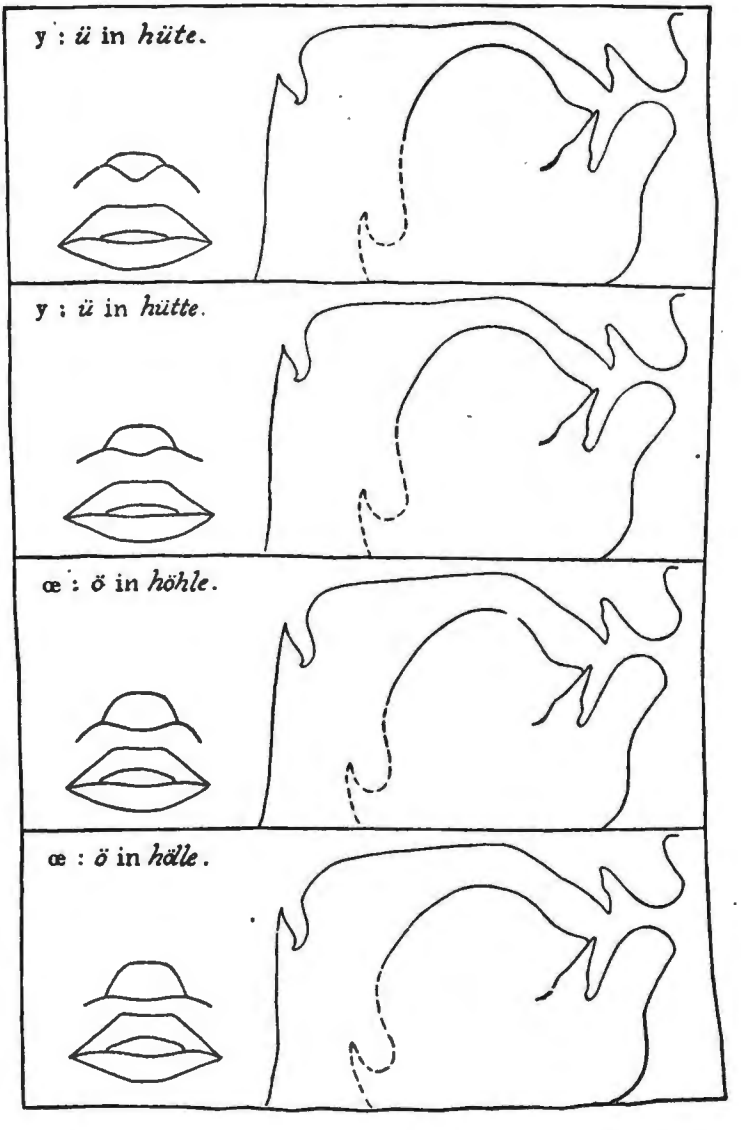

PLATE XXII.

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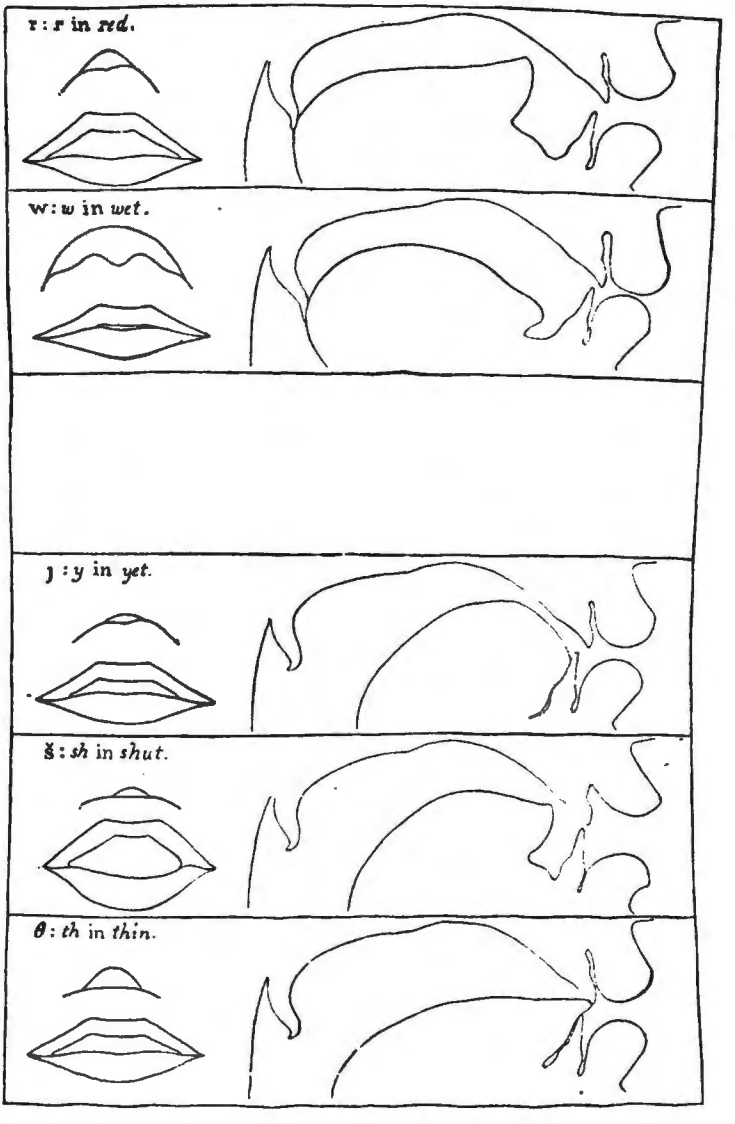

PLATE XXIII.

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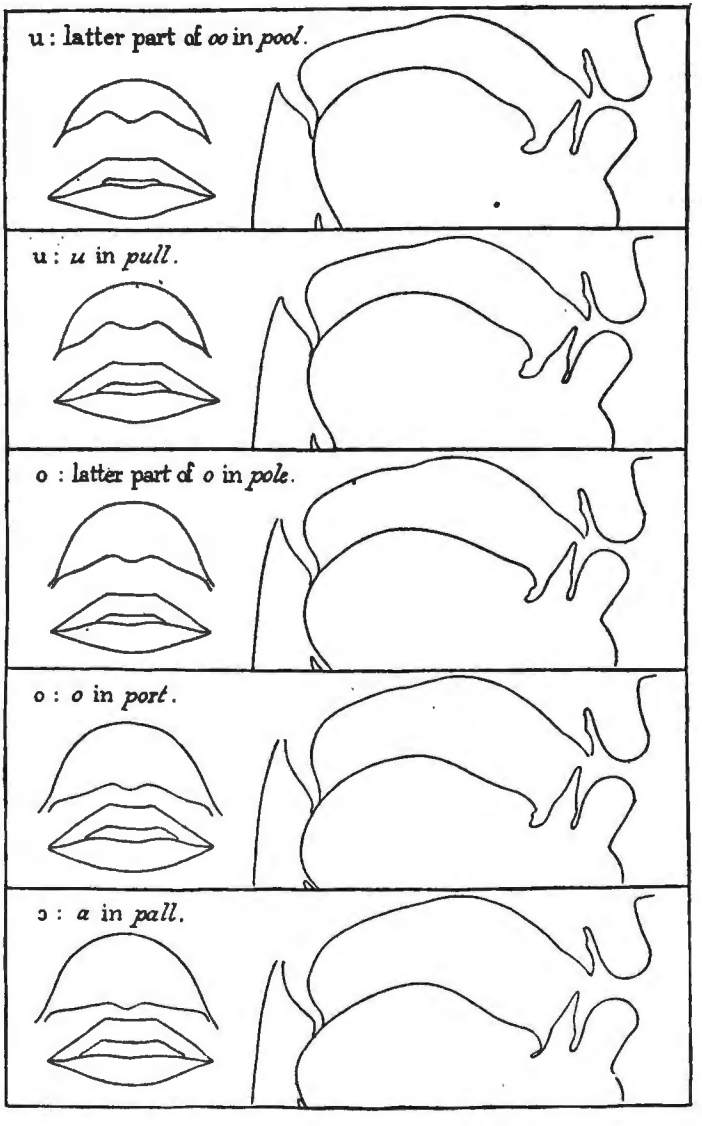

PLATE XXIV.

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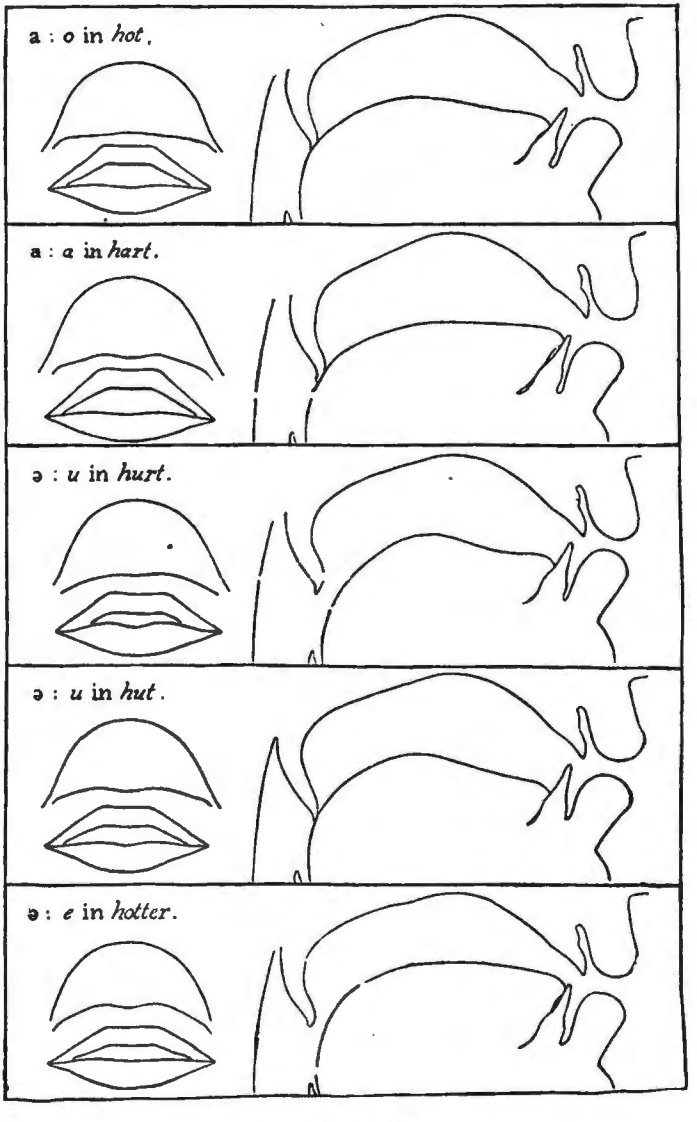

PLATE XXV.

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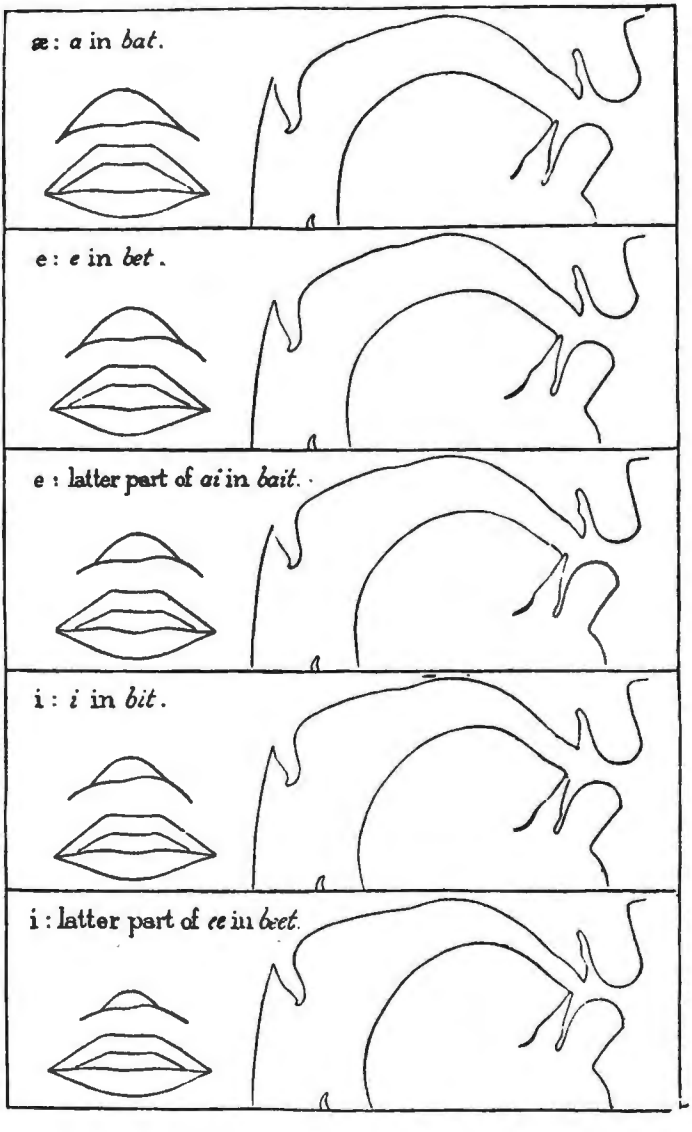

PLATE XXVI.

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