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NATIONAL HISTORY

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*** *The* PLATES *are wrong numbered, but may be distinguished by observing that some are marked with Arabic and some with Roman numerals.*

PLATE 1. refers to Mr. Airy's Paper on the Spherical Aberration of Eye-pieces, No. I.

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4. refers to Mr. Willis's Paper on Vowel Sounds, No. X.

6. refers to Mr. Challis's Paper on the Vibrations of Elastic Fluids, No. XI.

7. refers to Mr. Miller's Paper on Crystals, No. XV.

8. ——————————————— No. XIX.

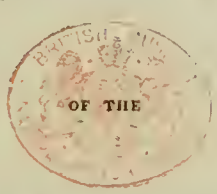
9. refers to Mr. Coddington's Paper on the Microscope.

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TRANSACTIONS



CAMBRIDGE

PHILOSOPHICAL SOCIETY.

VOL. III PART I.

X. *On the Vowel Sounds, and on Reed Organ-Pipes.*

By ROBERT WILLIS, M.A.

FELLOW OF CAIUS COLLEGE, AND OF THE PHILOSOPHICAL SOCIETY.

[Read *Nov.* 24, 1828, and *March* 16, 1829.]

The generality of writers who have treated on the vowel sounds appear never to have looked beyond the vocal organs for their origin. Apparently assuming the actual forms of these organs to be essential to their production, they have contented themselves with describing with minute precision the relative positions of the tongue, palate and teeth, peculiar to each vowel, or with giving accurate measurements of the corresponding separation of the lips, and of the tongue and uvula, considering vowels in fact more in the light of physiological functions of the human body than as a branch of acoustics.

Some attempts, it is true, have been made at various times to imitate by mechanical means the sounds of the human voice. Friar Bacon, Albertus Magnus, and others, are said to have constructed machines of this kind, but they were probably mere deceptions, like some contrivances which may be found in the works of Kircher and other writers of the same description*,

* Kircher. *Musurgia*, p. 303. Bp. Wilkins. *Dædalus*, p. 104. Schottus. *Mechanica. Hyd. Pneum.* p. 240, and *Magia Univ.* II. 155. B. Porta. *Magia Nat.* p. 287. The *Invisible Girl* was a contrivance of this kind. See *Nich. Journ.* 1802, p. 56, 1807, p. 69.

The abbè Mical (according to Rivarol)* made two colossal heads which were capable of pronouncing entire sentences, but the artist having destroyed them in a fit of disappointment at not receiving his expected reward from the government, and having left no trace of their construction, we are left completely in the dark, as to the means employed by him to produce the different sounds. He died about the year 1786. The only attempts which have a claim to a scientific character, are those of Kratzenstein and Kempelen; these gentlemen were both occupied about the year 1770, in the mechanical imitation of the voice, and have both in the most candid manner disclosed the means employed by them, and the results of their experiments, the first in a prize Essay presented to the Academy of Petersburgh in 1780†, the second in a separate treatise‡.

Kratzenstein's attempts were limited to the production of the vowels *a*, *e*, *o*, *u*, *i*, by means of a reed of a novel and ingenious construction attached to certain pipes, some of them of most grotesque and complicated figure, for which no reason is offered, save that experience had shewn these forms to be the best adapted to the production of the sounds in question.

Kempelen's treatise abounds with original and happy illustrations, and the author is no less remarkable for his ingenuity and success, than for the very lively and amusing way in which he has treated his subject. None of these writers, however, have succeeded in deducing any general principles.

---

* Rivarol. *Discours sur l'universalitè de la langue françoise.* Borgnis. *Traitè des machines imitatives*, p. 160.

† The abstract of this Essay will be found in the *Act. Acad. Petrop.* for 1780, and the whole Essay in the *Journal de Physique*, Vol. XXI. See also Young's *Nat. Phil.* I. p. 783.

‡ *Le Mecanisme de la parole suivi de la description d'une Machine parlante, par M. de Kempelen. Vienne* 1791. Dr. Darwin must also be reckoned among the mechanical imitators of speech. See *Darwin's Temple of Nature* 1803, Note XI.

Kempelen's mistake, like that of every other writer on this subject, appears to lie in the tacit assumption, that every illustration is to be sought for in the form and action of the organs of speech themselves*, which, however paradoxical the assertion may appear, can never, I contend, lead to any accurate knowledge of the subject. It is admitted by these writers†, that the mouth and its apparatus, was constructed for other purposes besides the production of vowels, which appear 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 soon induced me, upon entering on this investigation, to lay down a different plan of operations; namely, neglecting entirely the organs of speech, to determine, if possible, by experiments upon the usual acoustic 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

* Kempelen's definition of a vowel, for instance, is deduced entirely from the organs of speech, "Une voyelle est donc un son de la voix qui est conduit par la langue aux lèvres, qui "le laissent sortir par leur ouverture. La différence d'une voyelle à l'autre n'est produite que "par le passage plus ou moins large que la langue ou les lèvres, ou bien ces deux parties "ensemble accordent à la voix." §. 106.

† Kempelen, §. 98.

destined for the performance of their other functions, from those which are immediately peculiar to speech (if such exist.)

In repeating experiments of this kind, it must always be kept in mind, that the difference between the vowels, depends entirely upon contrast*, and that they are therefore best distinguished by quick transitions from one to the other, and by not dwelling for any length of time upon any one of them. A simple trial will convince any person, that even in the human voice, if any given vowel be prolonged by singing, it soon becomes impossible to distinguish what vowel it is.

Vowels are quite a different affection of sound from both pitch and quality, and must be carefully distinguished from them. By quality, I mean that property of sound, by which we know the tone of a violin from that of a flute or of a trumpet. Thus we say, a man has a clear voice, a nasal voice, a thick voice, and yet his vowels are quite distinct from each other. Even a parrot, or Mr. Punch, in speaking, will produce A's, and O's, and E's, which are quite different in their *quality* from human vowels, but which are nevertheless distinctly A's, and O's, and E's. Again, as to pitch, all the vowels may be sung upon many notes of the scale, but of this more hereafter.

Euler† has discriminated these affections of sound, and dis-

---

* Kempelen has remarked this with his usual acuteness. Describing one of his early experiments, with a machine something like fig. 5, from which he obtained some of the vowels by covering its mouth with his left hand, he says, "J'obtins d'abord diverses voyelles, suivant "que j'ouvrois plus ou moins la main gauche. Mais cela n'arrivoit que lorsque je faisois "rapidement de suite divers mouvemens avec la main et les doigts. Lorsqu'au contraire "je conservois pendant quelque tems la même position quelconque de la main, il me paroissoit "que je n'entendois qu'un A. Je tirai bientôt de ceci la conséquence, que les sons de la "parole ne deviennent bien distincts que par la proportion qui existe entr'eux et qu'ils n'ob-"tiennent leur parfaite clarté que dans la liaison des mots entiers et des phrases." p. 400.

† *De motu aëris in tubis.* Schol. II. and III. Prop. 73. *Nov. Comm. Petrop.* XVI. and *Mem. Acad. Berlin* 1767, p. 354. See also Bacon *Hist. Nat.* §. 290.

tributed them among the different properties of the aerial pulsations as follows. The pitch depends on the number of vibrations in a given time. Loudness on the greater or less extent of the excursion of the particles. Quality and the vowel sounds, he thinks must depend on the form of the curve by which the law of density, and velocity in the pulse is defined, or upon the latitude of the pulse, but this he offers as a mere opinion, unsupported by experiment, save that* to account for the peculiar property of sound, by which we know a flute from a trumpet, &c. he remarks, that as the vibrations of each instrument are excited in a manner peculiar to itself, its pulsations must also follow peculiar laws of condensation and motion, by which he thinks the sound will be characterized.

It is agreed on all hands, that the construction of the organs of speech so far resemble a reed organ-pipe, that the sound is generated by a vibratory apparatus in the larynx, answering to the reed, by which the pitch or number of vibrations in a given time is determined; and that this sound is afterwards modified and altered in its quality, by the cavities of the mouth and nose, which answer to the pipe that organ builders attach to the reed for a similar purpose. Accordingly, the whole of the phenomena I am about to describe, will be found to result from the application of reeds to pipes and cavities of different and varying magnitude.

Now it is important to the success of these experiments, that the tone produced by the reed should be as smooth and pure as possible. The coarse tone of the common organ reed completely unfits it for the purpose, and hence we find both Kempelen and Kratzenstein endeavouring to ameliorate it. Kempelen made the tongue of ivory, and covered its under side as well as the por-

* Schol. II. Prob. 80.

tion of the reed against which it beat, with leather. Kratzenstein succeeded better, by introducing a most important improvement in its construction. Instead of allowing the tongue to beat upon the edge of the reed, he made it exactly to fit the opening, leaving it just freedom enough to pass in and out during its vibrations*. By this construction, when carefully executed, the tone of the reed acquires altogether a new character, becoming more like the human voice than any other instrument we are acquainted with, besides possessing within certain limits the useful quality of increasing its loudness, with an increased pressure of air without altering its pitch.

All the reeds I have made use of are constructed on this principle, in one or other of the forms represented in Figs 1 and 2. They are all attached to blocks *fgh* furnished with a circular tenon *fg*, by which they can be fitted into the different pieces of apparatus represented in the plate; their place in all the figures being distinguished by the letter *R*. In Fig. 1, *ab* is a tongue of thin brass fixed firmly at its upper extremity *a*, but capable of vibrating freely in and out of a rectangular aperture in the side of the small brass tube or reed *ced*† which it very nearly fits. This is the original construction of Kratzenstein. In Fig. 2, *ab* is the tongue, attached at *a*, and capable of vibrating through an aperture, which it very nearly fits, in a brass plate screwed

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* Both these expedients are mentioned by M. Biot (*Physique* II.) but he has ascribed the first to M. Hamel (p. 170) the second to M. Grenié (p. 171) being apparently not at all aware of the existence of these Memoirs of Kratzenstein and Kempelen. There can be very little doubt but that Kratzenstein is to be regarded as the true inventor of this *anche libre*. His paper was published in 1780. See Young's *Nat. Ph.* Vol. I. p. 783.

† This brass tube is the *reed*, I believe, in the modern language of organ builders, and *ab* the *tongue*; but the term *reed* is often applied to the whole machine, and as such I have used it in this paper. In fact, in its primitive form, I suspect the whole was cut out of a single piece of reed or cane near a joint as in Fig. 3, which is copied from Barrington's drawing of the reed of the Anglesey *Pibcorn* (*Archael.* III. 33.)

to the upper surface of the block*. This is similar to the construction of the *Mundharmonicon*, or *Eolina*, lately introduced into this country from the continent, but it appears to have been originally suggested by Dr. Robison†.

My first object being to verify Kempelen's account of the vowels, I fitted one of my reeds *R* to the bottom of a funnel shaped circular cavity open at top, of which *Z*, Fig. 5, is a section (the pipe *TV* standing on the wind-chest in the usual way)‡, and by imitating his directions for the positions of the hand within the funnel, I obtained the vowels very distinctly§. I soon found

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* A section of Fig. 2, is seen in its place at *R*, Fig. 11. In all the other figures *R* is a section of Fig. 1.

† Art. Musical Trumpet. *Enc. Britt.* Supplement to 3d ed. 1801. Works iv. 538. Wheatstone in Harmonicon, Feb. and Mar. 1829.

‡ A reference to Fig. 13, in which a pipe is represented as standing on the wind-chest, will serve to illustrate the subject to persons unacquainted with the structure of the organ, and at the same time afford me an opportunity of defining certain technical terms which I shall be compelled to make use of.

A large pair of bellows kept in motion by the foot, and so constructed as to afford a constant pressure is connected with a long horizontal trunk, or *wind-chest*, of which *klno* is a cross section, and which is therefore constantly filled with condensed air. The upper side of this trunk consists of a very thick board *pkql*, which is pierced with a number of passages similar to *efg*, every one of which is furnished with a valve or *pallet kl* moving on a joint at *k*, and kept closed by a spring *m*; a wire terminating in a knob or key *r*, passes through a hole in the upper board, and rests on the pallet, so that on pressing down this knob the pallet opens and a current of air immediately rushes through the corresponding passage *efg*, and passes into any pipe *AT* which may be placed over the aperture. In this instance *R* is the vibrating reed, to be set in motion by the current. The term *porterent* is always used for that part of the tube *TR* which lies between the reed and the wind-chest, and the term *pipe* for the portion *BA*, which is between the reed and the open air, and it is to be understood that in all the figures the lower end of the tube *TV* is supposed to be placed upon one of the holes of the wind-chest. The pressure of the air is always measured by the number of inches of water it will support in a common bent tube manometer; this is generally about 3 inches in organs.

§ I think it necessary to mention that the whole of the experiments described in this paper were performed before the Philosophical Society on the same evenings that the paper was read.

that on using a shallower cavity than his, these positions became unnecessary, as a flat board *LM* sliding on the top of the funnel, and gradually enlarging the opening *KL*, would give the series U, O, A, just as well, and by making the funnel much shallower, as in Fig. 4*, I succeeded in getting the whole series in the following order: U, O, A, E, I†. Cylindrical, cubical and other shaped cavities answered as well, under certain restrictions, but I forbear to dwell on this form of the experiment because subsequent ones have rendered this more intelligible, and I merely mention it to shew the steps by which I was led from Kempelen's original experiment.

The success of this attempt induced me to try the effect of cylindrical tubes of different lengths, and for the more complete investigation of this case, I constructed the apparatus represented in Figs. 6 and 7. *TV* is a tube or *portevent* bent at right angles, and connected with the wind-chest at the extremity *T*, this tube terminates in a wooden piston *PQ*, provided with a socket for the reception of the reed *R* which is represented in its place. A piece of drawn telescope-tube *ABCD* is fitted to the piston which is leathered so as to be air-tight, but allows the tube to be drawn backwards or forwards, so as to alter the length of the portion *PB* beyond the reed at pleasure; the horizontal position is given to the tube to make it more manageable. There are other tubes *EFGH* of the same diameter as *ABCD* furnished with sockets at *EG* which fit on to *BD*, and their lengths are different multiples of *AB*‡.

If therefore any reed be fitted to *PQ*, and the tube *AB* be gradually drawn out, it will shew the effect of applying to this

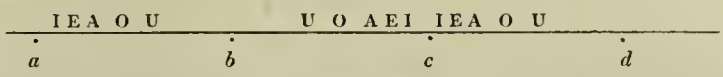
* Kempelen's funnel is 2 inches diameter at the mouth, and 3 inches deep from the mouth to the reed. Fig. 4, is only $\frac{1}{2}$ inch deep and same diameter.

† I use these letters throughout with the continental pronunciation.

‡ The inside diameter of *ABCD* = 1.3 in., its length = 1 ft. 6 in., and the whole length = 12 feet when all the joints are combined.

reed a cylindrical tube of any length from nothing to *AB*, then if the tube be pushed back, and a joint *EF* equal to *AB* be fitted on, a fresh drawing out of the tube will shew the effect of any length from *AB* to double *AB*, and in this way with different joints we may go on to any length we please. The results of experiments with this apparatus, I will describe in general terms,

No. 1.



Let the line *abcd* represent the length *PB* of the pipe measured from *a*, and take *ab*, *bc*, *cd*, &c., respectively equal to the length of the stopped pipe in unison with the reed employed, that is, equal to half the length of the sonorous wave of the reed.

The lines in these diagrams must, in fact, be considered as measuring rods placed by the side of the tube *ABCD* with their extremity *a* opposite to the piston *P*, the letters and other indications upon them shewing the effect produced when the extremity *B* of the pipe reaches the points so marked, and the distance therefore from these points to *a* respectively being the length of the pipe producing the effects in question.

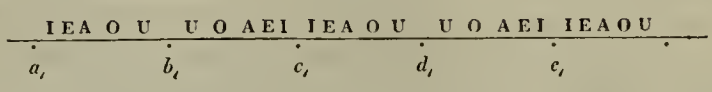
Now if the pipe be drawn out gradually, the tone of the reed, retaining its pitch, first puts on in succession the vowel qualities I E A O U; on approaching *c* the same series makes its appearance in inverse order, as represented in the diagram,

---

* In speaking of musical notes, I shall denote their place in the scale by the German tablature, the octave from tenor *c* to *b* on the third line of the treble is marked once thus *c'*, the next above, twice, *c''* and so on. As a standard for the pitch, I use a pitch-pipe which is made to sound by a small pair of attached bellows yielding a constant pressure of 2.5 in. The internal dimensions are .85 by .9 in., and 1 foot long. *Lumiere* .16 in. An attached scale is gradnated to shew the actual length of the pipe (that is, the distance from the bottom of the pipe to the bottom of the piston) in English inches and decimals.

then in direct order again, and so on in cycles, each cycle being merely the repetition of *bd*, but the vowels becoming less distinct in each successive cycle. The distance of any given vowel from its respective center points *a*, *c*, &c. being always the same in all.

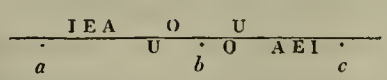
No. 2.



If another reed be tried whose wave $= a_1 c_1$ (No. 2.) the centers of the cycles a_1, c_1, e_1, &c. will be at the distance of the sonorous wave of the new reed from each other, but the vowel distances exactly the same as before, so that generally, if the reed wave $ac = 2a$, and the length of the pipe producing any given vowel measured from $a = v$, the same vowel will always be produced by a pipe whose length $= 2na \pm v$, n being any whole number.

When the pitch of the reed is high, some of the vowels become impossible. For instance, let the wave of the reed $= ac$ (No. 3.) where $\frac{1}{2}ac$ is less than the length producing U.

No. 3.



In this case it would be found that the series would never reach higher than O; that on passing *b*, instead of coming to U, we should begin with O again, and go through the inverse series. In like manner, if still higher notes be taken for the reed, more vowels will be cut off. This is exactly the case in the human voice, female singers are unable to pronounce U and O on the higher notes of their voice. For example, the proper length of pipe for O, is that which corresponds to the note *c*″,

and beyond this note in singing, it will be found impossible to pronounce a distinct O.

The short and long U however are indefinite in their lengths, the short U (as in *but*) seems to be the natural vowel of the reed, and as this is but little affected by the pipe, except in loudness, between O and *b* (No. 1.) this vowel will be found to prevail through a long space, and upon approaching *b*, to change gradually into the long U, (as in *boot*), which always appears more perfect the longer the distance *ab* can be made. When reeds of high pitch are used (as in No. 3.) the vowels always become indistinct in the neighbourhood of *b*, and with bass reeds there appears to be a series of vowels like the former, on both sides the points *b*, *d*, &c. (No. 1.) but differing from the other, both by being much less distinct, and also by each vowel occurring at twice the distance from these points that it does in the other series from *a*, *c*, &c. after the manner of No. 4, where this new series is marked with an accent.

No. 4.

I E A O U A′ E′ I′ I′ E′ A′ U O A E I

a *b* *c*

Cylinders of the same length give the same vowel, whatever be their diameter and figure. This may be conveniently shewn, by attaching a reed *R*, Fig. 11, to a portevent *T*, terminating in a horizontal flat plate *WX* covered with soft leather*. Tin or wooden tubes of any figure, open at both ends, and made flat at the bottom so as to fit air-tight to the leather plane, may then be applied, as in the figure, and their effect upon the reed tried. Another such leather plane, Fig. 12, may be provided, but furnished with an embouchure at *W*, like that of a common

* The diameter of my plate = 3 inches.

organ-pipe. By means of this, we can ascertain the note proper to any cavity, such as the cone $\mathcal{Z}$ placed above it in the figure. If this be transferred to the former plane its vowel will be ascertained.

As far as I have tried this, I have always found that any two cavities yielding the identical note when applied to Fig. 12, will impart the same vowel quality to a given reed at Fig. 11, or indeed to any reed, provided the note of the reed be flatter than that of the cavity, according to the principle explained in No. 3*.

The vowel distances in the first series, that is, those measured from *a* (No. 1.) are always rather less than those measured from the center points *c*, *e*, &c. This diminution varies with different reeds, and appears to be due to some disturbing effect of the reed itself, or the short pipe annexed to it which I have not been enabled as yet to examine so satisfactorily as I could wish. For this reason I have preferred in the following table obtaining the vowel lengths from the second and third series, by bisecting their respective distances from each other measured across *c*, which appear liable to no such alterations. These lengths, in inches, occupy the third column. For want of a definite notation, I have given in the second column the English word containing the vowel in question. The fourth contains the actual note of the musical scale corresponding to a stopped pipe of the vowel length, supposing O to yield c'' which it does as nearly as possible. In effect its length = 4.7 inches which with Bernouilli's correction† gives 4 inches for the length of the pitch pipe, and this will be found to give c''.

* We can now connect the results of Figs. 4 and 5 with those of Fig. 6. If the cavity *Z*, Fig. 4, be placed on Fig. 12, and the flat board *EM* slid over its mouth, a scale of notes will be heard. If now any position of *LM* be taken by which *Z* is made to yield the same note as a given cylinder, then both will yield the identical vowel upon Fig. 11.

† *Mem. Ac. Par.* 1762, p. 460. Biot, *Phys.* II. p. 134.

TABLE I.

I	See	.38 ?	g^v
E	Pet	.6	c^v
	Pay	1	d^{iv}
A	Paa	1.8	f'''
	Part	2.2	$d''b$
A^0	Paw	3.05	g''
	Nought	3.8	$e''b$
O	No	4.7	c''
U	But Boot	Indefinite	

I have found this table as correct a general standard as I could well expect; for vowels, it must be considered, are not definite sounds, like the different harmonics of a note, but on the contrary glide into each other by almost imperceptible gradations, so that it becomes extremely difficult to find the exact length of pipe belonging to each, confused as we are by the difference of quality between the artificial and natural vowels. Future experiments, in more able hands than mine will, I trust, determine this matter with greater accuracy, and I should not even despair of their eventually furnishing philologists with a correct measure for the shades of difference in the pronunciation of the vowels by different nations.

A few theoretical considerations will shew that some such effects as we have seen, might perhaps have been expected. According to Euler*, 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

* Prob. 77, and Cors. Schol. to Prop. 76. and Schol. 2 and 3, Prop. 78. in *Nov. Comm. Petrop.* XVI. *Mem. Acad. Berl.* 1767. See also *Enc. Metrop.* Art. Sound, p. 776.

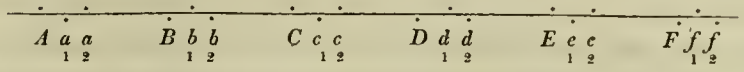
will be formed which will run back again, be reflected from the bottom of the tube, and again present itself at the mouth where a new echo will be produced, and so on in succession till the motion is destroyed by friction and imperfect reflexion. If it be a condensed pulsation that is echoed from the open end of a tube, the echo will be a rarefied one and *vice versâ*, but the direction of the velocity of translation of its particles will be the same. On the other hand when the reflexion takes place from the stopped end, the pulsation retains its density, but changes its velocity of translation. The effect therefore will be the 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.

Let us now endeavour to apply this result of Euler's to the case before us, of a vibrating reed, applied to a pipe of any length, and examine the nature of the series of pulsations that ought to be produced by such a system upon this theory.

The vibrating tongue of the reed will generate a series of pulsations of equal force, at equal intervals of time, but alternately condensed and rarefied, which we may call the primary pulsations; on the other hand each of these will be followed by a series of secondary pulsations of decreasing strength, but also at equal intervals from their respective primaries, the interval between them being, as we have seen, regulated by the length of the attached pipe. Take an indefinite line Af_2 (No. 5) to represent the time, and let *ABC*...&c. be the primary pulsations, $\underset{1}{a}\underset{2}{a}...\underset{1}{b}\underset{2}{b}...$ their respective secondaries, and for simplicity we will suppose that after the third they become insensible, also we will denote a condensed pulse by a stroke above the line, and a rarefied one

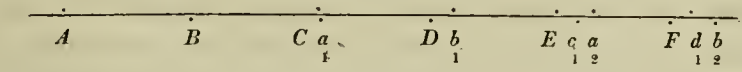
by a stroke below. Suppose in the first place that the intervals of the secondary pulses are less than those of the primaries, and take AB, BC, &c. ($= a$) to represent the primary interval, and $A\underset{1}{a}$, $\underset{1}{a}\underset{2}{a}$, &c. ($= s$) the secondary. The order of the pulses in this case will be evidently that represented in the diagram.

No. 5.



Suppose now that the secondary interval instead of being $= s$, should $= 2a + s$,

No. 6.

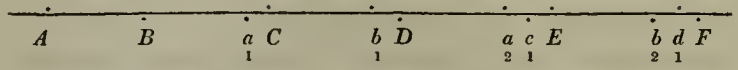


then taking $ABC\ldots$ at equal intervals ($=a$) as before, to represent the primary pulses, we must place $\underset{1}{a}$ at the interval $2a+s$ from A, that is, at the distance s from C, $\underset{2}{a}$ at the distance $2s$ from E, and so on, and similarly for $\underset{1}{b}\,\underset{2}{b}$, &c. but in this way we plainly get, after the four first, a series of pulses precisely similar to those we obtained before, both in order of intervals, succession of intensity, and alternations of condensed and rarefied pulses. If we take the secondary interval $= 4a + s$, we shall find the same series occurring after the eighth primary, and in like manner when the secondary interval $= 2na + s$, we always obtain the same succession of pulses after the $4n$ first which may be neglected, and as we may take the distances AB, $A\underset{1}{a}$, &c. to represent the length of stopped pipes, which give musical notes, the interval of whose pulses are in that ratio respectively; we may say that whatever effect be produced on the ear by applying a pipe, length $= s$ to a vibrating reed whose note is in unison with a stopped

pipe, length $= a$, will also be produced by applying to the same, a pipe, length $= 2na + s$, n being any whole number.

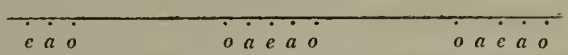
Let now the secondary interval $= 2a - s$, a similar process will give the following series.

No. 7.



This after the four first is exactly similar to the former in the order of the intervals of the pulses, and the alternation of condensation and rarefaction, and only differs from it by the little groups of pulses increasing in intensity in this case, and diminishing in the other, a difference scarcely worth noticing, so that we may now say, that whatever effect be produced by applying a pipe ($= s$) to reed ($= a$), the same will be produced by a pipe $2na \pm s$.

No. 8.



Hence if a given effect a be produced by a pipe whose length is ea (No. 8.) the same will be produced by a pipe whose length is $ee - ea$, $ee + ea$, &c. (taking $ee = 2a$). Again, if another effect o be produced by a pipe $= eo$, the same will be produced by a pipe $= ee - eo$, $ee + eo$, &c. and so on, and in this way it appears that if upon gradually lengthening the pipe we find a certain series of effects produced at the beginning, we shall have the same series in inverse and direct order alternately, the centers of each set of effects being separated by an interval ($= ee$) the length of the open pipe in unison with the reed. So far we find a perfect agreement with experiment, and it is plainly impossible to extend our reasoning much further with respect to the effect which

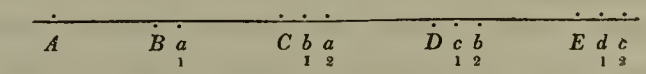
a series of pulsations of this kind might be expected to produce on our organs of hearing.

If we examine the nature of our series, we shall find it merely to consist of the repetition of one musical note in such rapid succession as to produce another. It has been long 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'', and that of the reed c', which is 512 beats in a second, then their combined effect is $g''...g''...g''...g''...$(512 in a second) in such rapid equidistant succession as to produce c', g'' 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'.

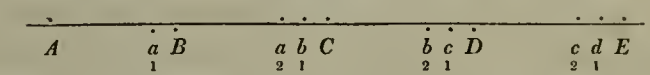
Experiment shows us that the series of effects produced are characterized and distinguished from each other by that quality we call the vowel, and it shews us more, it shews us not only that the pitch of the sound produced is always that of the reed or primary pulse, but that the vowel produced is always identical for the same value of s. Thus, in the example just adduced, g'' is peculiar to the vowel A^0 (Tab. I.): when this is repeated 512 times in a second, the pitch of the sound is c', and the vowel is A^0: if by means of another reed applied to the same pipe it were repeated 340 times in a second, the pitch would be f, but the vowel still A^0. Hence it would appear that the ear in losing the consciousness of the pitch of s, 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, &c. 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. To confirm this, we ought to be able to shew that the note peculiar to each vowel in simple sounds, is identical with that of the secondary pulse in the compound sound, that is, with the note produced by a stopped pipe of the same length as that in Tab. I. corresponding to the given vowel, and as far as I have tried, it appears to be the case, but there is so much room for the exercise of fancy in this point, from the difficulty of fixing on the exact vowel belonging to a simple sound, that I do not mean to insist upon it.

No. 9.



No. 10.



If we were to take the secondary interval $= a + s$ or $a - s$, we should obtain series of pulses like those in Nos. 9 and 10. These being after the two first precisely similar to No. 5, in the order of intervals and succession of intensity, would seem, at first sight, to prove that we ought to have a direct and inverse series of vowels like the others, on both sides of *b*, No. 1,

* Kempelen has a curious remark about this, §. 110....." Il me semble, que lorsque " je prononce des voyelles differentes sur le même ton, elles ont pourtant quelque chose " qui donne le change à mon oreille, et me fait penser qu'il y a une certaine melodie, " qui cependant, comme je le sais très-bien ne peut-être produite que par la variation " des tons en aigus et graves....."

and similarly, if the secondary interval were taken $= a \pm 2\overline{n+1}.s$, we ought to have the same on both sides of *d*, *f*, &c. The pulsations in each of these groups, however, are either all condensed or all rarefied. Near *b*, therefore, they will tend to coalesce, and will scarcely be sufficiently distinguished from each other to impart the vowel quality in the same way that groups of alternate pulsations do. When they suggest any musical note at all, it will plainly be an octave higher than if the pulsations were alternate, because in the latter case, the interval between one *condensed* pulse and another, is twice that in the former. As the vowels have been shewn to be identified by the musical note of the secondary groups, it follows, therefore, that each vowel will, in this new series, be at twice the distance from *b*, *d*, &c. that it is in the original series from *a*, *c*, *e*, &c. I have already mentioned, that vowels of this kind are to be found on both sides of these points, *b*, *d*, &c. (See No. 4.)

Having shewn 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. Robison and others had shewn that a quill held against a revolving 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 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 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 succes-

sion 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.

But there is another remarkable phenomenon to be observed in the experiment with Fig. 6, which, as it is wholly unconnected with the vowels, I have hitherto, to prevent confusion, omitted to notice. I stated that during the experiment the reed retained its pitch, in fact however there is a considerable change in it which I proceed to describe.

In Fig. 18, the indefinite line $abcb'\ldots$ is taken, as before, to represent the measuring rod; the ordinates of the curve, traced below this line as an axis, are the lengths of the pitch-pipe in unison with the note produced by the apparatus, when the extremity of the pipe reaches their respective feet*. Let ab, bc, $cb'\ldots$ be respectively equal to the half-wave of the reed, therefore c is the center of the second series of vowels.

Let the pipe be gradually drawn out; the pitch will remain constant till its extremity approaches f, about midway between a and b. Here the note begins to flatten (which is represented by the increase of the ordinates), proceeding still farther, it continues to flatten till the pipe reaches a point n beyond b, where the note suddenly leaps back to one about a quarter tone sharper than the original, which however it soon after drops gradually to, and preserves till the pipe reaches c; proceeding from c through the successive cycles, the same phenomena will be found at the

* To save room on the plate, but at the same time to shew the real nature of this change of pitch, these ordinates were constructed for the particular case of a reed (pitch $=6.6$) and drawn to the same scale as the rod ($\frac{1}{4}$ of the original) but taken equal, not to the length of the pitch-pipe, but to the excess of its length above six inches. If the line ab were drawn an inch and a half higher up, the ordinates would be exactly proportional to the real ones. (See Note A.)

corresponding points of each, but not in so great a degree. The whole amount by which the note is flattened varies, but is generally about a tone, it is accurately stated in the Tables*.

The point n is by no means fixed, a jerk of the apparatus, a too hasty motion of the pipe, will make the reed leap back to the original note much sooner than it would do with a very gentle and gradual motion; it varies too with different reeds, although their pitch be the same, and it varies with the pressure of the bellows, the note changing sooner with a greater pressure.

Now if we begin from any point beyond n, and shorten the pipe gradually, its extremity may be brought considerably behind n, (say to m) before it leaps back to the other note, so that in fact at any point p between m and n there are two notes pq, pr, which it may be made to produce, neither of them exactly its proper one, but one a little *flatter* and the other a little *sharper*. Some reeds upon fixing the extremity of the pipe between m and n, may be made to change these notes from one to the other by a dexterous jerk of the bellows upwards or downwards, and to retain either of them for any length of time, at pleasure.

With others again there is a point between m and n, where the two notes appear actually to be heard at once, producing a most singular effect. The real fact in this case seems to be that the reed is producing its two notes alternately, but changing quickly and periodically from one to the other, so that they seem to be both going on at once.

To produce these effects completely, a considerable pressure of wind is sometimes required†. Should the reed be stiff, or the pressure on it not sufficiently great, it becomes quite silent for a considerable extent on both sides of p.

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* Vide Note A.

† As much as six inches.

The note always increases in loudness on approaching *f*, and diminishes when it begins to flatten. After the leap it is commonly husky and bad for a little distance, and at every point *c*, that is, whenever the pipe is a multiple of the whole wave of the reed, the tone of the reed appears to be perfectly unaffected by the pipe, and is, if any thing, rather less loud than it would be without it.

Similar phenomena have been imperfectly observed by the old organ builders, and have been described by Robison, who set a reed in a glass foot, and adapted a sliding telescope tube to it. Again by Biot, who also used a glass foot, but made the length of the reed to vary instead of that of the pipe*. All these experiments were made however with the old-fashioned reed, whose oscillations were disturbed by the tongue beating on the edge of the tube, so that the phenomena could not be defined with so much precision as they are, when the free reeds are made use of. To discover how the motion of my reed was affected, I therefore adapted a telescope tube *ABC*, Fig. 17, to a glass *portevent DdEeT*. Behind the tongue *R*, but at such a distance as not to disturb its action, I placed a micrometer scale *mn*, supported by a wire *o*, by which I could measure the extent of its excursions towards *m*, which are very well defined: of course in the other direction they are concealed by the brass reed. I found that the excursions were constant as long as the pitch remained constant: when the flattening or sharpening took place, the excursions were diminished. (See Note B.) The ordinates of the dotted curve above the axis, in Fig. 18. represent the semi-excursions of the reed in this experiment. It was remarked that when the reed was managed so as to produce the double

* *L'Art du Facteur d'Orgues*, par D. B. de Celles, pp. 439, 440. (Vide Note E.) Robison, *Works* IV. 508, and *Enc. Brit.* Biot, *Physique* II. 169.

note, that its excursions were no longer well defined, but it seemed thrown into strange convulsions.

Let us now consider how to account for these effects. We have seen that an aerial wave travelling along a pipe will be regularly deflected backwards from the extremity, changing the sign of its density, and preserving that of its velocity when the pipe is open; but if closed, then retaining the sign of its density, and changing that of its velocity. Let the curve (Fig. 19.) represent in the usual manner, the densities of the series of waves generated from a reed *R*, in a pipe *AB*, and proceeding in the direction of its axis, the ordinates above the axis indicating condensation, and those below, rarefaction.

To take the simplest case, let the pipe be stopped at *A* and *B*. The series therefore will have been reflected from *B* to *A*, and back again continually, diminishing in force each time, till the effect of the waves becomes insensible. The whole effect upon any given particle within the pipe at any time, will, upon the principle of the superposition of small motions, be the sum of the effects produced by all these reflected waves, upon that particle at that moment. If therefore *BA'*, *A'B'*, &c. be taken equal to *AB*, the actual density of every point of the pipe, at the instant when any given portion *R* of a wave is issuing from *A*, will be represented by the curve formed by combining all the alternate portions *AB*, *A'B'* taken directly, with all the portions *BA*, *B'A''*,...&c. taken reversely, and allowing for the gradual diminution of force.

If *B* be open, the curve must at each point *B*, *B'*, &c. be reversed with respect to the axis, as is shewn by the dotted lines, since the density is reversed at the open end of the pipe.

Suppose now that the tube is exactly the length of a wave, as *AB*, (Fig. 20,) and first let *A* and *B* be both closed. In this

case the direct portions $\underset{1}{A}\underset{1}{B}$, $\underset{2}{A}\underset{2}{B}$, &c. will be exactly similar to AB, also all the retrograde portions $\underset{1}{A}B$, $\underset{2}{A}\underset{1}{B}$ will be exactly similar whatever portion of the wave is issuing from A, therefore all the direct waves will unite and assist each other, and in like manner all the retrograde waves, so that the column of air in the pipe will vibrate in the well known manner of a common organ-pipe. We should obtain a similar result if the pipe had been taken equal to any multiple of the wave.

But if B be open, the alternate portions $B\underset{1}{B}$, $\underset{2}{B}\underset{3}{B}$, &c. will be inverted: in this case $\underset{1}{A}\underset{1}{B}$ being exactly similar to AB, but on the opposite side of the axis, will tend to counteract it; again $\underset{2}{A}\underset{2}{B}$ destroys $\underset{1}{A}\underset{1}{B}$ and so on, and in like manner the retrograde waves alternately tend to neutralize each other, so that, in fact, were it not for the gradual decay of the secondary pulsations, there ought to be no sound at all in this case.

Again, if we consider a tube ab equal in length to half a wave, we shall find, in a similar way, that when b is stopped, the secondary pulses mutually *interfere* and destroy each other, and when open that they strengthen each other, and the same results would be found if the length of the pipe were taken equal to any odd multiple of the half wave. In the same way we may examine the case of pipes open at both ends, and so generally we find, that in pipes stopped or open at both ends, the pulsations strengthen each other when the pipe equals a wave or its multiple, and destroy each other when the pipe equals a half wave or its odd multiple, and that in pipes stopped at one end, the reverse is the case.

This mutual destruction of the pulsations, when the pipe is a multiple of the wave is confirmed by experiment. It has been shewn that such a pipe rather weakens than strengthens the tone of the reed.

We may now be partly able to see how the reed is affected

by different lengths of pipe. Its motion, taken alone, is well known to be considerably under the dominion of the current of air by which its pulsations are maintained*, and if a pipe be attached to it, it will plainly be also subjected to the periodic return of the secondary pulsations, by which we may expect to find the time and mode of its oscillations affected. We have seen, however, that when the pipe is about the length of some odd multiple of the half wave, the secondary pulses are united. Here it is then that we may look for the greatest disturbance of the motion, and accordingly our experiments have shewn us, that the pitch of the reed, and consequently its oscillations, are only affected on approaching such lengths of the attached pipe. At other lengths it would appear that their impulses being separated, and falling in succession on the reed, are incapable of producing any sensible effect on its motion, although they are able to qualify the tone by imparting to it the vowel qualities.

Now as the reed moves outwards, a rarefied pulse is generated, which travels to the extremity of the pipe, and returns condensed; and supposing the pipe equal half a wave, the beginning of this secondary pulse will just coincide with the extremity of the first, so that as the reed returns, it is met by this reflected pulse, which tends to check the extent of its excursion, and, as it seems, to increase the time. The condensed pulse now generated will, in like manner, present a new secondary rarefied one, which will retard the reed during its outward motion, and so on.

But as the length of the pipe was taken equal to half the wave of the reed in its *free* oscillations, it appears that the wave now produced, since the note is flatter, will be of greater extent,

* Biot, *Physique* II. 167.

so that the pipe may be lengthened to correspond to the new value of the half wave. But this being done, the same reasoning will shew that the excursion of the reed should be still further diminished in extent, and augmented in time; and in this way we may go on increasing the length of the pipe, diminishing the extent of the excursions, and flattening the note, till we reach some point where it will be easier for the reed to oscillate in the original mode, and there it will of course return to that mode of vibration. But the length of pipe at which this change takes place, will manifestly depend upon the elasticity of the reed, and the pressure of the current, and may therefore vary with different reeds and pressures as we have found it to do.

But we have seen that when the interval of the secondary pulses is somewhat greater than that of an oscillation of the reed, there is a slight tendency to accelerate the motion in diminishing its extent. If this once takes place, a similar line of reasoning will shew, that upon shortening the pipe to accommodate it to the new wave, it must go on rising in pitch till it reaches some point where it will be easier for it to vibrate in the other way.

That the lengths of pipe producing all these alterations of pitch are unfavorable to the reed's motion, is proved by the fact, that with them a less weight of wind reduces the reed to silence, although such less weight is quite sufficient to make the reed speak freely with favorable lengths. It also appears by the same test, that the lengths with which the sharpening takes place are considerably more unfavorable to the reed's motion, than those which flatten it.

The fact of certain lengths of pipe being unfavorable to the motion of the reed, naturally recalls the experiments of M. Grenié*. This gentleman found, that with some notes of the scale, he

* Biot, *Physique*, II. 173.

was obliged to alter the length of the *portevent*, or tube conveying the wind from the bellows to the reed, as there appeared to be some given length of *portevent* for each reed, which completely prevented the reed from speaking, but it did not appear that these lengths followed any law. As this phenomena appeared to be of the same nature, as that I have just described, I set about to investigate it with the following apparatus.

By way of *portevent* I took two brass telescope tubes *AB*, *CD*, Fig. 16, sliding tightly over each other, and each a foot in length, the internal diameter of *CD* being .5 inches, at *A* was a socket for the reception of the reed *R*. Two additional tubes (as *EF*), with sockets, served to increase the length, so that by combining the use of these with the slide *BC*, I could try the effect of a *portevent* of any length from one foot to four.

For shorter lengths than this, I made use of a pipe *AB*, Fig. 13, to the end of which was attached a piston *BV*, carrying a reed *R*, and fitting air-tight in the *portevent TVC*, which is represented as standing on the wind-chest of the organ.

The note of the first reed I tried was = 4.7 inches by the pitch-pipe, and upon drawing the piston *BV* up by means of its attached pipe *AB*, the reed refused to speak, when *TV* = 3.4 in. and sounded again when *TV* = 5.5

Now according to the former experiments, this should have begun to happen when *TV* was nearly equal to the half wave; but the note of the reed I employed = 4.7 inches by the pitch-pipe, which, corrected by Bernouilli's Table, gives about 5.3 for the half wave, so that the *portevent* was much too short for my theory*. The cause of this anomaly appeared to lie in the short passage *efg* already described, which conveys the wind from the

* Especially as the waves in these experiments always come out rather *longer* than the corrected length of the pitch-pipe, (See Note A.)

wind-chest to the *portevent*. To get rid of this, I fairly set the end of the *portevent* into the lid of the bellows, as represented in Fig. 14, so that the lower extremity T' of the pipe, or vibrating column, should be perfectly well defined. Now indeed the reed became silent, when $T'V' = 5.9$, and spoke again at about 8, leaving a difference in length from the former experiment of 2.5 inches, so that there can be little doubt, but that the passage *efg* is to be reckoned as part of the *portevent*, and perhaps may serve to account for the anomalous results obtained by M. Grenié. Pursuing this enquiry, by means of the longer tubes, Figs. 15, and 16, I found as I expected, that these intervals of silence, flattening, &c. occurred regularly, whenever the *portevent* was made nearly equal to some odd multiple of the half-wave of the reed*. There are faint indications of vowels in this case. (See Note C).

I shall conclude with a few experiments, which appear to confirm the views already laid down. Take a piston *MN*, Fig. 8, very nearly of the diameter of the tube *ABCD*, Fig. 6.† By means of the slender handle *o*, it may be made to slide up and down the tube, as represented in Fig. 8. If this is done, the sound of the reed goes on without interruption, putting on, but rather less distinctly than before, the vowel qualities, in direct and inverse order alternately, corresponding to the length of tube *BN*, between the end of the piston and the mouth, whatever be the length of *PB*: while, on the other hand, whenever the length *PM* is made nearly equal to the whole wave of the reed, or some multiple of it, the flattening and other phenomena take place,

* As therefore there are certain lengths of *portevent*, which prevent the reed from speaking, it is necessary to have the power of adjusting *TVR*, Fig. 6, to the reed made use of: this is done by a sliding joint at *V*, which may be fixed to the required length by a clamp, all this is omitted in the figure to avoid confusion.

† Diameter of tube = 1.3 in., of piston = 1.25 in.

which in the former experiments were found to occur only at odd multiples of the half length. In this case, one portion of the pulses generated by the reed, is propelled past the sides of the piston to the mouth of the pipe, and thence echoed backwards and forwards between *B* and *N*, producing the vowels, and the remaining portion echoed between *M* and *P*, as if *PM* were a pipe stopped at both ends, in which case we have seen that the secondary pulses unite, and therefore disturb the motion of the reed, when the pipe equals the whole wave, or a multiple of it.

If the reed *R*, instead of being inserted into the piston as in Fig. 6, be fixed to the end of a slender tube *WR*, (Fig. 9), which slides air-tight through a collar of leather attached to the piston, so that the length *PS* admits of alteration at pleasure, the vowels and other phenomena are still found to depend upon the length *PB*, (all those of course that would have been produced from *P* to *S* being lost.)

If the reed be attached to the end of a *portevent TVR*, (Fig. 10), and presented to the tube *ABCD*, which is provided with a solid piston *PQ*, the vowels and other phenomena are still produced as before, and still depend upon the actual length *PB* of the greater tube.

There is one curious circumstance about the two last experiments, that although the flattening takes place only when *PB*, (Figs. 9, and 10.) is equal to the half wave of the reed, or some odd multiple of it, the amount of it varies with the distance of the reed from the mouth of the tube; being greatest, when *BS* is the half wave, or an odd multiple of it, and almost imperceptible, when *BS* is the whole wave, or a multiple, or when *BS* vanishes, that is, when the reed is exactly at the mouth of the pipe*. This appears to depend upon the different variation

* See Note (D).

of density, at different parts of the pipe. We have seen, that when the pipe was equal to the half wave, or its odd multiples, that the variation of density took place as in a common organ-pipe, being nothing at the mouth, or at a multiple of the wave from it, where our flattening nearly disappears, and greatest at the distance of the half wave, or its odd multiples, where our flattening is greatest. Now as it has been shewn, that this alteration of pitch is occasioned by the reaction of the secondary pulses which disturb the motion of the reed by a periodic variation of density, it is clear, that if in the stratum of air *S*, (Figs. 9, and 10,) where the reed is placed, this variation is destroyed or diminished by the pulses returning from *BD*, that the effect on the reed's motion will be proportionally diminished.

Lastly, if instead of presenting a stopped pipe to a reed, as in Fig. 10, we substitute one open at both ends, such as a telescope without the glasses, or for shorter lengths, tin tubes, the flattening takes place when the tube equals the wave, or a multiple of it, and the vowels at double the length they did with stopped pipes. That this ought to happen is plain from what has been already said, and from the explanation of Nos. 9, and 10, which it will be easily seen, are the vowel diagrams for this case.

Some useful hints may now be deduced, for improving the construction of the reed-pipes of organs. Organ builders have been in the habit of attaching pipes to reeds, for two purposes. First, as in the ordinary reed stops, by applying to the reed a conical pipe, giving the same note, they hoped that the vibrations of reed and pipe would assist each other, and the whole effect be improved, and this view of the matter has always been taken by the theorists: the builders however have been perplexed by finding the motion of the reed obstructed, and its note flattened by such a pipe, and have therefore always made the pipe

a little sharper than the reed, and its principal use appears to be, that by its conical shape, it augments the loudness of the note, on the principle of the speaking trumpet. But we have seen, that although when the reed and pipe give the same note, the undulations of the pipe disturb the motions of the reed, whether the pipe be open or stopped at both ends, or stopped at one end only; (always recollecting that the organ builder's reed-pipe must be considered as stopped at the reed end), yet that the amount of this disturbance varies with the place of the reed in such a pipe, being greatest at the bottom of the pipe, and least at its mouth*, so that it seems that the place hitherto chosen for the reed is the worst possible, and that it ought rather to be at the mouth of the pipe, in short that the best arrangement would be that of Fig. 10, supposing the reed to be at *BD*, and the pipe placed vertically. This too would give the means of conveniently tuning the pipe to the reed by the plug *PQ*. With this arrangement the note of the reed is greatly augmented, and its motions being undisturbed, it speaks more readily.

The other application of pipes to reeds has been in the vox-humana stop, where very short pipes, not in unison with the reed, are employed: the principles of this, however, have never been thoroughly understood, and the whole has always been a puzzle to the builders†.

If by a voxhumana stop, we understand a stop possessing the same vowel quality in every note, the thing is easily to be

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* See Note (D).

† According to Biot, the pipes of the voxhumana are nearly of the same size, (*Phys.* II. 171.) but in the diapason given by B. de Celles, they differ considerably, although very short (*Facteur d'Orgues*, pp. 84, 366). Their form is a cylinder set upon a truncated inverted cone, and half closed at the mouth. The length of $cc = 9.1$ in. diameter 1.4 in. length of $c''' = 3.3$ in. diameter 1 in.

obtained on the principles I have laid down, and I think would be a source of very pleasing variety; but it must be remembered, that there will always be a natural limit to the extent of such a stop upwards, from the impossibility of imparting each vowel quality to the notes of the scale beyond its own peculiar one. Thus we might have an O stop, but it could not extend above c'', an A stop might reach to f''', and an E to d^{iv}*, and so on.

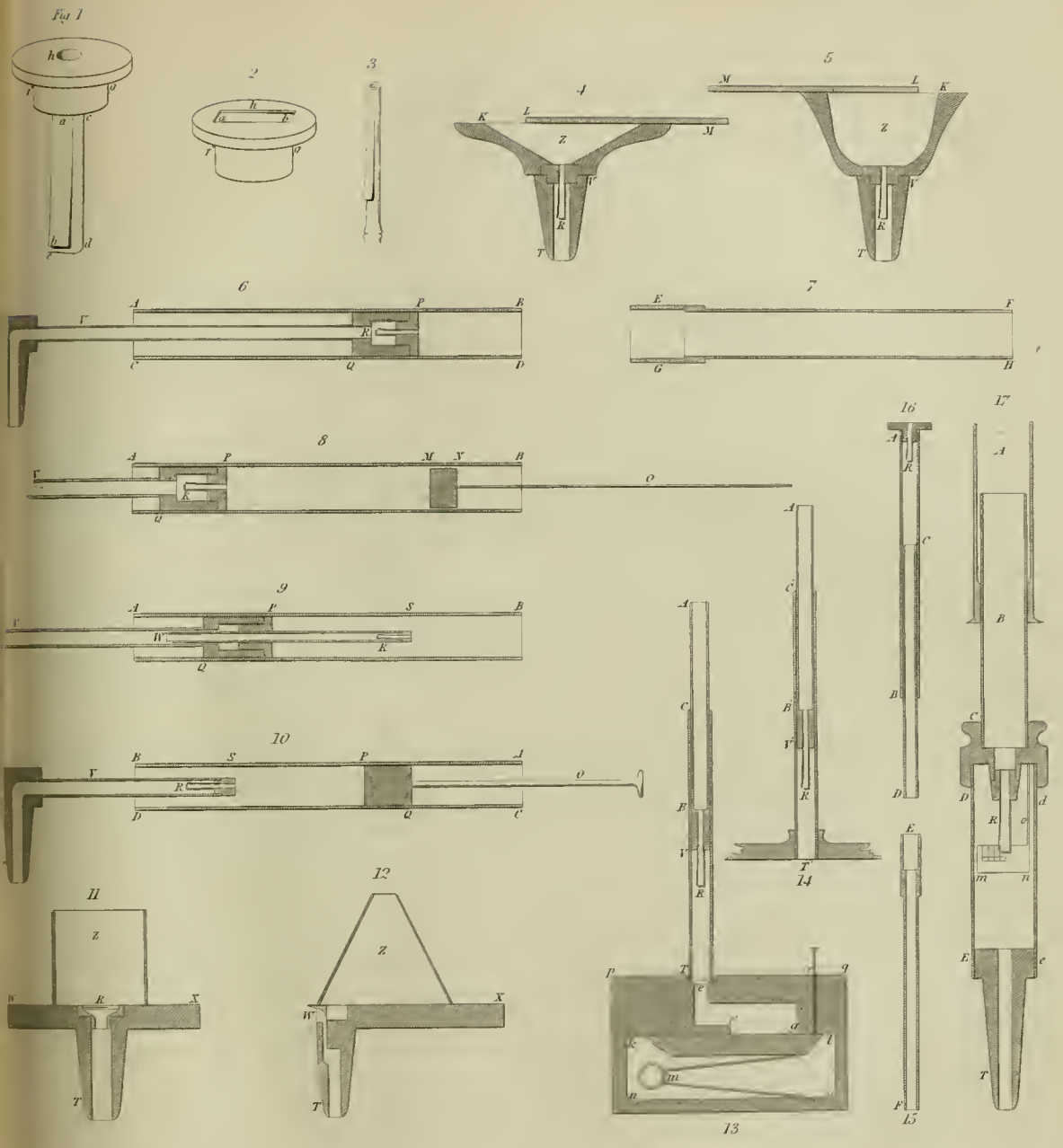
I shall here, for the present, conclude; reserving the application to the action of the human organs, of the facts and principles I have endeavoured to bring forward, to a future opportunity.

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* The pipes attached to the reeds might be made to give E, and shades be brought over all their mouths simultaneously, by a pedal, so as to enable them to give any vowel at pleasure, imitating Fig. 4, where however the cavity *Z* may be made of any convenient form, and the shade *LM* need not rest on its edges, but be made to approach the mouth in any way most suitable to the mechanism employed. The common reeds *may* be used, but their vowels are by no means so distinct as those produced by the free reeds, which should always be employed in experimenting.

ROBERT WILLIS.

CAIUS COLLEGE,
March 16, 1829.



J W Lowry sculp



APPENDIX.

Note A.

The following Table will serve to illustrate the remarks on the change of pitch, and, in fact, is the one from which Fig. 18. was constructed. The pitch of the reed = 6.6 inches or g' nearly. I have in all the Tables denoted the pitch by the actual length of the pitch-pipe, as the most accurate method; all the measures are in inches and decimals.

Table II.

Length of tube *PB*, Fig. 6.		Pitch.	
	4	6.63	
	5	6.71	
	6	6.76	
	7	6.85	
	8	7.1	
1st duplication.....	8.74 = *am*		6.43
	8.8 = *ap*	7.5 or	6.45
	8.89 = *an*	7.55	
	9		6.53
	10		6.6
center of 2nd Cycle	17.1 = *ac*		
2nd duplication.....	26 = *am'*	7.03 or	6.5
	26.45 = *an'*	7.11 —	6.53
center of 3rd Cycle	34.7		
4th duplication.....	43.3	6.96 —	6.53
	44.1	7.01 —	6.58
5th duplication.....	60.7	6.87 —	6.55
	62	6.96 —	6.6

Table III.

Pitch of Reed = 2.5.							
Length of tube at successive doubling points as the pipe was lengthened.	4.75	13.8	23.1	32.15	41.45	50.85	59.9

Table IV.

Pitch of reed, an octave above 4.2. In this case the pitch of the reed being high, the vowels were all lost. The reed, instead of altering its pitch, and doubling at successive periods, became silent for a little space and then resumed its note, but always gradually increasing in loudness to a painful degree, just before its silent places.							
Length at silent points.	2.55	8.9	15.3	21.7	28.05	34.45	40.85
—— when note resumed.	3.65	9.9	16.1	22.55	28.9	35.2	41.6

I have stated that the cycles of phenomena recur at distances equal to the sonorous wave of the reed. I must remark, however, that this distance is always somewhat greater than it ought to be, if calculated from the length of the pitch-pipe corrected by Bernouillis's Table. (Biot. *Phys.* II. 135. *Mem. Acad. Par.* 1762.) The difference is about an eighth or tenth of the wave. Thus,

Reed, Tab. II. by a mean of the different distances gives the half wave..... = 8.8
But pitch = 6.6, and this corrected..... = 7.2

Diff. = 1.6

Reed, Tab. III. gives half wave..... = 4.65
Pitch = 2.5, and corrected..... = 3.4

Diff. = 1.25

Reed, Tab. IV..... half wave = 3.2
Pitch..... = octave above 4.2
Corrected = ... 4.95, ∴ true pitch = 2.475

Diff. = .725

Note B.

Table V. contains a set of experiments with Fig. 17, and may serve to shew the effect which the length of the pipe, and the force of the wind has on the excursions of the reed. The reed employed, was one of those which produced the double sound.

Table V.

Pressure 6 inches.			Pressure 4 inches.			Pressure 2 inches.		
Length.	Pitch.	½ Excursion.	Length.	Pitch.	½ Excursion.	Length.	Pitch.	½ Excursion.
12	11.05	.076	12	10.93	.07	12	11	.046
15	11.52	.06	14	11.13	.066	14	11.1	.03
16	11.6	.05	15	11.3	.056	15	11.3	.03
17		.046	16	11.6	.046		Silence	
18		.036	17	11.8	.034	17	9 6	
18.75		.03	18	Silence		18	10.2	
19	Double	.024?	19	10.65?	.02	20	10.4	.02
19.5		.03	19.4	10.7	.04	21	10.75	.03
20	10.8	.06	20		.052	24 to 33	10.87	.054
21	10.87	.07	21	10.75	.064			
24 to 33	10.9	.08	22 to 33	10.8	.074	40.8	11.2	.030
35	11.05	.076	34	10.83	.074			
39	11.15	.07	35	10.95	.072			
40	11.24	.068	39	11.1	.066			
40.8	11.4	.06	40.8	11.3	.05			

Note C.

Table VI. is a set of results from Fig. 16, applied to the wind-chest, as in Fig. 13. Table VII. is a set from Fig. 13, with the same reed. It will be seen, that in this case the length of AB affects the results as might have been expected.

Table VI.

6 Inches pressure.

Length of DA from Wind-chest.	Pitch.
15.25	5.2
19	5.25
20.75	5.5
22.5	5.7
23.25	5.9
23.4	Leap.
23.9	Fluttering Tone.
24.1	5.1 } Husky
24.5	} Tone.
25	Good.
27.4	5.15
29.8	5.2
32	5.25
34	5.35
35.5	5.4
36.75	5.65
37.6	5.7 and Leap
38.1	5.
38.75	5.1
39.8	5.15
43.5	5.2
49.2	5.35
51.25	5.45
53.5	5.65

Table VII.

	Pitch.		
Length of TV.	$AB=12.$	$AB=20.$	$AB=22.$
3	5.23		
4	5.25		5.45
5	5.3		5.5
6	5.6	5.63	5.65
6.4	5.65	4.75	5.05
	Silence at 6.5		
8	4.75	5.2	5.33
	Tone bad.		
9.2	5.	5.3	5.4
10.7	5.2	5.3	5.45

Note D.

Table VIII. contains a set of experiments with Fig. 10. The tube *ABCD* was fixed with respect to *TVR* in such a manner that *R* was protruded into the tube at distances expressed in the first column. The piston was then moved till the flattening took place, and the note jumped back to the original one, or rather as before-mentioned to one a little sharper. The distance of the piston from the end of the tube, when this took place is seen in the second column. The note to which the pitch had sunk in the third column, and the sharp note to which it returned in the fourth.

Table VIII.

PITCH OF REED, 4.87.

First Leap.

Length of *BS*.	Length of *BP*.	Pitch.	
		Flat.	Sharp.
0	6.45	4.95	
.5	6.38	5.05	
1	6.28	5.1	4.83
2	6.03	5.15	4.65
4	6.06	5.17	4.5
5	6.19	5.23	4.4

Second Leap.

Length of *BS*.	Length of *BP*.	Pitch.	
		Flat.	Sharp.
0	20.78	4.95	
1	20.7	5.05	
2	20.53	5.01	4.85
4	20.58	5.07	4.83
5	20.65	5.16	4.72
6	20.85	5.17	4.75
8	21.	5.13	4.74
10	21.22	5.06	4.73
12	21.2	5.03	4.85
14	20.73	4.94	
16	20.35	5.03	4.83
18	20.3	5.13	4.70

Here the flattening is almost insensible at the mouth of the tube, and when *BS* = about 14, and is greatest midway. As the first leap takes place when *BP* = 6.45, and the second when *BP* = 20.78, we may infer the wave of the reed to be 13.4, nearly, so that here the least effect is produced, when the pipe is nothing or the whole wave, and the greatest when it equals the half wave, as I had stated. The value of *BP* is very nearly constant, and its variations appear to follow a regular law, its mean value being nearly at the half waves.

Note E.

As this book is scarce, I have given the passage, which is curious, (*Facteur d'Orgues*, par D. Bedos de Celles 1766—70, p. 439.)

" On doit remarquer que lorsqu'on veut mettre un Tuyau d'Anche au ton qui lui est propre selon la longueur où il se trouve, on le fait monter en baissant la rasette (je suppose que celle-ci touchoit le coin,) le son devient mâle, harmonieux. Si l'on baisse un peu plus la rasette, le son devient plus doux, plus tendre, mais moins mâle et moins éclatant. Si l'on baisse encore la rasette, le son diminué, il s'éteint et devient sourd; si l'on baisse encore la rasette, le son double, c'est à dire, qu'il monte tout à coup d'un ton ou d'un tierce et quelquefois davantage; il change d'harmonie, et ce son ne vaut rien. On le fait redescendre en rehaussant la rasette, jusqu'à ce qu'il revienne à son vrai ton, qui doit-être mâle, èclatant et harmonieux, jusqu'à faire sentir un Bourdon qui parleroit ensemble avec le Tuyau d'Anche," p. 439.

.... " Pour les éprouver, on mettra la main dessus un instant tandis qu'ils parlent; comme si on vouloit les boucher, alors le Tuyau commencera à doubler; mais il se remettra de lui même au ton aussitôt qu'on aura oté la main. S'il ne se remet pas de lui même, ce sera une marque qu'il sera un peu trop long, &c."..... p. 440.

Erratum.

Page 241, line 11, *for* with bass reeds, *read* with bass and tenor reeds.