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ERRATA.

Page 82, line 22, *for* vibrate, *read* oscillate.
84, 4, *for* parallelopedal, *read* parallopiped.
85, 29, *for* quantity, *read* quality.
88, 5, *for* parallelium, *read* parallelism.
— 27, *for* harp-unisons, *read* harp, unisons.
89, 7, *for* repulsing, *read* repelling.
90, 24, *for* place, *read* plane.
95, 6, *for* Baden Bowell, MA. *read* Baden Powell, MA.
215, 14, from bottom, *for* 100 feet, *read* 1000 feet.
218, 14, *for* Dex, *read* Dax.
232, 15, *for* New England, *read* Connecticut.
299, 10, *for* alternatis, *read* alternis.
371, 6, *for* mean of result, *read* mean of his result.
— 24, *for* potash, *read* alkali.

The notice respecting the Correctness of the Greenwich Observations inserted in p. 397, *and signed X. should have had the signature of "James South, Blackman-street."*

ANNALS

OF

PHILOSOPHY.

AUGUST, 1823.

Article I.

New Experiments on Sound. By Mr. C. Wheatstone.

(To the Editor of the *Annals of Philosophy.*)

On the Phonic Molecular Vibrations.

SIR,

Before I enter on the immediate subject of this article, it may be necessary to exhibit a general view of those bodies, which, being properly excited, make those sensible oscillations, which have been thought to be the proximate causes of all the phenomena of sound. These bodies, to avoid many circumlocutions otherwise inevitable, I have termed Phonics.

Linear Phonics.

Transversal,	*Longitudinal,*
Making their oscillations at right angles to their axis.	Making their oscillations in the direction of their axis.
1. Capable of tension, or variable rigidity: chords, or wires.	1. Columns of aeriform fluids or liquids: cylindric and prismatic rods.
2. Permanently rigid: rods, forks, rings, &c.	

Superficial Phonics.

1. Capable of tension: extended membranes.
2. Permanently rigid; laminæ, bells, vases, &c.

Solid Phonics.

1. Volumes of aeriform fluids.

The sensation of sound can be excited by any of these bodies when they oscillate sufficiently rapidly, either entire, or divided into any number of parts in equilibrium with each other. The laws of these subdivisions differ in the various phonics according to their form and mode of connection or insulation; and the velocities of the oscillations, or degrees of tune, depend on the form, dimensions, mode of connection, mode of division, and elasticity of the body employed. The points of division in linear phonics are called nodes, and the boundaries of the vibrating parts of elastic surfaces are termed nodal lines. The parts at which the oscillatory portions have their greatest excursions are named centres of vibration; these are always at the greatest mean distances from the nodal points or lines.

These mechanical oscillations are not, however, themselves the immediate causes of sound; they are but the agents in producing in the bodies themselves, and in other contiguous substances, isochronous vibrations of certain particles varying in magnitude according to the degree of tune. I convinced myself of this important fact by the following simple experiments: I took a plate of glass capable of vibrating in several different modes, and covered it with a layer of water; on causing it to vibrate by the action of a bow, a beautiful reticulated surface of vibrating particles commenced at the centres of the vibrating parts, and increased in dimensions as the excursions were made larger. When a more acute sound was produced, the centres consequently became more numerous, and the number of coexisting vibrating particles likewise increased, but their magnitudes proportionably diminished. The sounds of elastic laminæ are generally supposed to be owing to the entire oscillations of the simple parts as shown by Chladni, when, by strewing sand over the sonorous plates, he observed the particles repulsed by the vibrating parts, accumulate on the nodal lines, and indicate the bounds of the sensible oscillations. Did no other motions exist in the plate but these entire oscillations, the water laid on its surface would, on account of its cohesion to the glass, show no peculiar phenomena, but the appearances above described clearly demonstrate that the oscillating parts consist of a number of vibrating particles of equal magnitudes, the excursions of which are greatest at the centres of vibration, and gradually become less as they recede further from it, until they become almost null at the nodal lines.

To multiply these surfaces, and to observe whether the magnitudes of these particles vary in different media, in a glass vessel of a cylindric form, I superposed three immiscible fluids of different densities; namely, mercury, water, and oil. On producing the sounds corresponding with each mode of division, I observed a number of vibrating parts, agreeing with the sound, and showing similar appearances to the plate, formed on the surfaces of each of the fluids; not the least agitation appeared

in the uniform parts. I afterwards inserted this glass in another vessel of water in order to observe the vibrations of the external surface, and found the same results as in the interior, though the levels of the surfaces were different.

The most accurate method to observe these phenomena is by employing a metallic plate of small dimensions, which must be fixed horizontally in a vice at one end, and covered on its upper side with a surface of water; on causing it to oscillate entirely by means of a bow, a regular succession of these vibrating corpuscles will appear arranged parallel to the two directions of the plate, and if the action of the bow be rendered continuous, their absolute number might be counted with the aid of a micrometer. Diminishing the oscillating part of the plate to one half of its length, the double octave to the preceding was heard, agreeably to the established rule, that the velocities of the oscillations are inversely as the squares of the lengths; four vibrating corpuscles then occupied the space before occupied by one, and the absolute number was double to that in the former instance; but the absolute number of these corpuscles have no influence whatever on the degree of tune, which entirely depends on their relative magnitude in the same substance; theory shows us that in plates of this description alteration of breadth does not affect the degree of tune; let us, therefore, reduce this half of the plate to half its breadth, and we shall find the note remain the same, but the absolute number of the corpuscles will in this case be equal to that in the entire plate. Let us now take two plates of equal lengths and breadths, but one double in thickness to the other; the rule is, that the velocities of the oscillations are as the thicknesses of the plates; we shall, therefore, in the thicker plate see a double number of particles to that of the other, occupying the same extent of surface. The last circumstance in which two plates may differ is their specific rigidity, and in this respect it will be found that two plates of exactly equal dimensions, and covered with the same number of vibrating corpuscles of equal magnitudes, but of different substances, differ in sound; therefore, the absolute magnitudes of the particles cannot be assumed as a standard of tune, unless regulated by the specific rigidity.

Unassisted by any means of actual admeasurement, the above are but the proximate results sensible to the eye; more extended and accurate experiments are necessary to confirm the results with mathematical certainty. As the absolute magnitudes of these particles will, I imagine, be hereafter a most useful element for calculation, I will here indicate the most effectual way I am acquainted with to arrive at this knowledge. A thick metallic slip of considerable length and breadth, bent similarly to a tuning fork, and fixed at its curved part in a vice, is very easily excited by friction, and a more considerable surface of regularly arranged vibrating particles is seen than in most other superficies; any description of common exciter may be employed,

When this bent plate is excited by percussion, the particles, before their disappearance, will assume an apparent rotatory motion, on account of the force exerted, and its susceptibility of continuing the vibrations. Employing a parallelopedal rod, the appearances of the higher modes of subdivisions are particularly neat; the entire vibrating parts between the nodes form ellipses, and the semi-part at the free end, a regular half of the same figure. It is important to remark, that the crispations of the water only appear on the sides in the plane of oscillation; the other two sides, on one of which the exciter must be applied, do not show similar appearances.

I have also rendered the phonic molecular vibrations visible, when produced by the longitudinal oscillations of a column of air; the following were the means employed: I placed the open end of the head of a flute or flagiolet on the surface of a vessel of water, and on blowing to produce the sound, I observed similar crispations to those described above, forming a circle round the end of the tube, and afterwards appearing to radiate in right lines; on the harmonics of the tube being sounded, the crispations were correspondently diminished in magnitude. These phenomena will be more evident if the tube be raised a little from the surface of the liquid and a thin connecting film be left surrounding it; the vibrating particles will then occupy a greater space, and be more sensible.

The existence of the molecular vibrations being now completely established, it becomes a critical question, in what manner the sensible oscillations induce these vibrating particles. I do not know whether what I am now going to adduce will be admitted as the right explanation, but it is certainly analogous, so far as the superficial and transversal linear oscillations are concerned. A flexible surface, covered with a coat of resinous varnish, being made to assume any curve, the cohesion of the varnish will be destroyed in certain parts, and a number of cracks will be observed more regularly disposed as the force inducing the curve has been more regularly applied; when the original position of the surface is restored, the cracks will be imperceptible, but will again appear at every subsequent motion. Be this as it may, these particles are invariable concomitants of the sensible oscillations, and there is no reason to suppose otherwise than that their vibrations are isochronous with them. To avoid confusion, I have restricted the word vibrations to the motions of the more minute parts, and the term oscillations to those of the sensible divisions. We may reasonably suppose that the molecular vibrations pervade the entire substance of a phonic; their excursions, however, are not the same in all parts, and they can only be rendered visible, when these excursions are large; they may be so few in number as to be entirely inaudible, as in their transmission through linear conductors; but however few, when they are properly directed, they induce the mechani-

cal divisions of sonorous bodies, each of which will give birth to numerous vibrating corpuscles whose excursions are greater, and the sound will be rendered audible. Dr. Savart has well investigated the modes of division in surfaces put in motion by communicated vibrations. All those phonics whose limited superficies preclude them from exciting in themselves a sufficient number of vibrating corpuscles, when insolated, produce scarcely any perceptible sound, as extended chords, tuning forks, &c. but those whose superficies or solidities are more extended, as bells, elastic laminæ, columns of air, &c. produce sufficient volume of sound without accessory means.

Loudness of sound is dependent on the excursions of the vibrations; volume, or fulness of sound, on the number of co-existing particles put in motion. Thus the tones of the Æolian harp, on account of the number of subdivisions of the strings, are remarkably beautiful and rich, without possessing much power; and the sounds of an Harmonica glass, in which a greater number of particles are excited than by any other means, are extraordinarily so united, according to the method of excitation, with considerable intensity; their pervading nature is one of the greatest peculiarities of these sounds.

The following is a recapitulation of the various properties of sound, which are attributable to modifications of the vibrating corpuscles:

The tune	Depends on the	velocities of the vibrations.
The time		continuance of the vibrations.
The intensity		excursions of the vibrations.
The richness, or volume		number of co-existing vibrations.
The quantity (timbre)		magnitudes of the vibrating corpuscles.

It has often been thought necessary to admit the existence of more minute motions than the sensible oscillations, in order to account for many phenomena in the production of sound. Perrault in his "Essai du Bruit," insisted on their necessity more than any other author I have read: he imagined, that the vibrations have a much greater velocity than the oscillations which cause them, but the experiment he adduced to prove this is far from conclusive; he mistook for these vibrations the oscillations of the subdivisions of the long string he employed. Other distinguished philosophers have had ideas of a similar nature, and Chladni thinks their existence necessary to account for the varieties of quality. I, however, conceived I was the first who had indicated these phenomena by experiment, until a few days ago repeating them, together with the others which form the subject of this paper, in the presence of Prof. Oersted, of Copenhagen, he acquainted me with some similar experiments of his own. Substituting a very fine powder, Lycopodion, instead of the sand used by Chladni, for showing the oscillations of

elastic plates, this eminent philosopher found the particles not only repulsed to the nodal lines, but at the same time accumulated in small parcels, on and near the centres of vibration; these appearances he presumed to indicate more minute vibrations, which were the causes of the quality of the sound: subsequently he confirmed his opinion, by observing the crispations of water, or alcohol, on similar plates, and showed that the same minute vibrations must take place in the transmitting medium, as they were equally produced in a surface of water, when the sounding plate was dipped into a mass of this fluid. These experiments were inserted in Lieber's History of Natural Philosophy, 1813.

Rectilineal Transmission of Sound.

As the laws of the communication of the phonic vibrations are more evident in linear conductors, I shall confine the present article to a summary of their principal phenomena.

In my first experiments on this subject, I placed a tuning fork, or a chord extended on a bow, on the extremity of a glass, or metallic rod, five feet in length, communicating with a sounding board; the sound was heard as instantaneously as when the fork was in immediate contact, and it immediately ceased when the rod was removed from the sounding board, or the fork from the rod. From this it is evident that the vibrations, inaudible in their transmission, being multiplied by meeting with a sonorous body, become very sensibly heard. Pursuing my investigations on this subject, I have discovered means for transmitting, through rods of much greater lengths and of very inconsiderable thicknesses, the sounds of all musical instruments dependant on the vibrations of solid bodies, and of many descriptions of wind instruments. It is astonishing how all the varieties of tune, quality, and audibility, and all the combinations of harmony, are thus transmitted unimpaired, and again rendered audible by communication with an appropriate receiver. One of the practical applications of this discovery has been exhibited in London for about two years under the appellation of "The Enchanted Lyre." So perfect was the illusion in this instance from the intense vibratory state of the reciprocating instrument, and from the interception of the sounds of the distant exciting one, that it was universally imagined to be one of the highest efforts of ingenuity in musical mechanism. The details of the extensive modifications of which this invention is susceptible, I shall reserve for a future communication; the external appearance and effects of the individual application above-mentioned have been described in the principal periodical journals.

The transmission of the vibrations through any communicating medium as well as through linear conductors is attended by peculiar phenomena; pulses are formed similar to those in longitudinal phonics, and consequently the centres of vibration and

the nodes are reproduced periodically at equal distances; in this we observe an analogous disposition with regard to light. I had intended to include in this paper all the analogical facts I have observed illustratory of the identity of the causes of these two principal objects of sensation, but want of time, and the danger of delay, now the subject is occupying so much the attention of the scientific world, has induced me hastily to collect the present experiments, and to defer the others for a future opportunity.

The thicknesses of conductors materially influence the power of transmission, and there is a limit of thickness, differing for the different degrees of tune, beyond which the vibrations will not be transmitted. The vibrations of acute sounds can be transmitted through smaller wires than those of grave sounds: a proof of this is easy; attach a tuning fork to one end of a very small wire, and apply the other end to the ear, or a sounding board; on striking the fork rather hard, two co-existing sounds will be produced, that which is more acute will be distinctly heard, but the other will not be transmitted. If the vibrations of a tuning fork be conducted through a piece of brass wire of the size and thickness of a large needle, the sound, imperfectly transmitted, will become more audible by the pressure of the fingers on the conducting wire; but if a steel wire of the same length and thickness be employed, the sound will be unaltered by any pressure, because steel has a greater specific elasticity than brass.

Polarization of Sound.

Hitherto I have only considered the vibrations in their rectilineal transmission; I shall now demonstrate, that they are peculiarly affected, when they pass through conductors bent in different angles. I connected a tuning fork with one extremity of a straight conducting rod, the other end of which communicated with a sounding board; on causing the tuning fork to sound, the vibrations were powerfully transmitted, as might be expected from what has already been explained; but on gradually bending the rod, the sound progressively decreased, and was scarcely perceptible when the angle became a right one; as the angle was made more acute, the phenomena were produced in an inverted order; the intensity gradually increased as it had before diminished, and when the two parts were nearly parallel, it became as powerful as in the rectilineal transmission. By multiplying the right angles in a rod, the transmission of the vibrations may be completely stopped.

To produce these phenomena, however, it is necessary that the axis of the oscillations of the tuning fork should be perpendicular to the plane of the moveable angle, for if they be parallel with it, they will be still considerably transmitted. The following experiment will prove this: I placed a tuning fork perpendi-

cularly on the side of a rectilinear rod; the vibrations were, therefore, communicated at right angles; when the axis of the oscillations of the fork coincided with the rod, the intensity of the transmitted vibrations was at its maximum; in proportion as the axis deviated from parallelism, the intensity of the transmitted vibrations diminished; and, lastly, when it became perpendicular, the intensity was at its minimum. In the second quadrant, the order of the phenomena was inverted as in the former experiment, and a second maximum of intensity took place when the axis of the oscillations had described a semicircumference, and had again become parallel, but in an opposite direction. When the revolution was continued, the intensity of the transmitted vibrations was varied in a similar manner, it progressively diminished as the axis of the oscillations deviated from being parallel with the rod, became the least possible when it arrived at the perpendicular, and again augmented until it remained at its first maximum, which completed its entire revolution.

The phenomena of polarization may be observed in many corded instruments: the cords of the harp are attached at one extremity to a conductor which has the same direction as the sounding board; if any cord be altered from its quiescent position, so that its axis of oscillation shall be parallel with the bridge, or conductor, its tone will be full; but if the oscillations be excited so that their axis shall be at right angles with the conductor, its tone will be feeble. By tuning two adjacent strings of the harp-unisons with each other, the differences of force will be sensible to the eye in the oscillations of the reciprocating string according to the direction in which the other is excited.

It now remains to explain the nature of the vibrations which produce the phenomena, the existence of which has been proved by the preceding experiments. The vibrations generally assume the same direction as the oscillations which induce them; in a longitudinal phonic the vibrations are parallel to its axis; in a transversal phonic, they are perpendicular to this direction; a circular or an elliptic form can be also given to the vibrations by causing the oscillations to assume the same forms. Any vibrating corpuscle can induce isochronous vibrations of similar contiguous corpuscles *in the same plane* either parallel with, or perpendicular to, the direction of the original vibrations, and the polarization of the vibrations consists in the similarity of their directions, by which they propagate themselves equally in the same plane; therefore the vibrations being transmitted through linear conductors, it is the plane in which the vibrations are made that determines their transmission, or non-transmission, when the direction is altered. A longitudinal or a transversal vibration may be transmitted two ways to a conductor bent at right angles; their axis may be in that direction, as to be in the

same plane with the right angle, in which case the former will be transversally, or the latter longitudinally transmitted in the new direction; or their axis may be perpendicular to the plane of this new direction, under which circumstances neither can be communicated.* In explaining the polarization of light, there is no necessity to suppose that the reflecting surfaces act on the luminous vibrations by any actual attracting or repulsing force, causing them to change their axes of vibrations; the directions of the vibrations in different planes, as I have proved exist in the communication of sound, is sufficient to explain every phenomenon relative to the polarization of light.

Let us suppose a number of tuning forks oscillating in different planes, and communicating with one conducting rod; if the rod be rectilinear, all the vibrations will be transmitted, but if it be bent at right angles, they will undergo only a partial transmission; those vibrations whose planes are perpendicular, or nearly so, to the plane of the new direction, will be destroyed. The vibrations are thus completely polarized in one direction, while passing through the new path, and on meeting with a new right angle, they will be transmitted or not, accordingly as the plane of the angle is parallel with, or perpendicular to, the axes of the vibrations. In this point of view, the circumstances attending the phenomena are precisely the same as in the elementary experiment of Malus on the polarization of light.

Double refraction is a consequence of the laws of polarization, by which a combination of vibrations having their axes in different planes, after travelling in the same direction, are separated into two other directions, each polarized in one plane only. That this well-known property of light has a correspondent in the communication of phonic vibrations, I shall now demonstrate. When two tuning forks, sounding different notes by a constant exciter, and making their oscillations perpendicularly to each other, have their vibrations transmitted at the same time through one rod, at the opposite extremity of which two other conductors are attached at right angles, and when each of these conductors is parallel with one of the axes of the oscillations of the forks, on connecting a sounding board with either conductor, those vibrations only will be transmitted through it which are polarized in the same plane with the angle made by the two rods through which the vibrations pass; either sound may be thus

* I have just seen a paper by M. Fresnel, entitled "Considerations Mécaniques sur la Polarization de la Lumiere," in which this eminent philosopher had previously arrived at the same conclusions with respect to light, as I have proved in this communication respecting sound. The important discoveries of Dr. Thomas Young, followed by those of M. Fresnel, have recently re-established the vibratory theory of light, and new facts are every day augmenting its probability. The new views in acoustical science, which I have opened in this paper, will, I presume, give additional confirmation to the opinions of these eminent philosophers; and I hope, when I resume the subject, to be enabled to account for the principal phenomena of coloration, with regard to their acoustic analogies, in a way calculated to establish the permanent validity of the theory.

separately heard, or they may both be heard in combination by connecting both the conductors with sounding boards.

The phenomena of diffraction regarding only the form of the surfaces, or the superficies over which the vibrations extend, are by the conformation of the organs of hearing, not of any consequence to the perception of sound, though the same phenomena when the chromatic vibrations are concerned, are very evident to the eye. They, however, undoubtedly take place equally in both instances, and may be well explained by the theory already laid down. Each separate vibration propagating itself in the plane of its vibrating axis, a number of vibrations in different planes, after passing through an aperture, naturally expand themselves transversely as well as rectilineally, and thereby occupy a greater space than they would, were they only longitudinally transmitted.

I have still to indicate a new property of the phonic vibrations, but whether it is analogous to any of the observed phenomena of light, I am yet ignorant. When the source of the vibrations is in progressive motion, the vibrations emanating from it are transmitted, when the conductor is rectilineal and parallel with the original direction, and they are destroyed when the conductor is perpendicular to the direction, though the axis of vibration and the conductor, being in both instances *in the same place*, would transmit the vibrations were the phonic stationary. These circumstances are proved by the following experiments: When a tuning fork placed perpendicularly to a rod, communicating at one or both extremities with sounding boards, and caused to oscillate with its vibrating axis parallel with the rod, moves along the rod, preserving at the same time its perpendicularity and parallelism, the vibrations will not be transmitted while the movement continues, but the transmission will take place immediately after it has remained motionless. When the tuning fork moves on the upper edge of a plane perpendicular to a sounding board, the vibrations rectilineally transmitted will not be influenced by the progressive motion.

Article II.

On Granite Veins. By M. P. Moyle, Esq.

(To the Editor of the *Annals of Philosophy.*)

DEAR SIR, *Helston, May 7, 1823.*

Various statements and representations, have from time to time been given, of the gigantic granite veins which are so very conspicuous in the slate cliffs about a quarter of a mile east of