Max Planck Research Group
Epistemes of Modern Acoustics

Sound & Science: Digital Histories

Rayleigh, John William Strutt. “On the perception of the direction of sound.“ Proceedings of the Royal Society, Series A 83, no. 559 (1909): 61-64.

https://acoustics.mpiwg-berlin.mpg.de/node/630

Scan licensed under: CC BY-SA 3.0 DE | Max Planck Institute for the History of Science

MAX PLANCK INSTITUTE
FOR THE HISTORY OF SCIENCE

PROCEEDINGS

OF THE

ROYAL SOCIETY OF LONDON

SERIES A

CONTAINING PAPERS OF A MATHEMATICAL AND PHYSICAL CHARACTER.

VOL. LXXXIII.

ZN 1929.2086

LONDON:

PRINTED FOR THE ROYAL SOCIETY AND SOLD BY
HARRISON AND SONS, ST. MARTIN'S LANE,
PRINTERS IN ORDINARY TO HIS LATE MAJESTY.

MAY, 1910.

UNIVERSITÄTS-BIBLIOTHEK
BERLIN

LONDON:
HARRISON AND SONS, PRINTERS IN ORDINARY TO HIS LATE MAJESTY,
ST. MARTIN'S LANE.

CONTENTS.

SERIES A. VOL. LXXXIII.

No. A 559.—November 3, 1909.

PAGE

On the Effect of Previous Magnetic History on Magnetisation. By Prof. Ernest Wilson, G. F. O'Dell, and H. W. K. Jennings. Communicated by Sir William H. Preece, K.C.B., F.R.S. 1

On the Resolving Power of Photographic Plates. By C. E. Kenneth Mees, D.Sc. Communicated by Sir William Ramsay, K.C.B., F.R.S. 10

Thermal Conductivity of Air and other Gases. By George W. Todd, M.Sc., Research Scholar of the University of Birmingham. Communicated by Prof. J. H. Poynting, F.R.S. 19

Experiments to test whether the Secondary γ-Rays are polarised. By R. D. Kleeman, D.Sc., B.A., Research Student of Emmanuel College, Cambridge. Communicated by Prof. E. Rutherford, F.R.S. 40

The Spectrum of Radium Emanation. By Herbert Edmeston Watson, B.Sc., 1851 Exhibition Scholar, University College, London. Communicated by Sir William Ramsay, K.C.B., F.R.S. 50

On the Perception of the Direction of Sound. By Lord Rayleigh, O.M., F.R.S. ... 61

On the Physical Properties of Gold Leaf at High Temperatures. By J. C. Chapman and H. L. Porter, Wheatstone Laboratory, King's College, London. Communicated by Prof. H. A. Wilson, F.R.S. 65

Functions of Positive and Negative Type, and their Connection with the Theory of Integral Equations. By J. Mercer, B.A., Trinity College, Cambridge. Communicated by Prof. A. R. Forsyth, Sc.D., LL.D., F.R.S. (Abstract) 69

Note on the Spontaneous Luminosity of a Uranium Mineral. By the Hon. R. J. Strutt, M.A., F.R.S., Professor of Physics, Imperial College of Science, South Kensington 70

On Flapping Flight. By Maurice F. FitzGerald, B.A., Professor of Engineering in Queen's College, Belfast. Communicated by Lord Rayleigh, O.M., F.R.S. 72

A Wave-length Comparator for Standards of Length. By Dr. A. E. H. Tutton, F.R.S. (Abstract) 79

The Use of Wave-length Rulings as Defining Lines on Standards of Length. By Dr. A. E. H. Tutton, F.R.S. (Abstract) 81

PAGE

No. A 560.—December 10, 1909.

The Use of Wave-length Rulings as Defining Lines on Standards of Length. By Dr. A. E. H. Tutton, F.R.S. (Abstract) 81

Bakerian Lecture.—On the Statistical and Thermodynamical Relations of Radiant Energy. By Prof. Sir J. Larmor, Sec. R.S. 82

The Accumulation of Helium in Geological Time.—II. By the Hon. R. J. Strutt, F.R.S., Professor of Physics, Imperial College of Science, South Kensington ... 96

The Aberrations of a Symmetrical Optical Instrument. By H. C. Pocklington, M.A., D.Sc., F.R.S. 99

The Boiling Point of Sulphur corrected by Reference to New Observations on the Absolute Expansion of Mercury. By H. L. Callendar, M.A., LL.D., F.R.S., Professor of Physics, and H. Moss, B.Sc., A.R.C.S., Demonstrator in Physics at the Royal College of Science, S.W. 106

The Motional Effects of the Maxwell Æther-stress. By E. Cunningham, M.A., Fellow of St. John's College, Cambridge, Assistant Professor of Applied Mathematics in University College, University of London. Communicated by Prof. Sir J. Larmor, Sec. R.S. 109

On the Change in Hue of Spectrum Colours by Dilution with White Light. By Sir W. de W. Abney, K.C.B., D.Sc., D.C.L., F.R.S. 120

Harmonic Tidal Constants for certain Chinese and New Zealand Ports. By Thomas Wright, formerly of the Nautical Almanac Office. Communicated by Sir George H. Darwin, K.C.B., F.R.S. 127

The Electric Conductivity and Density of Solutions of Hydrogen Fluoride. By Prof. E. G. Hill, D.Sc., Muir College, Allahabad, and Dr. A. P. Sirkar, Muir College, Allahabad. Communicated by Prof. H. A. Miers, F.R.S. 130

Obituary Notices of Fellows deceased :—

Eleuthère Élie Nicolas Mascart ; William Edward Wilson ; Francis Elgar ; Georg von Neumayer ; Lord Rosse ; Antoine Henri Becquerel.

(At end of volume.)

No. A 561.—January 7, 1910.

On the Refraction and Dispersion of Neon. By Clive Cuthbertson, Fellow of University College, London, and Maude Cuthbertson. Communicated by Prof. F. T. Trouton, F.R.S. 149

On the Refraction and Dispersion of Air, Oxygen, Nitrogen, and Hydrogen, and their Relations. By Clive Cuthbertson, Fellow of University College, London, and Maude Cuthbertson. Communicated by Prof. F. T. Trouton, F.R.S. 151

On the Refraction and Dispersion of Sulphur Dioxide and Hydrogen Sulphide, and their Relation to those of their Constituents. By Clive Cuthbertson, Fellow of University College, London, and Maude Cuthbertson. Communicated by Prof. F. T. Trouton, F.R.S. 171

PAGE

On the Nature of the Hydrogen Flocculi and their Structure at Different Levels in the Solar Atmosphere. By George E. Hale, For. Mem. R.S., and Ferdinand Ellerman. (Plate 1) 177

On the Distribution of the Röntgen Rays from a Focus Bulb. By G. W. C. Kaye, B.A. (Cantab.), D.Sc. (Lond.), A.R.C.Sc., Trinity College, Cambridge. Communicated by Prof. Sir J. J. Thomson, F.R.S. 189

On the Nature of the Ionisation of a Molecule by an α-Particle. By R. D. Kleeman, D.Sc., B.A., formerly Research Student of Emmanuel College, Cambridge, Mackinnon Student of the Royal Society. Communicated by Prof. Sir J. J. Thomson, F.R.S. 195

The Crystalline Structure of Iron at High Temperatures. By Walter Rosenhain, B.A., D.Sc., and J. C. W. Humfrey, B.A., M.Sc., of the National Physical Laboratory. Communicated by R. T. Glazebrook, F.R.S. (Plate 2) 200

The Spectrum of Magnesium Hydride. By Prof. A. Fowler, A.R.C.S., F.R.A.S. Communicated by Prof. H. L. Callendar, F.R.S. (Abstract) 210

The Relation of Thallium to the Alkali Metals : a Study of Thallium-Zinc Sulphate and Selenate. By A. E. H. Tutton, M.A., D.Sc., F.R.S. 211

A Critical Study of Spectral Series. Part I.—The Alkalies, H and He. By W. M. Hicks, F.R.S. (Abstract) 226

No. A 562.—February 10, 1910.

Address of the President, Sir Archibald Geikie, K.C.B., at the Anniversary Meeting on November 30, 1909 229

Recombination of Ions at Different Temperatures. By P. Phillips, D.Sc., B.A., Royal Veterinary College, Camden Town. Communicated by Prof. F. T. Trouton, F.R.S. 246

Conduction of Heat through Rarefied Gases. By Frederick Soddy, M.A., and Arthur John Berry, B.A., Physical Chemistry Laboratory, University of Glasgow. Communicated by Prof. Sir J. Larmor, Sec. R.S. 254

On a Method of Determining the Viscosity of Gases, especially those Available only in Small Quantities. By A. O. Rankine, B.Sc., Assistant in the Department of Physics, University College, London. Communicated by Prof. F. T. Trouton, F.R.S. 265

On the Atomic Weight of Strontium. By Sir Edward Thorpe, C.B., LL.D., F.R.S., and Arthur Gordon Francis, B.Sc., F.I.C. 277

On the Extinction of Colour by Reduction of Luminosity. By Sir W. de W. Abney, K.C.B., D.Sc., D.C.L., F.R.S. 290

The Accumulation of Helium in Geological Time.—III. By the Hon. R. J. Strutt, F.R.S., Professor of Physics, Imperial College of Science, South Kensington ... 298

No. A 563.—March 2, 1910.

PAGE

On the Nature of the Diffraction Figures due to the Heliometer. By Philip Francis Everitt. University College, London. Communicated by Prof. Karl Pearson, F.R.S. (Plate 3) 302

On the Nature of Magneto-cathodic Rays. By H. Thirkill, B.A. (Cantab.), B.Sc. (Lond.), Research Scholar, Clare College, Cambridge. Communicated by Prof. Sir J. J. Thomson, F.R.S. 324

On the Approximate Arithmetical Solution by Finite Differences of Physical Problems involving Differential Equations, with an Application to the Stresses in a Masonry Dam. By L. F. Richardson. Communicated by Dr. R. T. Glazebrook, F.R.S. (Abstract) 335

The Initial Accelerated Motion of Electrified Systems of Finite Extent, and the Reaction produced by the Resulting Radiation. By George W. Walker, A.R.C.Sc., M.A. Communicated by Prof. Sir J. Larmor, Sec. R.S. (Abstract) 336

On the Shapes of the Isogeotherms under Mountain Ranges in Radio-active Districts. By Charles H. Lees, D.Sc., F.R.S., Professor of Physics in the East London College, University of London 339

On the Propagation of a Disturbance in a Fluid under Gravity. By F. B. Pidduck, B.A., Fellow of Queen's College, Oxford. Communicated by Prof. A. E. H. Love, F.R.S. 347

On the Velocity of Steady Fall of Spherical Particles through Fluid Medium. By E. Cunningham, M.A., Fellow of St. John's College, Cambridge, Assistant Professor of Applied Mathematics, University College, London. Communicated by Sir Joseph Larmor, Sec. R.S. 357

On the Flow of Water through Pipes and Passages having Converging or Diverging Boundaries. By Prof. A. H. Gibson, D.Sc., University College, Dundee. Communicated by Prof. J. E. Petavel, F.R.S. 366

No. A 564.—March 22, 1910.

On the Polarisation of X-Rays compared with their Power of exciting High Velocity Cathode Rays. By L. Vegard, "Universitets-stipendiat" of Christiania University. Communicated by Prof. W. H. Bragg, F.R.S. 379

On the Electricity of Rain and Snow. By George C. Simpson, D.Sc. Communicated by Dr. Gilbert T. Walker, F.R.S. 394

Long-Period Determination of the Rate of Production of Helium from Radium. By Sir James Dewar, M.A., Sc.D., LL.D., F.R.S. 404

Note on Carbon Monosulphide. By Sir James Dewar, M.A., LL.D., Sc.D., F.R.S., Jacksonian Professor in the University of Cambridge, and Humphrey Owen Jones, M.A., D.Sc., Jacksonian Demonstrator in the University of Cambridge . 408

The Effect of Pressure upon Arc Spectra.—Titanium. By R. Rossi, M.Sc. Communicated by Arthur Schuster, F.R.S. 414

PAGE

The Absorption Spectra of Vapours of the Alkali Metals. By P. V. Bevan, M.A. Communicated by Prof. Sir J. J. Thomson, F.R.S. (Plate 4) 421

On a Novel Phenomenon in the Diurnal Inequality of Terrestrial Magnetism at certain Stations. By Robert B. Sangster. Communicated by Dr. C. Chree, F.R.S. 428

The Photographic Action of the α-Particles emitted from Radio-active Substances. By S. Kinoshita. Communicated by Prof. E. Rutherford, F.R.S. 432

No. A 565.—April 14, 1910.

The Depression of Freezing Point in very Dilute Aqueous Solutions. By T. G. Bedford, M.A., Sidney Sussex College, Cambridge. Communicated by Prof. E. H. Griffiths, F.R.S. (Abstract) 454

Colour Blindness and the Trichromatic Theory of Colour-vision. By Sir William de W. Abney, K.C.B., D.Sc., D.C.L., F.R.S. 462

The Solubility of Xenon, Krypton, Argon, Neon, and Helium in Water. By A. von Antropoff, University College, London, 1908; Polytechnikum, Riga, 1909. Communicated by Sir William Ramsay, K.C.B., F.R.S. 474

The Influence of Pressure on the Boiling Points of Metals. By H. C. Greenwood, M.Sc., Beyer Fellow of the University of Manchester. Communicated by Prof. E. Rutherford, F.R.S. 483

The Scattering of the α-Particles by Matter. By H. Geiger, Ph.D. Communicated by Prof. E. Rutherford, F.R.S. 492

The Ionisation produced by an α-Particle. Part II.—Connection between Ionisation and Absorption. By H. Geiger, Ph.D. Communicated by Prof. E. Rutherford, F.R.S. 505

On the Viscosities of the Gases of the Argon Group. By A. O. Rankine, B.Sc., Assistant in the Department of Physics, University College, London. Communicated by Prof. F. T. Trouton, F.R.S. 516

The Change of Carbon Disulphide into a Gaseous Product Condensable and Explosive near the Temperature of Liquid Air. By Sir James Dewar, M.A., Sc.D., LL.D., F.R.S., Jacksonian Professor in the University of Cambridge; and Humphrey Owen Jones, M.A., D.Sc., Jacksonian Demonstrator in the University of Cambridge 526

The Ionisation of Various Gases by the β-Rays of Actinium. By R. D. Kleeman, D.Sc., B.A., Mackinnon Student of the Royal Society. Communicated by Prof. W. H. Bragg, F.R.S. 530

No. A 566.—May 11, 1910.

Bakerian Lecture.—The Pressure of Light against the Source: the Recoil from Light. By J. H. Poynting, Sc.D., F.R.S., and Guy Barlow, D.Sc. 534

The Extinction of Sound in a Viscous Atmosphere by Small Obstacles of Cylindrical and Spherical Form. By C. J. T. Sewell, B.A., Trinity College, Cambridge. Communicated by Prof. H. Lamb, F.R.S. (Abstract) 547

PAGE

The Phosphorescence produced by the α- and β-Rays. By E. Marsden, B.Sc., Assistant Lecturer and Demonstrator in Physics at the East London College, University of London. Communicated by Prof. E. Rutherford, F.R.S. 548

Theory of the Luminosity produced in certain Substances by α-Rays. By E. Rutherford, F.R.S., Professor of Physics, University of Manchester..... 561

Measurements of the Absolute Indices of Refraction in Strained Glass. By L. N. G. Filon, M.A., D.Sc., Fellow and Lecturer of University College, London. Communicated by Prof. F. T. Trouton, F.R.S. 572

Some Phenomena of Magnetic Disturbances at Kew. By Charles Chree, Sc.D., LL.D., F.R.S., Superintendent of the Observatory Department of the National Physical Laboratory. (Abstract) 579

OBITUARY NOTICES OF FELLOWS DECEASED.

Index xxv

PROCEEDINGS
OF
THE ROYAL SOCIETY.

Series A. Vol. 83. **No. A 559.**

MATHEMATICAL AND PHYSICAL SCIENCES.

CONTENTS.

	Page
On the Effect of Previous Magnetic History on Magnetisation. By Prof. ERNEST WILSON, G. F. O'DELL, and H. W. K. JENNINGS . . .	1
On the Resolving Power of Photographic Plates. By C. E. KENNETH MEES, D.Sc.	10
Thermal Conductivity of Air and other Gases. By GEORGE W. TODD, M.Sc., Research Scholar of the University of Birmingham . . .	19
Experiments to test whether the Secondary γ-Rays are polarised. By R. D. KLEEMAN, D.Sc., B.A., Research Student of Emmanuel College, Cambridge	40
The Spectrum of Radium Emanation. By HERBERT EDMESTON WATSON, B.Sc., 1851 Exhibition Scholar, University College, London .	50
On the Perception of the Direction of Sound. By LORD RAYLEIGH, O.M., F.R.S.	61
On the Physical Properties of Gold Leaf at High Temperatures. By J. C. CHAPMAN and H. L. PORTER, Wheatstone Laboratory, King's College, London	65
Functions of Positive and Negative Type, and their Connection with the Theory of Integral Equations. By J. MERCER, B.A., Trinity College, Cambridge. (Abstract)	69
Note on the Spontaneous Luminosity of a Uranium Mineral. By the Hon. R. J. STRUTT, M.A., F.R.S., Professor of Physics, Imperial College of Science, South Kensington	70
On Flapping Flight. By MAURICE F. FITZGERALD, B.A., Professor of Engineering in Queen's College, Belfast	72
A Wave-length Comparator for Standards of Length. By Dr. A. E. H. TUTTON, F.R.S. (Abstract)	79
The Use of Wave-length Rulings as Defining Lines on Standards of Length. By Dr. A. E. H. TUTTON, F.R.S. (Abstract)	81

PRINTED FOR THE ROYAL SOCIETY AND SOLD BY
HARRISON & SONS, 45, ST. MARTIN'S LANE, LONDON, W.C.

Price Two Shillings and Sixpence.

No. A 559. *November 3, 1909.*

decimals, though little significance can be attached to the last figure. Lines which are apparently diffuse are characterised by the letter *d*.

In conclusion, I should like to express my great indebtedness to Sir William Ramsay for allowing me the use of the emanation, and for purifying it on all occasions. My best thanks are also due to Dr. Gray for assisting in the purification of the emanation and the subsequent manipulation, and to Mr. Cameron for placing at my disposal all his original measurements.

On the Perception of the Direction of Sound.

By Lord Rayleigh, O.M., F.R.S.

(Received July 1, 1909.)

The nature of the clue by which we are able to pronounce whether a sound of low pitch reaches us from the right or from the left was long a mystery, seeing that in such cases the difference of intensities at the two ears, used singly, is inappreciable. By some special laboratory experiments conducted about three years ago,* I was able to show that the discrimination depends upon the *phase*-difference at the two ears, and that the sound is judged to be on that side where the phase is in *advance*. When the pitch is higher (much above g') no distinct lateral effect accompanies a phase-difference, and the discrimination of right and left in ordinary hearing undoubtedly depends upon intensities. Commenting on these results, I remarked (p. 224): "The conclusion, no longer to be resisted, that when a sound of low pitch reaches the two ears with approximately equal intensities, but with a phase-difference of a quarter of a period, we are able so easily to distinguish at which ear the phase is in advance, must have far-reaching consequences in the theory of audition. It seems no longer possible to hold that the vibratory character of sound terminates at the outer ends of the nerves along which the communication with the brain is established. On the contrary, the processes in the nerve must themselves be vibratory, not, of course, in the gross mechanical sense, but with preservation of the period and retaining the characteristic of phase—a view advocated by Rutherford, in opposition to Helmholtz, as long ago as 1886."

In the 'Proceedings'† for January, 1908, Profs. Myers and Wilson detail

* 'Phil. Mag.,' vol. 13, p. 214, 1907.

† Vol. 80, A, p. 260, 1908; see also 'Journal of Psychology,' vol. 2, October, 1908.

some interesting experiments, made by another method, which confirm my general conclusion that phase-differences at the outer ears are recognised and give rise to "lateral sensations," but they put a different interpretation upon the fact from that which I suggested in the paragraph above quoted In their view the ultimate cause of the lateral effect is still a difference of intensities at the *inner* ears which may occur, in spite of equality at the *outer* ears, in virtue of conduction of sound from one side to the other through the bones of the head. I had already (p. 227) considered the somewhat similar question of the consequences of conduction through the air round the head, and had shown that the observed effects could not be explained upon the intensity theory as the result of such conduction. At first sight there would seem to be but little difference between the two suppositions, and the opposite character of the conclusions depends, in fact, upon the introduction by Profs. Myers and Wilson of a phase-reversal. It may be well to quote their own statement* of the assumptions upon which they base their explanation. These are: "(*a*) that the sound entering one ear is transmitted through the bones of the head to the opposite inner ear; (*b*) that the retardation of phase due to such interaural conduction is small; and (*c*) that the two sets of waves, thus received at each ear directly and by bone conduction, meet coming from opposite directions." It is this arrival from opposite directions which is considered to entail a phase-reversal, and the required conclusion then readily follows. It will be convenient to generalise somewhat the algebraical statement.

Let $y_1 = a \sin(\omega t + \alpha)$ denote the vibration entering the right ear, and $y_2 = b \sin \omega t$ denote the vibration entering the left ear, so that α is the angle (less than π) by which the vibration at the right outer ear is in advance. The resulting effect at the right internal ear may be taken to be

$$y_1' = fa \sin(\omega t + \alpha) - gb \sin(\omega t - \beta).$$

Here f and g are proper fractions, of which f is much greater than g, and β is the retardation in phase due to the passage through the head. The negative sign of the second term expresses the phase-reversal, so that the whole retardation is really $\pi + \beta$. In the same way the effect at the left internal ear will be

$$y_2' = fb \sin \omega t - ga \sin(\omega t + \alpha - \beta).$$

Let I_1 denote the sound intensity at the right internal ear, and I_2 that at the left internal ear. Then

$$I_1 = f^2a^2 + g^2b^2 - 2fgab \cos(\alpha + \beta),$$

$$I_2 = f^2b^2 + g^2a^2 - 2fgab \cos(\alpha - \beta);$$

and

$$I_1 - I_2 = (f^2 - g^2)(a^2 - b^2) + 4fgab \sin\alpha \sin\beta. \qquad (1)$$

* 'Journ. Psych.,' *loc. cit.*, p. 380.

If $b = a$, this reduces to the value given by Myers and Wilson, viz.,

$$I_1 - I_2 = 4fga^2 \sin\alpha \sin\beta. \qquad (2)$$

In these expressions $\sin\alpha$ is supposed to be positive, that is the vibration at the right outer ear *leads;* and we see that $I_1 > I_2$, if β be positive and less than π. This conclusion depends, of course, upon the assumed reversal of phase, and would itself be reversed if β were the whole retardation incurred.

The question thus raised is of considerable interest. It must be admitted at once that simplicity is on the side of a theory that would attribute the lateral sensation in all cases to a difference of intensity at the two inner ears. Myers and Wilson are evidently much influenced, as I also was, by an *a priori* unwillingness to admit the possibility of a phase-difference being appreciated directly. But I was under the impression that this difficulty would be less felt by physiologists now than in the days of Helmholtz.

When we come to scrutinise closely the intensity theory, as put forward by Myers and Wilson, we meet a good many difficulties, though perhaps none of them are insuperable. It would seem that the positive effect of the second term of (1), where g is very small and β is somewhat small, would be easily overpowered by the first term if b slightly exceeded a, especially if $\sin\alpha$ is also somewhat small. In my experiments, where two tones nearly in unison were led separately to the two ears, the lateral sensation changed over somewhat suddenly from left to right, or *vice versâ*, as the phase-difference passed through zero or 180°. And although the best effects required some regulation of the intensities, it did not appear that the adjustment needed to be at all precise. Myers and Wilson narrate a curious observation in which the intensities at the two outer ears were made unequal. The influence of the change seemed not to be permanent. "We see, then, how rapidly we become adapted to binaural differences of intensity, how susceptible we still are to phase-differences after such adaptation has been established, and how such adaptation, once acquired, persists for a short time after the sound intensity at the two ears has been equalised."

I had already (*loc. cit.*, p. 217) tried an experiment in order to see whether a small disturbance of relative intensities at the two ears would upset the judgment of any observer listening in the open. Unknown to him, a piece of board could be introduced near his ear on the same side as the sound, by which it was supposed that the intensity on that side would be reduced, perhaps even below the intensity upon the farther side. It was found that no misjudgment of direction could thus be induced. Although not actually conclusive, this result is unfavourable to a theory that would make the lateral

sensation dependent upon small differences of intensities. The repetition of the experiment by other observers, and in varied forms, seems to be desirable.

We come now to the third assumption (*c*). The theory under discussion assumes that two vibrations arriving at the inner ear from opposite directions co-operate if the phases are opposite, and tend to neutralise one another if the phases are the same. But this depends entirely upon the precise mode of action. The assumption is justified if the effect depends upon the velocity of vibration, as when aerial waves impinge from opposite directions upon a sensitive flame. But if the question were the effect upon a resonator, of the kind employed by Helmholtz, the direction of travel is indifferent, and co-operation in all cases requires that the phases be the same.* So far as I see, we have nothing to guide us in choosing between the two alternatives.

And there is a further question. If we are to suppose that the framework of the skull is thrown into vibration by sounds which enter at either ear, the matter is not exhausted when we have included one travel across the head. If a finite system, free from viscosity, is excited by an incident force following the harmonic law, the phases of the resulting vibration are the same (or the opposite) at all points of the system. On this basis the phase-difference β, on which everything depends, disappears. This conclusion may be evaded by appealing to viscous effects, but then it becomes a question whether the propagation across the head represented by g would suffice. It is difficult to form a confident opinion.

Further evidence, if it can be obtained, is very desirable. For the moment, the choice between the competing views is likely to depend upon preconceptions as to the manner in which the nerves act. And it should be remembered that the question is not whether phase-differences at the two outer ears are competent to arouse the lateral sensation, but only as to the manner in which this effect is produced.

* 'Phil. Mag.,' vol. 7, p. 153, 1879; 'Theory of Sound,' 2nd edit., vol. 2, p. 403.