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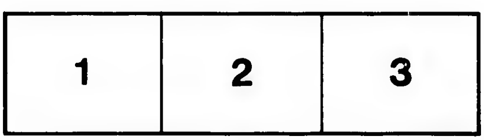
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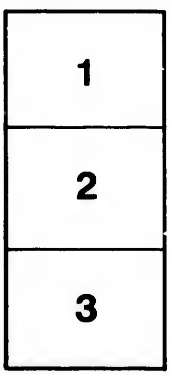
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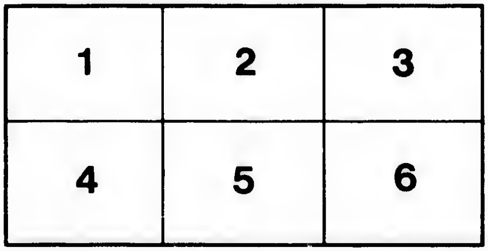
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DARKNESS AND LIGHT.

Hail, holy Light, offspring of Heaven first-born!
Or of the Eternal, co-eternal beam
May I express thee unblamed? since God is light,
And never but in unapproachèd light
Dwelt from eternity, dwelt then in thee,
Bright effluence of bright essence increate.
Or were'st thou rather pure ethereal stream.
Whose fountain who shall tell? before the sun,
Before the heavens, thou wert, and at the voice
Of God, as with a mantle, didst invest
The rising world of waters dark and deep,
Won from the void and formless infinite.
Thee I revisit now with bolder wing,
Escaped the Stygian pool, though long detained
In that obscure sojourn, while in my flight
Through utter and through middle darkness borne
With other notes than to the Orphean lyre,
I sung of Chaos and eternal Night,
Taught by the heavenly Muse to venture down
The dark descent, and up to reascend,
Though hard and rare: thee I revisit safe,
And feel thy sovereign vital lamp; but thou
Revisitest not these eyes, that roll in vain
To find thy piercing ray, and find no dawn;
So thick a drop serene hath quenched their orbs,
Or dim suffusion veiled. Yet not the more
Cease I to wander where the Muses haunt
Clear spring, or shady grove, or sunny hill,
Smit with the love of sacred song; but chief
Thee, Sion, and the flowing brooks beneath,
That wash thy hallowed feet, and warbling flow,
Nightly I visit: nor sometimes forget
Those other two equalled with me in fate,
So were I equalled with them in renown,
Blind Thamyris and blind Mæonides,
And Tiresias and Phineus, prophets old:
Then feed on thoughts that voluntary move
Harmonious numbers; as the wakeful bird
Sings darkling, and in shadiest covert hid
Tunes her nocturnal note. Thus with the year
Seasons return, but not to me returns
Day; or the sweet approach of even or morn,
Or sight of vernal bloom, or summer's rose,
Or flocks, or herds, or human face divine;
But cloud, instead, and ever-during dark,
Surrounds me; from the cheerful ways of men
Cut off, and for the book of knowledge fair
Presented with a universal blank
Of nature's works, to me expunged and rased,
And wisdom at one entrance quite shut out;
So much the rather thou, celestial Light,
Shine inward, and the mind through all her powers
Irradiate; there plant eyes, all mist from thence
Purge and disperse, that I may see and tell
Of things invisible to mortal sight.

JOHN MILTON.

SUPPLEMENT D.

PART FIRST.

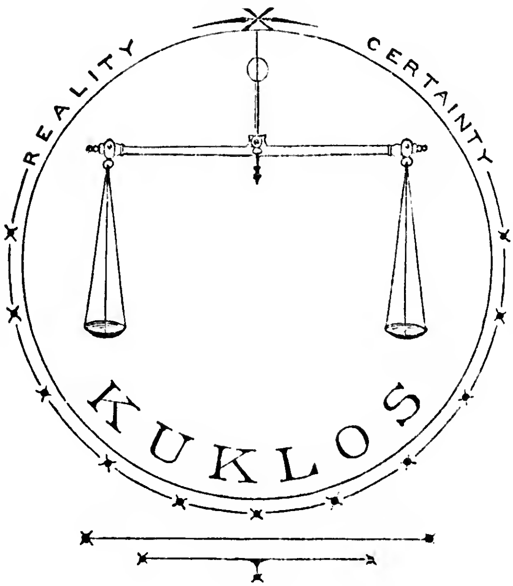
—oo—

CENTRIFUGAL FORCE

—oo—

AND

GRAVITATION.



SUPPLEMENT D.

PART FIRST.

CENTRIFUGAL FORCE

AND

GRAVITATION

A LECTURE.

BY

JOHN HARRIS.

MONTREAL:
JOHN LOVELL, ST. NICHOLAS STREET.

NOVEMBER, 1873.

MONTREAL:—JOHN LOVELL, Printer.

DARKNESS AND LIGHT.

A theoretical explanation of the observed phenomena belonging to the subject of light, proposed by Sir Isaac Newton, is known as Newton's emission theory, or as it is sometimes called, the corpuscular theory of light. It will be desirable to keep in mind this theory; and, as we may have occasion to refer to it particularly, we give the following explanation of the most important propositions contained in it.

From *Lardner's Natural Philosophy.*

1222. "*Corpuscular Theory.*—In the corpuscular theory, which was adopted by Newton as the basis of his optical enquiries, light is considered as a material substance, consisting of infinitely minute molecules which issue from luminous bodies and pass through space with prodigious velocities. Thus, in this hypothesis, the sun is regarded as a source from which such molecules or corpuscles proceed in every direction, with such a velocity that they pass from that luminary to the earth, over a distance of ninety-five millions of miles in about eight minutes and thirteen seconds.

This immense velocity with which they are endued, amounting to nearly two hundred thousand miles per second, united with the fact established by observation, that they do not impress with the slightest momentum the lightest objects which they strike, render it necessary to suppose that they are so minute as to be altogether destitute of inertia or gravity. The strongest beam of sunlight acting upon the most delicate substance, upon the fibres of silk or the web of the spider, or upon gold leaf," "does not impress upon them the slightest perceptible motion. Now, in order that a particle of matter, endued with a velocity so great, should have no perceptible momentum, it is necessary to suppose it to be almost infinitely minute.

But this minuteness requires to be admitted to a still greater extent; when it is considered that particle after particle, striking upon bodies so light, even after the communication of their forces, impart to them no perceptible motion."

1223. "*Difference of colour explained.*—In this system the difference of colour which prevails among the different homogeneous lights, the combination of which constitutes solar light, is ascribed to different velocities.

Thus the sensation of red is produced by luminous molecules animated by one velocity, orange by another, blue by another, and so on."

1224. "*Laws of refraction and reflection explained.*—The law which renders the angle of reflection equal to the angle of incidence, is explained by supposing such molecules to have perfect elasticity. The law of refraction is explained by supposing that such molecules are subject to an attraction towards the perpendicular when they enter a denser, and by a repulsion from it when they enter a rarer medium."

In consequence of the foregoing [Newton's emission] theory being found insufficient to satisfactorily explain some of the more recently observed phenomena of light, belonging in particular to what is termed *interference*; it has been generally given up, and, in its place, the undulatory theory of light has been adopted as the recognised basis of optical science. The undulatory theory is of almost the same age as the emission theory of Newton, having been first proposed and adopted by Hooke and Huygens, contemporaries of Newton; it is only, however, since the commencement of the present century that this theory has been more completely developed, and still more recently that it has been generally (now, almost unanimously) adopted. This theory is also sometimes called the wave-theory of light, and it has been primarily derived from what is known as the wave-theory of sound*, light being considered as the effect of an undulation or agitation propagated through and by means of the particles of a subtle and extremely elastic fluid called *ether;* analagous to the effect of the wave agitations of the particles of air, or other gaseous fluid, which according to the wave-theory is recognised as causing the effect, or class of effects, denominated sound.

Lardner's Natural Philosophy.

1225. "*Undulatory theory.*—In the undulatory theory which was adapted by Huygens, and after him by most continental philosophers, light is regarded as in all respects analagous to sound.

The luminous body in this system does not transmit any matter through space any more than a bell transmits matter when it sounds. The luminous body is regarded as a centre of vibration; but in order to explain the transmission of this vibration through space, the existence of a subtle fluid is assumed, which plays, with regard to light, nearly the same part as the atmosphere plays with regard to sound. The sun, in this theory, then, is a centre of vibration, and the space which surrounds him being filled with an atmosphere of this subtle fluid, transmits this vibration exactly as the atmosphere transmits the vibration of a sounding body."

1226. "*The luminous ether.*—This hypothetical fluid has received the name of *ether.* It is supposed not only to fill all the vacant spaces of the universe which are unoccupied by bodies, but also to fill the interstices which exist between the component parts of bodies. Thus it is not only mingled with the atmosphere which surrounds the earth, but also with the component parts"

* The theory now recognised as the basis of that division of Science named Acoustics.

"of water, glass, and all transparent substances; and since opaque substances, when rendered sufficiently thin, are penetrable more or less by light, it is necessary to admit that it also fills the pores of such bodies. If this luminous ether did not prevail throughout the whole extent of the atmosphere, the light of the stars could not reach our eyes. If it did not exist in water, glass, precious stones, and all transparent substances, these substances could not be penetrable by light as they are; in fine, if it did not exist in the humours of the eye, light could not affect this organ, and the undulations could not reach the membrane of the retina."

1227. "*Effects ascribed to its varying density.*—But although this luminous ether is thus assumed to be omnipresent, it does not everywhere prevail with the same density. It is probable that its density in the celestial spaces which intervene between planet and planet is the same which it has under the exhausted receiver of an air-pump or above the mercurial column in a barometer.

But its density in transparent media must be different, because to explain the phenomena of light passing through them it is necessary to suppose that the undulations change their magnitude, a supposition which is only compatible with a change in the elasticity of the ether. We shall see further, that in some transparent bodies existing in a crystallized state it is necessary to suppose also that the density of the ether in different directions in the same medium varies.

If this universal ether were for a moment in a state of perfect repose, the universe would be in absolute darkness; but the moment its equilibrium is disturbed, and that an undulation or vibration is imparted to it, that instant light is created, and is propagated indefinitely on all sides, as, in an atmosphere perfectly tranquil, the vibration of a musical string or the sound of a blow is propagated to a distance in all directions according to determinate laws."

"Light itself, must not, however, be confounded with the ether which is the medium of its propagation. Light is no more identical with the hypothetical ether than sound is identical with air. The ether, in the one case, and the air in the other, are merely the media by which the systems of undulations which constitute the real sense of light and sound are propagated."

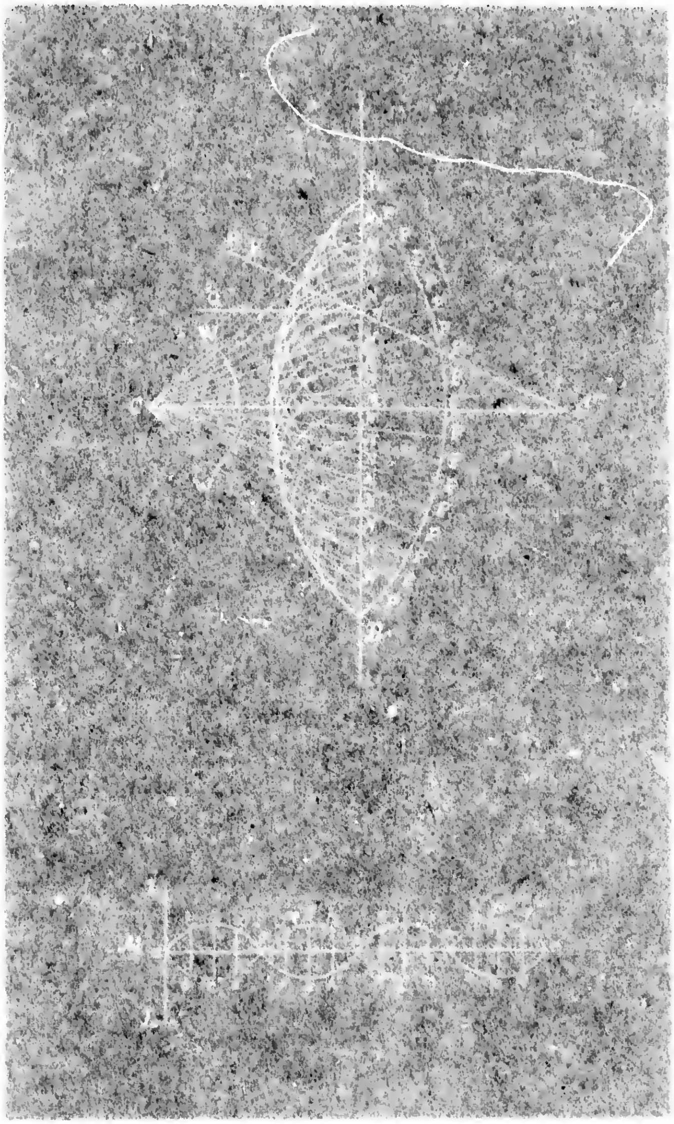
1228. "*Analogy of light and sound.*—In considering the analogy between light and sound, however, there is an important distinction which must not escape notice. Sound is propagated, not only by undulations transmitted through the air, but also by undulations transmitted through other fluids as well as solids, as has been already explained. Light, however, according to the undulatory theory, is transmitted only by the undulations of the luminous ether. Light, therefore, does not pass through a transparent body, such as glass, in the same manner as sound is transmitted through the same body. The undulations by which sound is propagated through the air would be imparted to glass itself, which will continue them and transmit them to another portion of air, and thence to the ear; but when the undulations of light are transmitted through glass or any other transparent medium, they must be supposed to be propagated, not by the vibration of the glass itself, but by the vibration of the subtle ether which pervades its pores."

Since we have to propose and carefully consider certain objections to the undulatory (as well as to the emission) theory of light, it is desirable to give here an explanation of the wave-theory of sound from which the undulatory theory of light has been derived, and to which it is considered to have so close an analogy. It is, in the first place, to be remarked that the term wave-theory properly belongs to the original form of the theory, when the disturbances of the fluid occasioning the effect called sound were supposed to be of the same kind as, or to be strictly analogous to, those progressive undulations in water called waves; at a later period it was found that the disturbances or undulations in the elastic fluid, which produced the *sound-phenomena*, differed essentially in character from the waves of the liquid (water), consequently the theory underwent some modification which included the substitution of the term undulatory, for that of wave-theory.

Lardner's Natural Philosophy. Undulation of Liquids.

800. "*Stationary waves explained.*—Hence it appears that each of the particles composing the surface of a liquid is affected by an alternate vertical motion. This motion, however, not being simultaneous but successive, an effect will be produced on the surface which will be attended with the form of a wave, and such wave will be progressive. The alternate vertical motion by which the particles of the liquid are affected will, however, sometimes take place under such conditions as to produce, not a progressive, but a stationary undulation. This would be the case if all the particles composing the surface were simultaneously moved upwards and downwards in the same direction, their spaces varying in magnitude according to their distance from a fixed point.

To explain this, let us suppose the particles of the surface of a liquid between the point *a. e.* Fig. 234, (Pl. 1) to be simultaneously moved in vertical lines upwards, the centre particle *c.* being raised through a greater space than the particles contiguous to it on either side. The heights to which the other succeeding particles are raised will be continually diminishing, so that at the end of a second the particles of liquid which, when at rest, formed the surface *a. e.* will form the curved surface *a. b. c. d. e.* In like manner, suppose the particles of the surface *e. i.* to be depressed in vertical lines, corresponding exactly with those through which the particles *a. e.* were elevated. Then the particles which originally formed the surface *e. i.* would form the curved surface *e. f. g. h. i.*,"



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From Lardner's Natural Philosophy.

PLATE I.

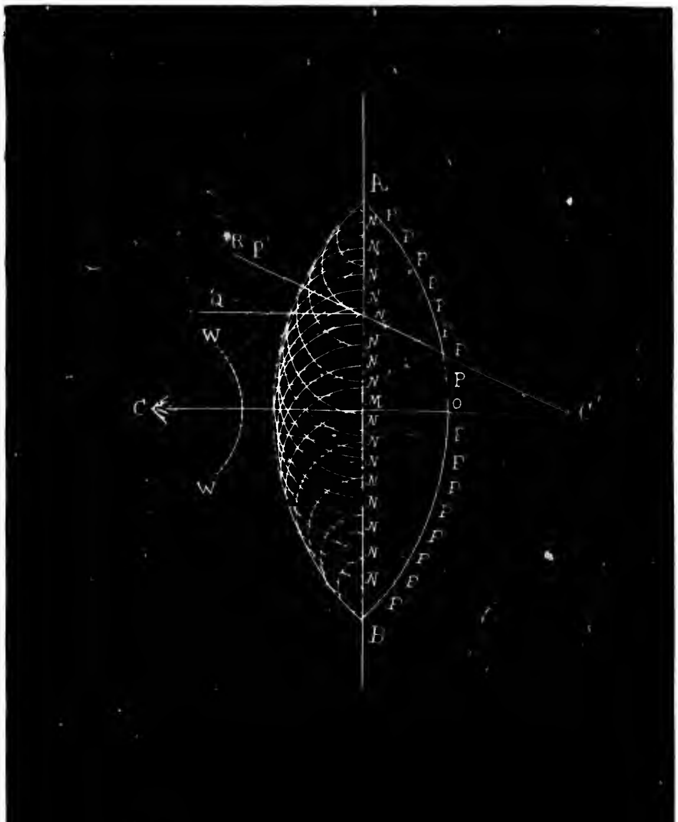


Fig. 235

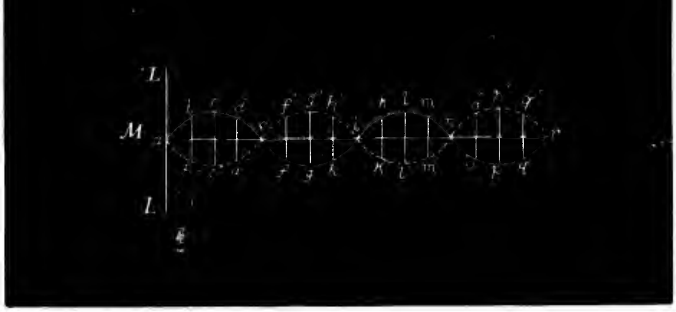


Fig. 234

The Form and Reflection of Waves.

"and they would become the depression of a wave. Thus the elevation of the wave would be *a. b. c. d. e.*, and its depression *e. f. g. h. i.*

Having attained this form, the particles of the surface *a. b. c. d. e.* would fall in vertical lines to their primitive level, and having attained that point, would descend below it; while the particles *e. f. g. h. i.* would rise to their primitive level, and, having attained that position, would continue to rise above it. In fine, the particles which originally formed the surface of the undulation *a. b. c. d. e. f. g. h. i.* would ultimately form the surface *a. b.' c.' d.' e. f.' g.' h.' i.* represented by the dotted line. Having attained this form, the particles would again return to their primitive level, and would pass beyond it, and so on alternately. In this case therefore, there would be an undulation, but not a progressive one. The nodal points would be *a. e. i. n. r.* and these points, during the undulation, would not be moved; they would neither sink nor rise, the undulatory motion affecting only those between them. This phenomenon of a stationary undulation produced on the surface of a liquid may easily be explained, by two systems of progressive undulation meeting each other under certain conditions, and producing at the points we have here called nodal points the phenomenon of interference, which we shall presently explain."

801. "*Conditions under which a stationary undulation may be produced.*—Stationary undulations may be produced on a surface of liquid confined in a straight channel by exciting a succession of waves, separated by equal intervals, moving against the end or side of the channel and reflected from it. The reflected waves, combined with the direct waves, will produce the effect here described.

It may also be produced by exciting waves in a circle from its central point. These waves being reflected from the circular surface, will produce another series," "which, combined with the former, would be attended with the effect of a stationary undulation."

802. "*Depth to which the effect of waves extend.*—When a system of waves is produced upon the surface of a liquid by any disturbing force, a question arises to what depth in the liquid this disturbance in the equilibrium extends. It is possible to suppose a stratum of the liquid at any supposed depth below which the vertical derangement would not be continued. Such a stratum would operate as the bottom of the agitated part of the fluid.

The Messrs. Webber, to whose experimental inquiries in this department of physics, science is much indebted, have ascertained that the equilibrium of the liquid is not disturbed to a greater depth than about three hundred and fifty times the altitude of the wave."

803. "*Reflection of waves.*—If a series of progressive waves impinge against any solid surface, they will be reflected, and will return along the surface of the fluid as if they emanated from a centre equally distant on the other side of the obstructing surface. To explain this it is necessary to consider that when any part of a wave encounters the obstructing surface its progress is retarded, and the particles composing it will oscillate vertically in contact with the surface exactly as they would oscillate if they had at this point been first disturbed. They will therefore, at this point, become the centre of a new system of waves, which will be propagated around it, but which will form only semicircles, since the centre of undulation will be against the obstructing surface, which will, as it were, cut off half of each circular undulation. As the several points of the wave meet the obstructing surface in succession, other series of semicircular waves will be formed, and we shall see that by the combination of these various systems of semicircular waves, a single wave will be formed, the centre of which will be a point just so far on the other side of the obstructing surface as the original centre"

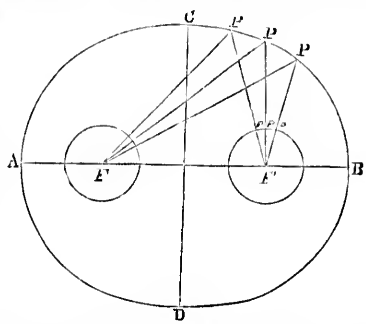
"was on the side of the fluid. Let *C*, Fig. 235, Pl. 1, be the original centre of undulation, and let a wave *W. W.* issuing from the centre move towards the obstructing surface *A. B.* The first part of this wave which will meet the obstructing surface will be the point *V.*, which moves along the line *C. M.*, perpendicular to it. After this the other points of the wave on the one side and on the other will successively strike it.

Let us take the moment at which the surface is struck at the points *B.* and *A.*, equally distant from the middle point *M.* by two parts of the wave. All the intermediate points between *B.* and *A.* will have been previously struck ; and if the wave had not been intercepted by the obstructing surface, it would, at the moment at which it strikes the points *B.* and *A.* have had the form of the circular arc *A. O. B.*, having the original point *C.* as its centre.

But as the successive points of the wave strike the surface *A. B.* they will, according to what has been explained, each become the centre of a new wave which will have a semicircular form ; and to ascertain the magnitude of such wave at the moment the original wave strikes the points *A.* and *B.* it is only necessary to ascertain the distance through which each semicircular wave will expand, and the interval between the moment at which the vertex of the original wave strikes the point *A.* and the moment at which the two extremities of the wave strike the points *A.* and *B.* It is evident that if the wave had not been interrupted at *M.* its vertex would have moved on to *O.* ; and as the new wave reflected from *M.* will have the same velocity, it follows that at the moment the original wave would have arrived at *O.* the reflected wave will have expanded through a semicircle whose radius is *M. O.* Therefore, if we take the point *M.* as a centre, and a line equal to *M. O.* as a radius, and describe a semicircle, this semicircle will be the position of the new wave formed, with *M.* as a centre, at the moment that the" "extremities of the original wave struck the points *A.* and *B.* In like manner, it may be shewn that if *P.* be the position which the point of the original wave which struck *N.* would have attained had it not been interrupted, the distance from which the semicircular wave, having *N.* as a centre, would have expanded in the same time will be determined by describing a semicircle with *N.* as a centre and *N. P.* as a radius. In the same manner it may be shewn that the forms of all the semicircular waves produced with the points *N.* of the obstructing surface between *A.* and *B.* as centres, will be determined by taking the several parts of the radii *C. P.*, which lie beyond the obstructing surface, as radii, and the points *N.* where they cross the obstructing surface, as centres. This has been accordingly done in the diagram, by which it will be perceived that the space to the left of the obstructing surface is intersected by the numerous semicircular waves which have been formed. But it appears also that the series of points where they intersect each other most closely is that of a circular arc *A. O'. B.*, having for its centre the point *C'.* whose distance behind the surface *M.* is equal to the distance of the centre *C.* before it, so that *C. M.* shall be equal to *C'. M.* The effect will be, that a circular wave *A. O'. B.* will be formed, the intersection of the semicircles within this being so inconsiderable as to be imperceptible. This wave *A. O'. B.* will accordingly expand from the surface *A. B.* towards *C.* on the left in the same manner as the wave *A. O. B.* would have expanded on the right towards *C'.* if it had not been interrupted by the obstructing surface. If any radius of the original wave, such as *C. P.*, and the corresponding radius *C'. P'.* of the reflected wave be also drawn, these two radii will evidently make equal angles with the line *C. M. C'.*, which is perpendicular to the obstructing surface; and consequently, if from the point *N.* a line *N. Q.* be drawn parallel to *C. M.*, and therefore perpendicular to *A. B.*, the lines *C. N.* and *N. R.* will form equal angles with it."

804. "*Law of reflection—angles of incidence and reflection equal.* The angle *C. N. Q.* is called *the angle of incidence* of the wave, and the angle *Q. N. R.* is called the *angle of reflection;* and hence it is established as a general law, that in the reflection of waves from any obstructing surface, the angle of incidence is equal to the angle of reflection, a law which has been already shown to prevail when a perfectly elastic body is reflected by a perfectly hard surface. When a wave strikes a curved surface, it will be reflected from it in a different direction, according to the point of the surface at which it is incident. It will be reflected from such point in the same direction as it would be if it struck a plane which coincides with the curved surface at this point."

805. "*Elliptic and parabolic curves.* There are two species of curves, which in those branches of physics which involve the principles of undulation are attended with considerable importance. These figures are the ellipse and the parabola. Fig. 236 represents an ellipse; *A. B.* is its major axis, and *C. D.* its minor axis; *F. F'.* are two points upon its major axis called its foci, which have the following property: If lines be



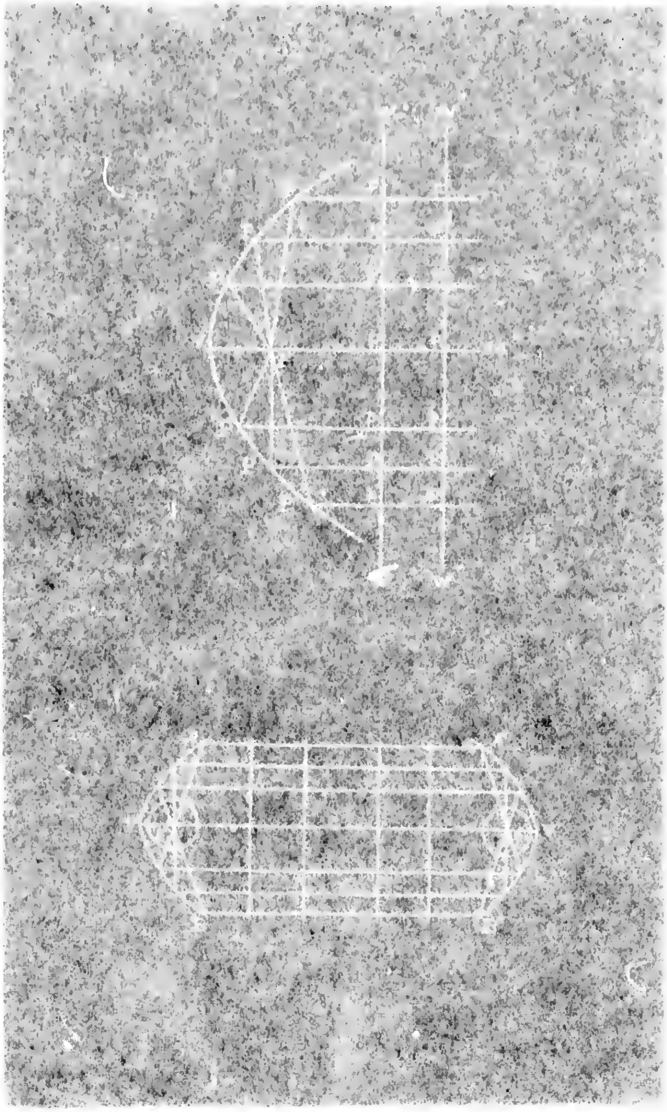
drawn from the foci to any point *P.* in the ellipse, these lines will form equal angles with the ellipse at *P.*, and their lengths taken together will be equal to the major axis *A. B.*"

806. "*Waves propagated from the foci of an ellipse.* A remarkable consequence of this property follows, relative to undulations having for their centres one or other of the foci. If the series of progressive circular waves, propagated from the focus *F.* as a centre, strike the surface, they will"

"be reflected from the surface at angles equal to those at which they strike it, because, by the law which has been already established, the angles of reflection will be equal to the angles of incidence. If, then, we suppose several waves of the same system diverging from the focus *F.* to strike successively the elliptical surface at the points *P.*, they will be reflected in the direction *P. F''.* toward the other focus. But as all the points of the same wave move with the same velocity, they will describe equal spaces in the same time. Let the points *p. p. p.* upon the lines *P. F''.* be those at which the points of the wave will arrive simultaneously. It then follows, that the lines *F. P.* and *P. p.* will, taken together, be equal, being in each case the spaces described in the same time by different points of the same wave. If then, these equal lengths *F. P. p.* be taken from the lengths *F. P. F''.* which are also equal to each other, as has been already explained, the remainders *F''. p.* will necessarily be equal; therefore the points *p.* will lie at equal distances from *F''.* and will therefore form a circle round *F''.* as a centre. Hence it follows, that each circular wave which expands round *F.* will, after it has been reflected from the surface of the ellipse, form another circular wave round *F''.* as a centre."

807. "*Waves propagated from the focus of a parabola.* The curve called a parabola is represented in Fig. 237, Pl. 2. The point *V.* is its vertex, and the line *V. M.* is its axis.

A certain point *F.* upon the axis near the vertex, called the focus, has the following property. Let lines be drawn from this point *F.* to any points such as *P.* in the curve: and let other lines be drawn from the points *P.* severally parallel to the axis *V. M.*, meeting lines *W. W'.*, drawn perpendicular to the axis, and terminated in the curve. The lines *F. P.* and *P. p.* will be inclined at equal angles to the curve at the points *P.*, and the sum of their lengths will be everywhere the same: that is, if the length of the line *F. P.* be added"



From Lardner's Natural Philosophy.

PLATE II.

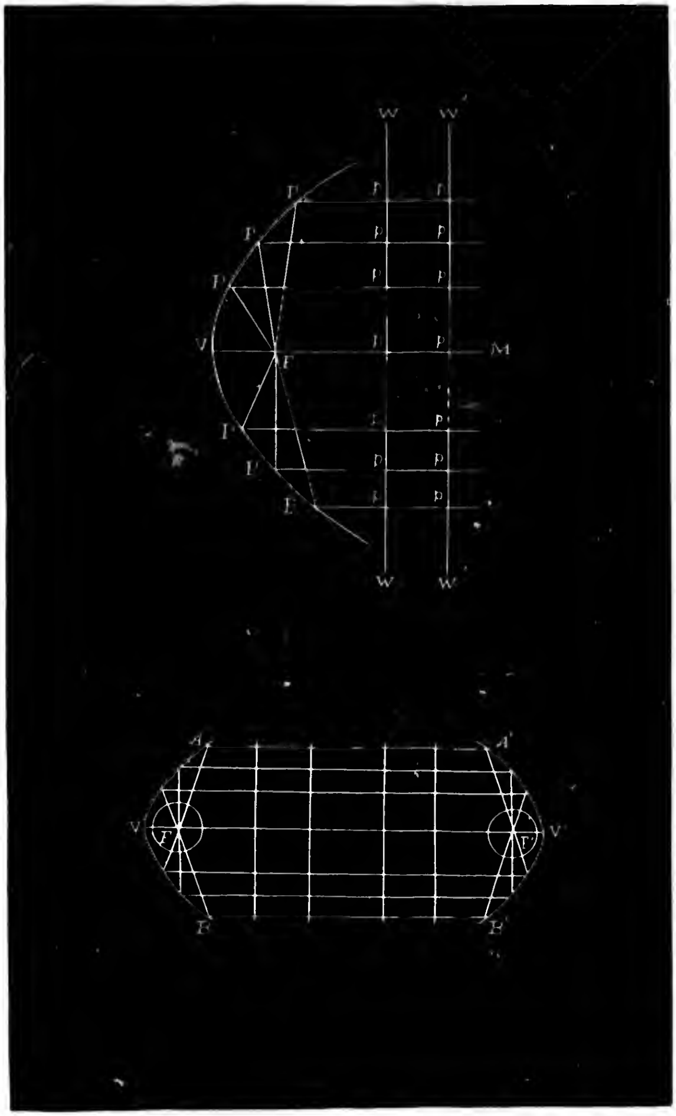


Fig. 237

Fig. 238

Waves propagated from the focus of a parabola.

"to the length of the line *P. p.*, the same sum will be obtained, whichever of the points *P.* may be taken; and this will be the case whatever line *W. W'.* be drawn perpendicular to *V. M.*

It follows from this property, that if the focus of a parabola be the centre of a system of progressive waves, these waves, after striking the surface, will be reflected so as to form a series of parallel straight waves in the direction of the lines *W. W'*, and moving from *F.* towards *M.*

This may be demonstrated in precisely the same manner as it has been proved in the case of the ellipse that the reflected waves form a circle round the focus *F.'*; for the lines *F. P.* and *p. P.*, Fig. 237, forming equal angles with the curve, will necessarily correspond with the direction of the incident and reflected waves, and the sum of these lines being the same wherever the point *P.* may be situated, the several points of the same wave striking different points of the parabola will arrive together at the line *W. W.'*, inasmuch as they move with the same velocity, and have equal spaces to move over.

On the other hand, it follows, by precisely similar reasoning, that if a series of parallel straight waves at right angles to *V. M.*, moving from *M.* towards *V.*, should strike the parabolic surface, their reflections would form a series of circular waves of which the focus *F.* would be the centre.

If two parabolas, *A. V. B.* and *A'. V'. B'.*, Fig. 238, Pl. 2, face each other so as to have their axes coincident and their concavities in opposite directions, a system of progressive circular waves issuing from one focus *F.* will be followed by a corresponding system having for the centre the other focus *F'.* The waves which diverge from *F.* after striking on the surface *A. V. B.* will be converted into a series of straight parallel waves moving at right angles to *V. V'.* and towards *V'.* These will strike the surface *A'. V'. B'.*, and after being reflected from it will form another series of circular waves, having the other focus *F'.* as their common centre."

"A circular surface, if its extent be not great, compared with the length of its radius, may be considered as practically coinciding with a parabolic surface whose focus is at the middle point of the radius of the circular surface. For example, let *A. B.*, Fig. 239, be a circular arc, whose centre is *C.*, and whose middle point is *V.* Let *F.* be the middle point of the radius *C. V.* Then *A. B.* may be considered as so nearly coinciding with a parabola whose

focus is *F.*, and whose vertex is *V.*, that it will possess all the properties ascribed to the parabola; and consequently spherical surfaces, provided their extent be small compared with their diameters, will have all the properties here ascribed to parabolic surfaces."

808. "*Experimental illustrations of these principles.*—All these effects have been beautifully verified by experiment by means of expedients contrived by the Messrs. Webber, whose arrangements, nevertheless, for this object admit of still further simplification.

Experiment 1.—Let a trough of convenient magnitude be partially filled with mercury, so as to present a surface of that fluid of sufficient extent. Let a piece of writing-paper be formed into a funnel, with an extremely small opening at the point, so as to allow a minute stream of mercury to flow from it. Let a piece of sheet-iron, having a perfectly plane surface, be now immersed vertically in the mercury, and let a small stream descend from the funnel at any point upon the surface of the mercury in the vessel. A series of progressive circular waves will be produced around the point where the mercury falls, which will spread around it. This will strike the plane surface of the sheet iron, and will be reflected from it, forming another series of circular waves," "whose centre will be a point equally distant on the other side of the sheet iron, as already described.

Experiment 2.—Let a piece of sheet iron be bent into the form of an ellipse, such as represented in Fig. 236; and let the position of the foci be indicated by a small wire index attached to it. Let this be immersed in the mercury in the trough; and let the funnel be brought directly over the point of the index which marks the position of one of the foci. When the mercury is allowed to fall, a series of circular waves will be produced round that focus, and, striking on the surface of the iron, will be reflected from it, forming another series of circular waves, of which the other focus is the centre as already expressed.

Experiments 3.—Let a piece of sheet-iron be bent into the form of a parabola, as represented in Fig. 237, the position of the focus being, as before, marked by an index. If this be immersed in the mercury, and the stream be let fall from the funnel placed at the point of the index, a series of circular waves will be produced around the focus, which, after being reflected from the parabolic surface, will be converted into a series of parallel straight waves at right angles to its axis, as already explained.

Experiment 4.—Let two pieces of sheet-iron formed into parabolic surfaces, with indices shewing the foci, be immersed in the mercury in such a position that their axes shall be in the same direction, and their concavities facing each other. From the funnel let fall a stream upon one focus *F*, Fig. 238. Circular waves will be formed which, after reflection from the adjacent parabola, will become parallel waves, and after a second reflection from the opposite parabola will again become circular waves with the other focus as a centre.

Experiment 5.—If pieces of sheet-iron be bent into the form of circular arcs whose length is small compared" "with their radius, the same effects will be produced as those which were produced by parabolic surfaces."

809. "*Phenomena produced when two systems of waves encounter each other.*—When two waves which proceed from different centres encounter each other, effects ensue which are of considerable importance in those branches of physics whose theory is founded upon the principles of undulation.

I. If the elevation of one wave coincides with the elevation of another, and the depressions also coincide, a wave would be produced, the height of whose elevation, and the depth of whose depression, will be equal to the sum of the heights and depths of the elevation and depression of the two waves which are thus, as it were, superposed.

II. If, however, the elevation of one wave coincide with the depression of the other, and *vice versâ*, then the effect will be a wave whose elevation will be equal to the difference of the elevation, and whose depression will be the difference of the depression of the two waves which thus meet.

III. If, in the former case, the heights and depressions of the waves superposed be equal, the resulting wave will have double the height of the elevation, and double the depth of the depression.

IV. If the heights and depressions be equal in the second case, the two waves will mutually destroy each other, and no undulation will take place at the point i.."

Note.–Nos. I. and III, of the above propositions are open to objection, and inadmissible unless strictly demonstrated. The probable effect (of such *superposition*) would be to increase the volume of, and to amplify the wave in breadth, and to increase the rapidity of its propagation (or velocity of the undulation) but not to increase its elevation and depression. The mean point of distance between the maximum elevation and depression must be the plane (i. e. mean-horizontal plane) of the liquid. It certainly requires demonstration that the elevation and depression of one wave can be increased by the addition or coincidence of a second wave, of which the elevation and depression is not greater than that of the first.

"question; for the difference of elevations and the difference of depressions being nothing, there will be neither elevation nor depression. In fact, in this latter case, the depression of each wave is filled up by the elevation of the other."

810. "*Interference of waves.*—This phenomenon, involving the effacement of an undulation by the circumstance of two waves meeting in the manner described, is called, in the theory of undulation, an interference, and is attended with remarkable consequences in several branches of physics."

811. "*Experimental illustration of it.*—The two systems of waves formed by an elliptical surface, and propagated, one directly around one of the foci, and the other formed by reflection around the other, exhibit in a very beautiful manner, the phenomena not only of reflection, as has been already explained, but also of interference, as has been shown with remarkable elegance by the Messrs. Webber already referred to. These phenomena are represented in Fig. 240, Pl.3, where *a.* and *b.* are the two foci. The strongly marked circles indicate the elevation of the waves formed around each focus, and the more lightly traced circles indicate their depression. The points where the strongly marked circles intersect the more faintly marked circles, being points where an elevation coincides with a depression, are consequently points of interference, according to what has been just explained. The series of these points form lines of interference, which are marked in the diagram by dotted lines, and which, as will be seen, have the forms of ellipses and parabolas round the same foci."

812. "*Inflection of waves.*—If a series of waves encounter a solid surface in which there is an opening through which the waves may be admitted, the series will be continued inside the opening and without interruption; but other series of progressive waves having a"

"circular form will be generated, having the edge of the opening as their centres.

Let *M. N.*, Fig. 241, Pl. 3, represent such a surface, having an opening whose edges are *A.* and *B.*, and let *C.* be a centre from which a series of progressive circular waves is propagated. These waves, entering at the opening *A. B.*, will continue their course uninterrupted forming the circular arcs *D. E.* But around *A.* and *B.* as centres, systems of progressive cirular waves will be formed which will unite with the waves *D. E.* completing them by circular arcs *D. F.* and *E. F.* meeting the obstructing surface on the outside; but these circular waves will also be formed throughout the remainder of their extent, as indicated in the figure, on both sides of the obstructing surface, and intersecting the original system of waves propagated from the centre *C.* They will also form with these, series of points of interference according to the principles already explained.

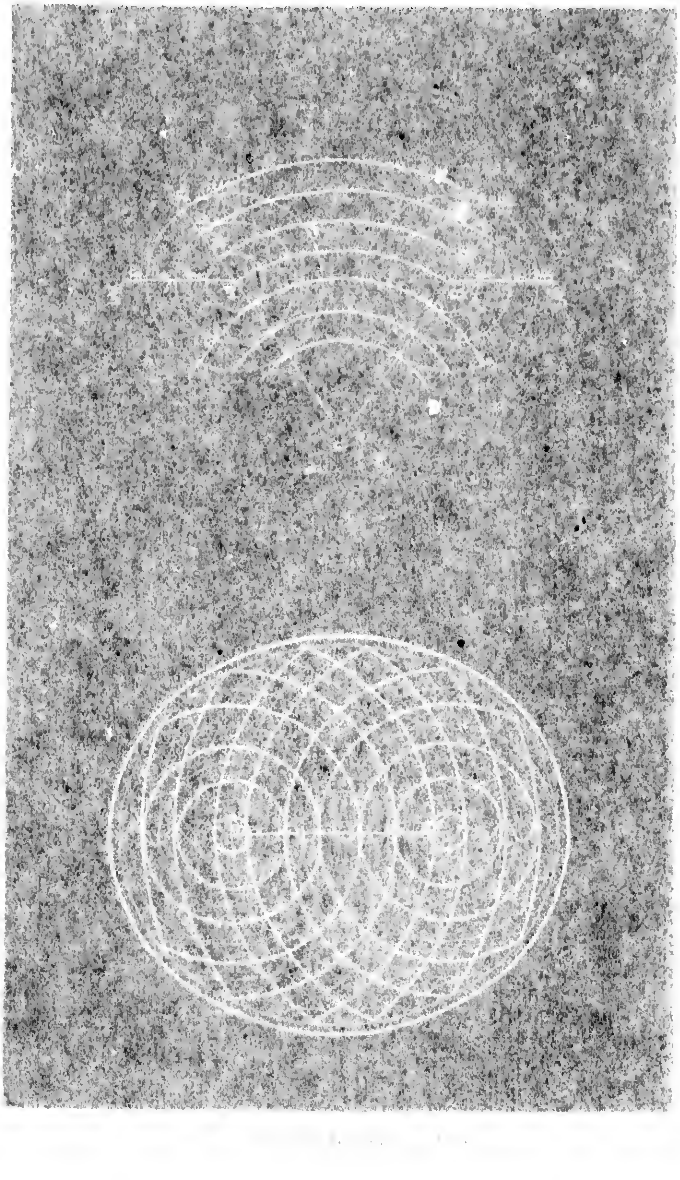
The effects here described as produced by the edges of an opening through which a series of waves is transmitted is called inflection, and it will appear hereafter that they form an important feature in several branches of physics whose theory is based upon the principles of undulation."

Quotation from *Lardner's Natural Philosophy*, continued.

Undulation of Elastic Fluids.

"If any portion of the atmosphere, or any other elastic fluid diffused through space, be suddenly compressed and immediately relieved from the compressing force, it will expand in virtue of its elasticity, and, like all other similar examples already given, will, after its expansion, exceed its former volume to a certain limited extent, after which it will again contract, and thus oscillate alternately on the one side and on the other of its position of repose.

814. "*Undulations of a sphere of air.*—We may consider this effect to be produced upon a small sphere of air having any proposed radius, as, for example, an inch. Let us"



[illegible]

From Lardner's Natural Philosophy.

PLATE III.

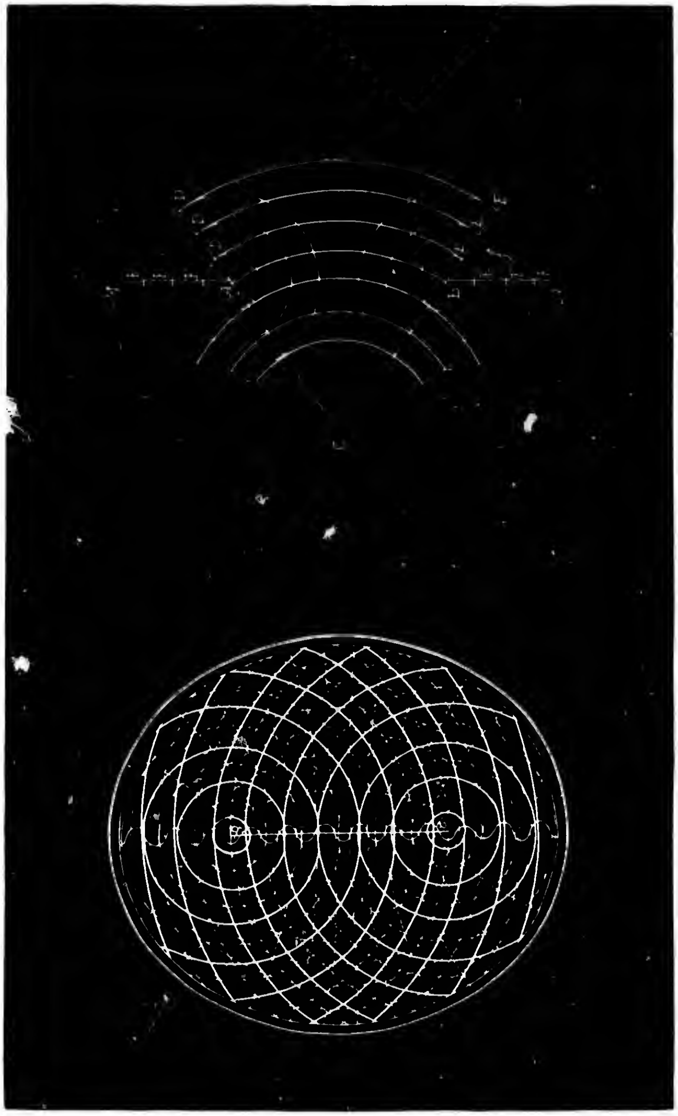


Fig. 241

Fig. 240

Interference and Inflexion of Waves.

"suppose that it is suddenly compressed, so as to form a sphere of half an inch in radius, and being relieved from the compressing force it expands again, and surpassing its former dimensions swells into a sphere of an inch and a half. It will again contract and return to the magnitude of a sphere, with a radius somewhat greater than half an inch, and will again expand and so oscillate, forming alternately spheres with radii less and greater than an inch, until at length the oscillation ceases, and it resumes permanently its original dimensions.

These oscillations will not be confined to the single sphere of air in which they commenced; the circumambient air will necessarily follow the contracting sphere when first compressed, so that a spherical shell of air which lies outside the sphere will expand and become less dense than in its state of equilibrium.

When the central sphere again expands, this external spherical shell will contract, and will become more dense than in its state of equilibrium. This shell will act in a similar manner upon another spherical shell outside it, and this upon another outside it, and so forth. If then we suppose a number of successive spheres surrounding the point of original compression, we shall have a series of spherical shells of air, which will be alternately condensed and expanded in a greater degree than when in a state of repose. This condensation and expansion thus spreading spherically round the original centre of disturbance, is in all respects analogous to a series of circular waves forming round the central point upon the surface of a liquid, the elevation of the wave in the case of the liquid corresponding to the condensation in the case of the gas, and the depression of the wave corresponding to the expansion of the gas.

815. "*Analysis of the propagation of an undulation through an elastic fluid.*—We will limit our observations in the first instance to a single series of particles of air, expanding in a straight line from the centre of disturb-"

"ance *A.*, Fig. 242, towards *T.* Let *S. A.* represent the space through which the disturbing force acts, and let us imagine this air suddenly pressed from *S.* to *A.* by some solid surface moving against it, and let us suppose that this motion from *S.* to *A.* is made in a second. Now, if air were a body devoid of elasticity, and like a perfectly rigid rod, the effect of this motion of the solid surface from *S.* to *A.* would be to push the remote extremity *T.* through a space to the right corresponding with and equal to *S. A.*

But such an effect does not take place, first, because air is highly elastic, and has a tendency to yield to the force excited by the solid surface upon it while it moves from *S.* to *A.;* and secondly, because to transmit any effect from *A.* to a remote point, such as *T.*, would require a much greater interval of time than that which elapses during the movement of the surface from *S.* to *A.* The effect, therefore, of the compression, in the interval of time which elapses during the motion from S. to *A.* is to displace the particles of air which lie at a certain definite distance to the right of *A.* Let this distance for example be *A. B.* All the particles, therefore, of air which lie in succession from *A.* to *B.* will be effected more or less by the compression, and will consequently be brought into closer contiguity with each other; but they will not be equally compressed, because to enable the series of particles of air lying between *A.* and *B.* to assume a uniform density requires a longer time than elapses during the motion of the solid surface from *S.* to *A.* At the instant, therefore, of the arrival of the compressing surface at *A.* the line of particles between *A.* and *B.* will be at different distances from each other; and it is proved by mathematical principles, that the point where they are most closely compressed is the middle point *m.* between *A.* and *B.* and therefore, departing from the"

" the middle point *m.* in either direction, they are less and less compressed. The condition, therefore, of the air between *A.* and *B.* is as follows. Its density gradually increases from *A.* to *m.* and gradually decreases from *m.* to *B.* Now, it is also proved that the effect of the elastic force of the air is such that, at the next moment of time after the arrival of the compressing surface at *A.* the state of varying compression which has just been described as prevailing between *A.* and *B.* will prevail between another point in advance of *A.* such as *A'.* and a point *B'.* equally in advance of *B.*, and the point of the greatest compression will, in like manner, have advanced to *m'.* at the same distance to the right of *m.* In short, the conditions of the air between *A'.* and *B'.* will be in all respects similar to its condition the previous moment between *A.* and *B.*, and in like manner, in the next moment, the same condition will prevail between the particles *A''.* and *B''.* to the right of *A'.* and *B'.* Now, it must be observed that as this state of varying density prevails from left to right, the air behind it, in which it formerly prevailed, resumes its primitive condition. In a word, the state of varying density which has been described as prevailing between *A.* and *B.* at the moment the compressing surface arrived at *A.* will in the succeeding moments, advance from left to right towards *T.*, and will so advance at a uniform rate; the distance between the points *A. B. A'. B'.* and *A''. B''.*, &c., always remaining the same. "

816. " *Aerial undulations.*—This interval between the points *A.* and *B.* is called a *wave* or *undulation*, from its analogy, not only in form but in its progressive motion, to the waves formed on the surface of liquids, already described; the difference being that in the one case the centre of the wave is the point of greatest elevation of the surface of the liquid, and in the other case it is the point of greatest condensation or compression of the particles of the air. The distance between *A.* and *B.*"

"or between A'. and B'. or between A''. and B''. which always remains the same as the wave progresses, is called the *length of the wave*.

In what precedes we have supposed the compressing surface to advance from *S.* to *A.* and to produce a compression of the air in advance of it. Let us now suppose this surface to be at *A.*, the air contiguous to it having its natural density.

If the wave *proceed contrariwise* from *A.* to *S.* the air which was contiguous to it at *A.* will rush after it in virtue of its elasticity, so that the air to the right of *A.* will be disturbed and rendered less dense than previously. An effect will be produced, in fine, precisely contrary to that which was produced when the wave advanced from *S.* to *A.*; the consequence of which will be that a change will be made upon the air between *A.* and B. exactly the reverse of that which was previously made, that is to say, the middle point *m.* will be that at which the rarefaction will be greatest, and the density will increase gradually, proceeding from the point *m.* in either direction towards the points *A.* and *B.* The same observations as to the progressive motion will be applicable as before, only that the progression *m.* instead of being the point of greatest condensation, will be the point of least density."

817. "*Waves condensed and rarefied.*—The space *A. B.* is also in this case denominated a wave or undulation. But these two species of waves are distinguished one from the other by being denominated, the former a *condensed*, and the latter a *rarefied wave*. Now, let it be supposed that the compressing surface moves alternately backwards and forwards between *S.* and *A.* making the excursions in equal times. The two series of waves, as already defined, will be produced in succession. While the condensed wave moves from *S.* towards *T.* the rarefied wave immediately follows it, and in the same manner this rarefied wave will be followed by another"

"condensed wave, produced by the next oscillation, and so on. The analogy of these phenomena to the progressive undulation on the surface of a liquid, as already described, is obvious and striking.

What has been here described with reference to a single line of particles extending from the centre of the distance *A*. in a particular direction, is equally applicable to every line diverging in every conceivable direction around such centre, and hence it follows that the succession of condensed and rarefied waves will be propagated round the centre, each wave forming a spherical surface, which is continually progressive and uniformly enlarges, the wave moving from the common centre with a uniform motion."

818. "*Velocity and force of Aerial waves.*—The velocity with which such undulations are propagated through the atmosphere depends on, and varies with, the elasticity of the fluid.

The degree of compression of the wave, which corresponds to the height of a wave in the case of liquids, depends on the energy of the disturbing force. All the effects which have been described in the case of waves formed upon the surface of a liquid are reproduced, under analogous conditions, in the case of undulations propagated through the atmosphere."

819. "*Their interference.*—Thus, if two series of waves coincide as to their points of greatest and least condensation, a series will be formed whose greatest condensation and rarefaction is determined by the sum of points, as prevailing in the separate undulations;* and if the two"

* See the note at page 16. Assuming that the soundness of the objection stated in that note, has to be allowed, it is not perhaps quite so obvious that it will also apply to the case above. We opine, however, that (assuming the possibility of an aerial wave such as described) the two cases are, in respect to this particular, strictly analogous, and that, consequently, the same objection does apply; namely, that the coincidence of two undulations (or waves) in the elastic fluid will not increase the condensation and rarefaction as stated above; but will increase the amplitude and wave length of the undulation.

"series are so arranged that the points of greatest condensation of the one coincide with the greatest rarefaction of the other, and, *vice versâ*, the series will have condensations and rarefactions determined by the difference of each of the separate series; and, in fine, if in this latter case the condensations and rarefactions be equal, the undulations will mutually efface each other, and the phenomena of interference, already described as to liquids, will be reproduced.

As the undulations produced in the air are spread over spherical surfaces having the centre of disturbance as a common centre, the magnitude of these surfaces will be in the ratio of the squares of the radii, or what is the same, of the squares of their distances from the point of central disturbance; and as the intensity of the wave is diminished in proportion to the space over which it is diffused, it follows that the effects or energy of these waves will diminish as the squares of their distances from the centre of propagation increase."

It appears to us that certain of the propositions relating to interference in the (liquid) wave theory, as stated in the preceding quotation, are not sufficiently supported by experimental demonstration and are by no means satisfactorily established. In the four cases, stated art. 809, of two systems of waves encountering each other, it seems most probable that, whether the elevations and depressions of the one coincide with those of the other or whether they do not coincide, the two waves will destroy or neutralise each other; and, moreover, it seems probable that such neutralisation would take place immediately in the case where the elevation of the one coincided with the elevation of the other, * (but this is directly the contrary to Dr. Lardner's statement in the

* If, however, the elevation and depression of the encountering waves be considerable, both waves would be partially reflected, and this reflection would be more complete the greater the velocity of the encountering waves.

preceding quotation), whereas if the elevation of the one coincided with the depression of the other, the one would probably pass over and under the other, and both would continue to undulate in the opposite directions for a limited distance and only gradually destroy each other by an interference which might be called frictional. The propositions would, as it seems to us, apply more correctly to two systems of waves travelling (or propagated) in the same direction, the undulations of the one having a greater velocity than, and overtaking, the other. (It is on the assumption of an actual interference of the kind supposed that the objection to the particular case contained in the note at p. 16 is made, and we are not to be understood thereby as affirming or admitting the soundness of any part of the general theory to which these propositions belong.) But the same propositions are applied, Art. 819, to interference of encountering undulations in elastic fluids; and it is, as appears, at once assumed, on the ground of analogy only, that these propositions are to be accepted as (fact) postulates or axioms. But the objection taken to them in their application to the liquid wave also applies, and even more obviously, to the encountering undulations of the elastic fluid. If two equal undulations encounter from opposite directions it seems almost obvious either that they must destroy (neutralise) each other, or that both of them must be reflected; but Nos. I. and III. of the propositions, applied to elastic fluids in Art. 819, teach that in such case, the effect (in the compression and rarefaction of the resulting undulation) is the sum of the two undulations; without defining, however, in which direction the resulting undulation or wave is to proceed. In the case of proposition II., where the resulting wave or undulation is stated to be the difference of the two, the doctrine does not appear so incredible—although, in this case, the result which anyone acquainted with the laws and phenomena belonging to mechanical science would probably expect to find, would be a velocity in the resulting wave or undulation equal to the *difference* in the *velocities* of the encountering unequal undulations.

However, the entire theory in its application to elastic fluids, as set forth, is quite at variance with the known facts and established laws of mechanical science. What should be our answer if told and called upon to admit that a pound of water in descending one foot could develope or eliminate mechanical power capable of raising a ton weight of water not only to a height of one foot but to a height of an unlimited or indefinite number of miles? and yet this is substantially and almost precisely what we are here, in other words, told and required to accept as science. Referring to the illustration, Fig. 242, "let *S. A.* represent the space through which the disturbing force acts, and let us imagine this air suddenly pressed from *S.* to *A.* by some solid surface moving against it, and let us suppose that this motion from *S.* to *A.* is made in a second." Herein we have clearly stated the definite exciting or developing cause of a definite quantity of mechanical force or power, because a definite amount of compression in a definite time of a definite quantity of air (or other elastic fluid) represents a definite amount of mechanical power just as certainly as the descent of a definite weight from a definite height, or the motion of a definite weight through a definite space in a definite time. And what is the effect which we are told this definite amount of mechanical force or power is capable of performing? In order to understand this clearly, let us, with the same figure, (Fig. 242,) take the point *A.* as a centre and with the distance *A. T.* describe the circle *T. U. V. Y.*; now let us suppose that the wave-undulation, as represented, has a volume the breadth of which when it has reached the point *T* will be equal to one degree of the circle. We are to.d at the end of Art. 817, that the effect defined and illustrated in respect to the one direct line "is equally applicable to every line diverging in every conceivable direction around such centre." By the illustration and statement the result or effect at the point *T.* in the one direct line, the volume of compressed fluid being the same, represents the whole of the mechanical power, developed in the compression from *S.* to *A.**; but the circle *T. U. V. Y.* contains 360 degrees of which the line terminating at *T.* only represents one, consequently if the effect is transmitted in undiminished quantity to every point in the circle, the original effect has been increased 360 times. Now, if in place of the circle we suppose a sphere, the square of this quantity, namely, 360 × 360, will represent the increase in the effect. We can, however, as an argument, if any difficulty is felt as to this preliminary increase, afford to leave this aside, and to suppose a circle or sphere of any definite small size to represent the original definite quantity of mechanical power eliminated. Then, if a circle and the distance from the central point is doubled, the area or areal content of the larger circle will equal the square of the areal content of the lesser circle; or, if a sphere and the distance from the central point is so doubled, then will the cube of the areal content of the lesser sphere represent the areal content of the greater. Therefore, since the effect as illustrated in the one line is "equally applicable to every line diverging in every conceivable direction around such centre," it follows that, when the distance from that centre is for the first time doubled, the effect (which is assumed to be transmitted in undiminished energy and amount to every part of the surface of the surrounding sphere) must have increased in cubical proportion, i. e., representing the original effect, or definite amount of power eliminated, by *P.*, we now have at the surface of the duplicated sphere $P \times P \times P$. (or P^3.) When this greater sphere is again duplicated, by increasing the

* This may be made more clearly apparent by supposing the line S. T., in the illustration Fig. 242, to represent a tube of any definite size.

radial distance in every direction, to four times *A. T.*, then the first resulting effect must be again cubed, and we obtain $P^3. \times P^3. \times P^3.$ (or $P^9.$) and so on. That the effective energy, in any one direction, of the mechanical power developed or eliminated by the primary compression must diminish as the distance from the originating point increases, is to a certain extent admitted at the end of Art. 819, where it is thus stated : "As the undulations produced in the air are spread over spherical surfaces having the centre of disturbance as a common centre, the magnitude of those surfaces will be in the ratio of the squares of their radii, or what is the same, of the squares of their distances from the point of central disturbance; and as the intensity of the wave is diminished in proportion to the space over which it is diffused, it follows that the effects or energy of these waves will diminish as the squares of their distances from the centre of propagation increase."

Now a little attentive consideration will make it apparent that the diminution of energy, in the case supposed, would be, not as the squares of the radial distances, but as the cubes of those distances; because, the increase is as the increasing areas of the spheres, through which increasing areas the undulation has to travel (to be propagated); the undulation is not spread *out into the surface* of the sphere, but has to travel *through every point in the surface* of the sphere.

*Note. This objection, viz., that the amplification, and consequent diminution of intensity, must be as the cube instead of as the square of the increasing distance, stands by itself.**

* If the primary sphere of compressed air (or ether), which forms the originating centre of the undulation be supposed to retain its individuality as a sphere of definite size and to propagate itself radially (if we can conceive it) in every direction, it is obvious that it must overcome the negative resistance, *vis inertiæ*, of the particles of air (or of ether), to its progress in each and every direction, and this resistance would increase as the cube of the distance from the origi-

As an argument, we are aware that an answer may be given which to the supporters of the undulatory theory might appear sufficient, namely, that the undulations once commenced are not supposed to increase in wave-length, nor to diminish directly in longitudinal intensity; i.e. that if it were not for the lateral increase in amplitude (lateral extension) the wave impulse might be propagated to an unlimited distance without diminution of intensity. But this assumption is not, as it seems to us, compatible with the fundamental origin and character of the wave impulse as set forth; it is not anywhere shown how a definite quantity of mechanical power eliminated, being contained in and propagated by the alternate expansion and contraction of a definite spherical portion of elastic fluid, can be amplified laterally without being also amplified longitudinally. It is true, in the impact theory propounded in the Encyc. Britt. by which the particles are supposed to transmit the impulse in a straight line in one direction only, the objection would not apply, but then it is not shown how that theory, or that form of the undulatory theory, is to be applied to an influence which extends itself radially from a centre in all directions; the writer of the Art., indeed, when the application of the theory to the actual circumstances has to be considered, appears to entertain a misgiving as to the tenability of the theory, a misgiving expressed in the sentence "expanding continually, if we can conceive it, into a wider and wider concentric

nating centre. It is just as evident that by Lardner's hypothesis (quoted page 19) of the alternately expanding and contracting spheres, all the particles of air (or ether), occupying space between the centre and the surface of the outermost sphere, have to be set in motion. We shall presently point out that the supposition of the spherical shells of elastic fluid, one outside another, propagating a limited and definite quantity of mechanical power, as stated by Lardner (quotation page 19), involves the necessary absurdity of supposing expansion and contraction in the volume of the air or ether (elastic fluid) to take place at one and the same time, because compression here means contraction in volume, and expansion in volume must be continuous for the volume of the lesser sphere to continually increase into the greater sphere surrounding it.

sphere." Now persons do not feel a difficulty in conceiving known facts as facts, the observation or recognition of the fact supplies (stands in the place of) the conception so far, but, when it is proposed to account for the fact according to a particular theory, and there is a difficulty in conceiving the fact in the proposed connection with the theory, it must then be the theory, and not the fact itself, which occasions the difficulty; for example, it being known as a fact that the impulse causing sound, having originated at a central point, spreads or extends itself spherically (radially) from that point in all directions, there is no difficulty in conceiving it to be so, but taking the fact in connection with the theory proposed by the writer of the Art. in the Encyclopedia Brittanica, the proviso becomes necessary "if we can conceive it."

Whether, however, the diminution be considered proportional to the cube or to the square of the distance, the admission thereof must be alike fatal to the theory, * as it is set forth in articles 815, 816, 817. The case supposed is that of alternate compression and expansion, of condensation and rarefaction; but if it be admitted that the energy diminishes because the undulation has to occupy a greater magnitude, then it follows that the matter of which the undulation consists must expand so as to occupy that greater magnitude, and it becomes impossible to conceive a compression to take place of its particles of matter into a smaller space which are at the same time expanding into a greater space. . . We are called upon to suppose the definite quantity of matter, of which the undulation consists, to be undergoing condensation and to be expanding at one and the same time.

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* In reference to this (unavoidable) admission, we would suggest a question .... What must have been the original intensity of a wave or undulation of solar-light which has come to us from a distance of 95 million miles, and which has been (by the admission) diminishing in intensity, as the square of the increasing distance from the centre of propagation (*i. e.* the sun)?

In reference to the explanations and comparison of the phenomena belonging to the wave undulations of liquids and to the supposed undulations of elastic fluids, contained in the preceding quotation from Lardner's Natural Philosophy, it may be remarked that the agreement or analogy between them is of that kind which exists, more or less, between all sorts of vibrations and oscillations; and the disagreement or distinctive difference in character, is that, in the one, gravitation is the agent in propagating the impulse, and in the other, the elastic property and compressibility of the fluid allows the supposed alternate contraction and expansion arising from the impulse to propagate the effect.

That the undulations in the elastic fluid, assuming that such may be propagated in the manner supposed and that they result in the effect called sound, are in fact of an entirely distinct nature from the liquid waves, is quite evident, because it is known that sound may be transmitted to a great distance through water without interruption or interference from the liquid undulations and oscillations of the wave character, which may be taking place at the same time therein. The particular character of the vibrations in the elastic medium which are supposed to propagate the disturbing impulse and to result in that effect known as sound is thus explained in the Art. *Acoustics of the Encyclopedia Brittanica.*

"In order to conceive the mode in which sound is propagated through the air, let us consider what takes place when we move a series of balls ranged in a line on a table, or suspended by threads. If we strike the one end of the line by impelling a ball against it, it is only the ball at the other end which appears to be affected. This flies off from the rest, and leaves them almost stationary. The intermediate balls, therefore, serve merely to transmit the impulse from the one end to the other of the series. In the same manner it is that the agitation or impulse, from which sound arises, is transmitted through the air. This" "fluid, like every other body, consists in an infinite number of little particles; a single series of which may be represented to us by the balls in the above example. These particles are not even in contact with each other; they are separated by minute intervals, but are yet connected together by attractive and repulsive forces, which tend to retain them perpetually in equilibrium. In every case, therefore, there is in reality a chain of such particles reaching from the sounding body to the ear. The former, by its agitation, strikes that particle which is next to it, the intermediate ones serve to convey the impression, and the last one, flying off, strikes the sentient organ of hearing. The process is exactly similar to that of impulse along a series of balls, only that in the case of the air, the intermediate particles, instead of remaining at rest, move each of them backwards and forwards by a very minute interval; the first communicating its motion to the second, the second to the third, and so on to the last; each performing a slight oscillatory movement, which advances from the beginning to the end of the series. We now see at once the cause of a remarkable and well-known fact, that the propagation of sound is not instantaneous; it requires time to advance from the sounding body to the ear, as is daily observed and illustrated in the discharge of fire-arms. If the distance be at all considerable, a sensible interval is always observed to elapse between the flash and the report. The light flies almost instantaneously, but the report is retarded according to the distance; as is also seen in other cases: when we observe the workmen, for example, cutting up large stones in any quarry; if we stand at a little distance, we see invariably and distinctly the blow of the hammer on the stone before the sound reaches the ear. These and other similar facts leave no doubt that sound advances only at a certain rate, and invariably requires time for its propagation; and the reason is, that each aërial particle in the chain of communication must have a certain time, minute no doubt.

"but still definite, to perform its oscillation, and communicate its motion to the rest; and thus the advance of the agitation and of the sound is retarded; and only sweeps with a regulated progression along the line. It is not through one series of particles merely that the oscillatory motion is communicated. The sounding body, having every part of it in a state of agitation, generally acts all round; but, even though it were only to act in one direction, the impulse, once begun at the centre, is propagated in all directions; for though only one particle were originally affected, so intimately were they all connected together and united into a system by their mutual attractions and repulsions, that this cannot advance in any degree forwards without affecting the particles on each side; these affect what are before and around them; and thus the impulse is communicated, and diffuses itself on all sides. These lateral impressions would appear to be necessarily somewhat enfeebled, yet it is one remarkable characteristic of such oscillatory movements, that, like the vibrations of a distended cord, or the oscillations of a pendulum in a cycloid, they are all performed in the same time, however minute or however extended. The lateral impressions, therefore, though ever so feeble, are yet transmitted with the same rapidity as the direct; the sound may be weakened, and we often observe it is so; a speaker, for example, is always best heard in front; the report of a cannon is also loudest in that direction, but still the sound is heard at the very same instant all around. It is owing to this diffusion of the agitation in all directions, the original impression being spread out, not merely in concentric circles like the waves in a pool, but expanding continually, if we can conceive it, into a wider and wider concentric sphere,—it is owing to this that every sound decreases so rapidly as we recede from it, and at last dies away in the distance."

The theory of the transmission of the sonorous impulse as thus defined by the writer in the Encyclopedia

Brittanica differs very much from the teaching of Lardner. The wave analogy, and the alternate compression and rarefaction of the elastic fluid, are, apparently, herein discarded, and the transmission is explained to consist in the communication of motion from one particle to the next by contact or impact. This hypothesis is much more simple, and is not in some respects so obviously objectionable as that stated by Lardner; but it does not explain some, and is irreconcilable with other particulars of the observed facts; for example, it is not explained how the phenomena of interference are to be accounted for under this hypothesis. The impact-communication, and transmission of the impulse from particle to particle, is supposed to apply also and in like manner to liquids and to such solids as are capable of transmitting sound. Notwithstanding the inelasticity of water, it is found to be a good conductor of sound. "It appears from the experiments of M. Calloden, at Geneva, that sounds are transmitted through the water to great distances with greater force than through air. A blow struck under the water of the Lake of Geneva was distinctly heard across the whole breadth of the Lake, a distance of nine miles."

We may here take the opportunity, also, to remark the hypothetical definitions contained in the several terms used by teachers to denote the impulses in connection with the partial explanations which frequently accompany their use, e.g., undulations, waves, vibrations, wave-lengths of the vibrations, or of the oscillations, longitudinal oscillating motions of the particles of ether; transverse oscillating motions of the particles of ether, &c. . . . we would suggest whether a careful examination might not show that herein we have an attempt to combine together the discordant elements of two or three distinct theories, neither of which will bear to be distinctly stated and examined separately on its own merits. Hence a general mystification and vagueness which assists to increase the apparent abstruseness and profundity of the *subject. Nothing, we may safely say, is more to be distrusted in a sound scientific sense, than a theory which will not bear to be definitely and distinctly stated, and which, in its most simple and general application becomes unintelligible.*

A liquid-wave is superficial and dependent upon gravitation, under the influence of which, the mobility of the particles of liquid admitting of such effect, the descent of certain particles causes the ascent of an equal number; the vertical deviation, (height and depth of the wave) being confined to a limited distance above and below the horizontal surface of the liquid. In the vibration of a string, the extent of the deviations from the straight line contained between the two extremities of the string (i.e. of the vibration) is confined to a very limited distance by the molecular cohesion (or mutual attraction of the particles). In each of these cases the result is the intelligible effect of a recognized cause; but in the hypothetical alternate expansions and contractions of a certain small portion of an elastic fluid, propagating itself through the bulk of that fluid to great distances and keeping itself distinct therefrom, we have an unintelligible supposition, or an arbitrary and unreasonable assumption, because no intelligible cause can be assigned for the supposed limitation of the effect. When the expansion commences why does it not continue? What is there to determine a limit? Let, for example, a small quantity of compressed ether be injected into space, what is there to prevent the continued and unimpeded expansion of that small quantity until it becomes as attenuated as that which surrounds it? Why should it expand and contract alternately? Or, if the particles of ether are supposed to oscillate and to make excursions to and fro; why should they so oscillate? Having commenced to move in the one direction, what is there to impede the continuous motion of the particles in that direction? What fact or natural law is there to support and render intelligible the assumption?

The following quotation from *Lardner's Natural Philosophy* contains the notice of certain of the observed facts belonging, more particularly, to the science of Acoustics.

821. "*Presence of air necessary to the production of sound.*—That the presence of air or other conducting medium is indispensable for the production of sound, is proved by the following experiment.

Let a small apparatus called an alarum, consisting of a bell, the tongue of which is governed by a string, be placed under the receiver of an air pump, through the top of which a rod slides, air-tight, the end of the rod being connected with a detent which governs the motion of the tongue through the intervention of the string. This rod can, by a handle placed outside the receiver, be made to disengage the string, so as to make the bell within it ring whenever it is desired. This arrangement being made, and the alarum being placed outside the receiver, upon a soft cushion of wool, so as to prevent the vibration from being communicated to the pump-plate, let the receiver be exhausted in the the usual way. When the air has been withdrawn, let the bell be made to ring by means of the sliding rod. No sound will be heard, although the percussion of the tongue upon the bell, and the vibration of the bell itself are visible. Now if a little air be admitted into the receiver, a faint sound will begin to be heard, and the sound will become gradually louder in proportion as the air is gradually readmitted.

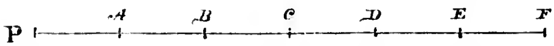
In this case the vibrations which distinctly act upon the ear are not those of the air contained in the receiver. These latter act upon the receiver itself and the pump-plate, producing in them sympathetic vibration; and those vibrations impart vibrations to the external air which are transmitted to the ear.

If in the preceding experiment a cushion had not been interposed between the alarum and the pump-plate, the sound of the bell would have been audible, notwithstanding the absence of air from the receiver."

"The vibration in this case would have been propagated, first from the bell to the pump-plate and to the bodies in contact with it, and thence to the external air."

822. "*A continuous body of air not necessary.*—Persons shut up in a close room are sensible of sounds produced at a distance outside such room; and they may be equally sensible of these, even though the windows and doors should be absolutely air-tight. In such case the undulations of the external air produce sympathetic vibration on the windows, doors or walls by which the hearers are enclosed, and then produce corresponding vibrations in the air within the room, by which the organs of hearing are immediately affected."

823. "*Propagation of sound progressive.*—Let a series of observers, *A. B. C.* &c., be placed in a line, at distances of about 1000 feet asunder, and let a pistol be discharged at *P.* about 1000 feet from the first observer.



This observer will see the flash of the pistol about one second before he hears the report. The observer *B.* will hear the report one second after it has been heard by *A.* and about two seconds after he sees the flash. In the same manner the third observer at *C.* will hear the report one second after it has been heard by the observer at *B.* and two seconds after it has been heard by the observer at *A.* and three seconds after he perceives the flash. In the same way, the fourth observer at *D.* will hear the report one second later than it was heard by the third observer at *C.* and three seconds later than it was heard by the observer at *A.* and four seconds after he perceives the flash.

Now it must be observed, that at the moment the report is heard by the second observer at *B.* it has ceased to be audible to the first observer at *A.*, and when it is" "heard by the third observer at *C.* it has ceased to be heard by the second observer at *B.*, and so forth. It follows, therefore, from this, that sound passes through the air, not instantaneously, but progressively, and at a uniform rate."

824. "*Breadth of sonorous waves.*—As the sensation of sound is produced by the wave of air impinging on the membrane of the ear-drum exactly as the momentum of a wave of the sea would strike the shore, it follows that the interval between the production of sound and its sensation is the time which such a wave would take to pass through the air from the sounding body to the ear; and since these waves are propagated through the air in regular succession, one following another without overlaying each other, as in the case of waves upon a liquid, the breadth of a wave may always be determined if we take the number of vibrations which the sounding body makes in a second, and the velocity with which the sound passes through the air. If, for example, it be known that in a second a musical string makes 500 vibrations, and that the sound of this string takes a second to reach the ear of a person at a distance of 1000 feet, there are 500 waves in the distance of 1000 feet, and consequently each wave measures two feet.

The velocity of the sound, therefore, and the rate of vibration, are always sufficient data by which the length of the sonorous wave can be computed."

825. "*Distinction between musical sounds and ordinary sounds.*—It has not been ascertained, with any clearness or certainty, by what physical distinctions vibrations which produce common sounds or noises are distinguished from such as produce musical sounds. It is nevertheless certain, that all vibrations, in proportion as they are regular, uniform and equal, produce sounds proportionably more agreeable and musical.

Sounds are distinguished from each other by their pitch of tone, in virtue of which they are high or low;"

"by their intensity, of which they are loud or soft; and by a property expressed in French by the word *timbre*, which we shall here adopt in the absence of any English equivalent."

826. "*Pitch of a sound.*—The pitch or tone of a sound is grave or acute. In the former case it is low, and in the latter high, in the musical scale. It will be shown hereafter that the physical condition which determines this property of sound is the rate of vibration of the sounding body. The more rapid the vibrations are, the more acute will be the sound. A bass note is produced by vibrations much less rapid than a note in the treble. But it will also be shown that the length of the sonorous wave depends on the rate of vibration of the body which produces it: the slower the rate of vibration, the longer will be the wave, and the more grave the tone. All the vibrations which are performed at the same rate produce waves of equal length and sounds of the same pitch."

827. "*Intensity or Loudness.*—The intensity of a sound or its degree of loudness, depends on the force with which the vibrations of the sounding body are made, and consequently upon the degree of condensation produced at the middle of the sonorous wave. Waves of equal length, but having different degrees of condensation at their centre, will produce notes of the same pitch, but of different degrees of loudness, in proportion to such degrees of condensation."

828. "*Timbre of a sound.*—The timbre of a sound is not easily explained, and still less easily can the physical conditions on which it depends be ascertained. If we hear the same musical note produced with the same degree of loudness in an adjacent room successively upon a flute, a clarionet, and a hautboy, we shall, without the least hesitation, distinguish the one instrument from the other. Now, this distinction is made by observing some peculiarity in the notes produced, yet the notes shall be the same, and be produced with equal loudness. This"

"property by which the one sound is distinguished from the other, is called the timbre."

829. "*All sounds propagated with the same velocity.*—All sounds, whatever be their pitch, intensity, or timbre, are propagated through the same medium with the same velocity. That this is the case, is manifest from the absence of all confusion in the effects of music, at whatever distance it may be heard. If the different notes imultaneously produced by the various instruments of an orchestra moved with different velocity through the air, they would be heard by a distant auditor at different moments, the consequence of which would be, that a musical performance would, to the auditors, save those in immediate proximity with the performers, produce the most intolerable confusion and cacophony; for, different notes produced simultaneously, and which, when heard together form harmony, would at a distance be heard in succession, and sounds produced in succession would be heard as if produced together, according to the different velocities with which each note would pass through the air."

830. "*Experiments on the velocity of sound.*—The velocity of sound varies with the elasticity of the medium by which it is propagated. Its velocity, therefore, through the air, will vary, more or less, with the barometer and thermometer.

The experimental methods which have been adopted to ascertain the velocity of sound are similar in principle to those which have been briefly noticed by way of illustration. The most extensive and accurate system of experiments which have been made with this object were those made at Paris by the Board of Longitude in the year 1822. The sounding bodies used on this occasion were pieces of artillery charged with from two to three pounds of powder, which were placed at Villejuif and Montlhéry. The experiments were made at midnight, in order that the flash might be more easily and accurately"

" noticed. They were conducted by MM. Prony, Arago, Mathieu, Humboldt, Gay Lussac, and Bouvard. The result of the experiment was that, when the barometer was at 29.8 inches, and the thermometer at 61°, the velocity of sound was 1118.39 feet per second.

By calculation it is ascertained, that at the temperature of 50°, the velocity would be 1106.58 feet per second; and at 32°, the velocity would be 1086.37 feet per second.

Thus it appears that between 50° and 61°, the velocity of sound increases about 1.07 feet per second for every degree which the thermometer rises, and betwen 50° and 32°, it increases at the mean rate of 1.12 feet per second for each degree in the rise of the thermometer."

831. "*Method of estimating the distance of a sounding body by velocity of sound.*—The velocity of sound being known, the distance of a sounding body can always be computed by comparing the moment the sound is produced with the moment at which it is heard. The production of sound is in many cases attended with the evolution of light, as, for example, in fire-arms and explosions generally, and in the case of atmospheric electricity. In these cases, by noting the interval between the flash and the report, and multiplying the number of seconds in each interval by the number of feet per second in the velocity of sound, the distance can be ascertained with great precision. Thus, if a flash of lightning be seen ten seconds before the thunder, which attends it, is heard, and the atmosphere be in sech condition that the velocity of sound is 1120 feet per second, it is evident that the distance of the cloud in which the electricity is evolved must be 11,200 feet.

Among the numerous discoveries bequeathed to the world by Newton, was a calculation, by theory, of the velocity with which sound was propagated through the air. This calculation, based upon the elasticity and temperature of the air, gave as a result about one sixth"

" less than that which resulted from experiments. This discrepancy remained without satisfactory explanation until it was solved by Laplace, who showed that it arose from the fact that Newton had neglected to take into account, in his computation, the effect of the heat developed and absorbed by the alternate compression and rarefaction of the air produced in the sonorous undulations. Laplace taking account of these, gave a formula for the velocity of sound which corresponds in its results equally with experiment."

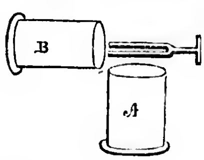
832. "*All gases and vapours conduct sound. Experimental illustrations.* As all elastic fluids are, in common with air, susceptible of undulation, they are equally capable of transmitting sound. This may be rendered experimentally evident by the following means. Let the alarum be placed under the receiver of an air pump, as already described, and let the receiver be exhausted. If, instead of introducing atmospheric air into the receiver we introduce any other elastic fluid, the sound of the alarum will become gradually audible, according to the quantity of such fluid which is introduced under the receiver. If a drop of any liquid which is easily evaporated be introduced, the atmosphere of vapour, which is thus produced, will also render the alarum audible."

833. "*The intensity of a sound increases with the density of the propagating medium.*—The same sounding body will produce a louder or lower sound, according as the density of the air which surrounds it is increased or diminished. In the experiment already explained, in which the alarum was placed under an exhausted receiver, the sound increased in loudness as more and more air was admitted into the receiver. If the alarum had been placed under a condenser, and highly compressed air collected round it, the sound would have been still further increased. When persons descend to any considerable depth in a diving-bell, the atmosphere around them is compressed by the weight of the column of water above them. In such "

"circumstances, a whisper is almost as loud as the common voice in the open air, and when one speaks with the ordinary force, it produces an effect so loud as to be painful.* On the summit of lofty mountains, where the barometric column falls to one half its usual elevation, and where, therefore, the air is highly rarefied, sounds are greatly diminished in intensity. Persons who ascend in balloons find it necessary to speak with much greater exertion, and as would be said louder, in order to render themselves audible. When Saussure ascended Mont Blanc, he found that the report of a pistol was not louder than a common cracker."†

837. "*Experimental illustration of interference of sound.*—This phenomena of interference may be produced in a striking manner by means of the common tuning-fork, used to regulate the pitch of musical instruments.

Let *A.* and *B.*, Fig. 243, be two cylindrical glass vessels, held at right angles to each other, and let the tuning-fork, after it has been put in vibration, be held in the middle of the angle formed by their mouths. Although, under such cir-



* But, is this the effect as usually experienced? We have some recollection under such circumstances, of a sensation of oppression in the ears, and as of a continued peculiar noise, accompanied with a considerable difficulty in hearing any one speak.

† These instances are given as evidences in support of the proposition that the transmitting or propagating capability of the elastic fluid increases or decreases according to the increased or decreased density of the fluid. But they do not in themselves furnish any conclusive evidence, because the effects noticed may be, with equal probability, attributed to another cause. The necessity for greater exertion in the balloon may arise from a difficulty in speaking instead of a difficulty in hearing; and again, if the noise, in quantity of sound, be dependent on the concussion, the rarefaction of the air would diminish the violence of the concussion [occasioned by the explosion] in firing the pistol, and consequently less noise or quantity of sound would be produced.

"cumstances, the vibration of the tuning-fork will be imparted to the columns of air included within the two cylinders, no sound will be heard; but if either of the cylinders be removed, the sound will be distinctly audible in the other. In this case the silence produced by the combined sounds is the consequence of interference. Another example of this phenomenon may be produced by the tuning-fork itself. If this instrument, after being put into vibration, be held at a great distance from the ear, and slowly turned round its axis, a position of the prongs will be found at which the sound will become inaudible. This position will correspond to the points of interference of the two systems of undulation propagated from the two prongs."

838. "*Examples of sounds propagated by solids.*—Solids which possess elasticity have likewise the power of propagating sound. If the end of a beam composed of any solid possessing elasticity be lightly scratched or rubbed, the sound will be distinct to an ear placed at the other end, although the same sound would not be audible to the ear of the person who produces it, and who is contiguous to the place of its origin. The earth itself conducts sound, so as to render it sensible to the ear when the air fails to do so. It is well known, that the approach of a troop of horses can be heard at a distance by putting the ear to the ground. In volcanic countries, it is said that the rumbling noise which is usually the prognostic of an eruption is first heard by the beasts of the field, because their ears are generally near the ground, and they then, by their agitation and alarm, give warning to the inhabitants of the approaching catastrophe. Savage tribes are well known to practise this method of ascertaining the approach of persons from a great distance.

The velocity with which sound is propagated through different media varies with their different physical conditions."

"In the following table are given teh velocities with which sound is propagated through the several liquids therein named, the temperature being 50°.

839. TABLE

NAMES.	Specific gravity.	Compressibility under one atmosph. in millionths of primitive volume.	Velocity of sound in feet per second.
Sulphuric ether	.712	131.35	3.409
Alcohol	.795	94 95	3.796
Hydrochloric ether	874	84 25	3.834
Essence of turpentine	.870	71 35	4.186
Water	1.000	47.85	4.767
Mercury	13.514	3.38	4.869
Nitric acid	1 403	30 55	5.036
Water of Ammonia (saturated).	.900	38.05	6.044

840. TABLE

NAMES.	Velocities (that through Air being 1.)
Whalebone	6·66
Silver	9 00
Walnut, and other sorts of wood	10 66
Tobacco pipes	12·00
Copper	12·00
Wood-Pear and Red-beech	12·50
do Maple.	13·33
do Mahogany, Birch, &c	14·40
do Pine and Willow, &c	16·00
Glass, Iron and Steel	16·66
Tin	7·50

841. "*Effects of elasticity of air.*—The velocity with which sound is transmitted through the air varies with its elasticity; and where different strata are rendered differently elastic by the unequal radiation of heat, the agency of electricity or other causes, the transmission of sound will be irregular.

"In passing from stratum to stratum differing in elasticity, the speed with which sound is propagated is not only varied, but the force of the intensity of the undulation is diminished by the combined effect of reflection and interference, so that the sound, on reaching the ear, after passing through such varying media, is often very much diminished. The fact, that distant sounds are more distinctly heard by night than by day, may be in part accounted for by this circumstance, the strata of the atmosphere being, during the day, exposed to vicissitudes of temperature more varying than during the night."

§12. "*Biot's experiment on the relative velocities of sound in air and metal.*—The relative velocities of sound, as transmitted by air and metal, are illustrated by the following remarkable experiment of Biot:—A bell was suspended at the centre of the mouth of a metal tube 3000 feet long, and a ring of metal was at the same time placed close to the metal forming the mouth of the tube, so that when the ring was sounded its vibration might affect the metal of the tube, and when the bell was sounded its vibration might affect only the air included within the tube. A hammer was so adapted as to strike the ring and the bell simultaneously. When this was done, an ear placed at the remote end of the tube heard the sound of the ring, and after a considerable interval heard the sound of the bell." *

§13. "*Chladni's experiment on hearing.*—The solids comprising the body of an animal are capable of transmitting the sonorous undulations to the organ of hearing, even though the air surrounding that organ be excluded from communicating with the origin of the sound. Chladni showed that two persons stopping their ears could converse with each other by holding the same stick between their teeth, or by resting their teeth upon the same solid. The same effect was produced when the stick is pressed against the breast or the throat, and other parts of the body. If a person speaks, directing

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* In the art. Acoustics of the Encyclopedia Britannica the length of the pipes is stated at 2550 feet. From a mean of two hundred trials the interval between the two sounds was found to be 2.79 seconds. The art. continues: "But the transmission of sound through the internal column of air would have taken 2.5 seconds; which leaves .29″ for the rapidity of the tremor conducted through the cast-iron." There is obviously some mistake in this statement; the interval between the sounds must be a part only of the whole time occupied in the transmission through the internal column of air. It was afterwards concluded that the conduction (or transmission) through the iron occupied ten to twelve times less time than through the atmosphere.

his mouth into a vessel composed of any vibratory substance, such as glass or porcelain, the other stopping his ears, and touching such vessel with a stick held between his teeth, he will hear the words spoken.

The same effect will take place with vessels composed of metal or wood. If two persons hold between their teeth the same thread, stopping their ears, they will hear each other speak, provided the thread be stretched tight."

THE UNDULATORY THEORY OF LIGHT.

We will now take for consideration the undulatory theory of light, in its present state of developement, as applied to the explanation of the various optical phenomena.

The Ether, and the doctrine of Interference.

Tyndall's Lectures on Light. Pages 44 to 50.

"Stand upon the sea-shore and observe the advancing rollers before they are distorted by the friction of the bottom. Every wave has a back and a front, and, if you clearly seize the image of the moving wave, you will see that every particle of water along the front of the wave is in the act of rising, while every particle along its back is in the act of sinking. The particles in front reach in succession the crest of the wave, and as soon as the crest is passed they begin to fall. They then reach the furrow or *sinus* of the wave, and can sink no farther. Immediately afterwards they become the front of the succeeding wave, rise again until they reach the crest, and then sink as before. Thus, while the waves pass onward horizontally, the individual particles are simply lifted up and down vertically. Observe a sea-fowl or, if you are a swimmer, abandon yourself to the action of the waves; you are not carried forward, but simply rocked up and down. The propagation of a wave is the propagation of" "a form, and not the transferrence of the substance which constitutes the wave. The length of the wave is the distance from crest to crest, while the distance through which the individual particles oscillate is called the *amplitude* of the oscillation. You will notice that in this description the particles of water are made to vibrate *across* the line of propagation.

And now we have to take a step forward, and it is the most important step of all. You can picture two series of waves proceeding from different origins through the same water, when, for example, you throw stones into still water, the ring-waves proceeding from the two centres of disturbance intersect each other. Now, no matter how numerous these waves may be, the law holds good that the motion of every particle of the water is the algebraic sum of all the motions imparted to it. If crest coincide with crest, the wave is lifted to a double height *; if furrow coincide with crest, the motions are in opposition, and their sum is zero. We have then still water, which we shall learn presently corresponds to what we call *darkness* in reference to our present subject. This action of wave upon wave is technically called *interference*, a term to be remembered.

Thomas Young's fundamental discovery in optics was that the principle of interference applied to light. Long prior to his time an Italian philosopher, Grimaldi, had stated that, under certain circumstances, two thin beams of light, each of which, acting singly, produced a luminous spot upon a white wall, when caused to act together, partially quenched each other and darkened the spot. This was a statement of fundamental significance, but it required the discoveries and the genius of Young to give it meaning. How he did so, I will now try to make clear to you. You know that air is compressible; that by pres-"

*We have already made an objection (note to page 16) to the teaching in this particular as not according with the known laws of mechanical (physical) science.

"sure it can be rendered more dense, and that by dilatation it can be rendered more rare. Properly agitated, a tuning-fork now sounds in a manner audible to you all, and most of you know that the air through which the sound is passing is parcelled out into spaces in which the air is condensed, followed by other spaces in which the air is rarefied. These condensations and rarefactions constitute what we call *waves* of sound. You can imagine the air of a room traversed by a series of such waves, and you can imagine a second series sent through the same air, and so related to the first that condensation coincides with condensation and rarefaction with rarefaction. The consequence of this coincidence would be a louder sound than that produced by either system of waves taken singly. But you can also imagine a state of things where the condensations of the one system fall upon the rarefactions of the other system. In this case the two systems would completely neutralise each other. Each of them taken singly produces sound; both of them taken together produce no sound. Thus, by adding sound to sound we produce silence, as Grimaldi in his experiment produced darkness by adding light to light.

The analogy between sound and light here at once flashes upon the mind. Young generalised this observation. He discovered a multitude of similar cases, and determined their precise conditions. On the assumption that light was wave-motion, all his experiments on interference were explained; on the assumption that light was flying particles, nothing was explained. In the time of Huyghens and Euler a medium had been assumed for the transmission of the waves of light, but Newton raised the objection that, if light consisted of the waves of such a medium, shadows could not exist. The waves, he contended, would bend round opaque bodies and produce the motion of light behind them, as sound turns a corner, or as waves of water wash round a rock. It was proved that the bending round referred to" "by Newton actually occurs,* but that the inflected waves abolish each other by their mutual interference. Young also discerned a fundamental difference between the waves of light and those of sound. Could you see the ether, you would also find every individual particle making a small excursion to and fro, but here the motion, like that assigned to the water-particles above referred to, would be *across* the line of propagation. The vibrations of the air are *longitudinal*, the vibrations of the ether are *transversal*.

It is my desire that you should realize with clearness the character of wave-motion, both in ether and in air. And, with this view, I bring before you an experiment wherein the air-particles are represented by small spots of light. They are parts of a spiral, drawn upon a circle of blackened glass, and, when the circle rotates, the spots move in successive pulses over the screen. You have here clearly set before you how the pulses travel incessantly forward, while the particles that compose them perform oscillations to and fro. This is the picture of a sound-wave, in which the vibrations are longitudinal. By another glass wheel, we produce an image of a transverse wave, and here we observe the waves travelling in succession over the screen, while each individual spot of light performs an excursion to and fro across the line of propagation.

Notice what follows when the glass wheel is turned very quickly. Objectively considered, the transverse waves propagate themselves as before, but subjectively, the effect is totally changed. Because of the retention of impressions upon the retina, the spots of light simply describe a series of parelled luminous lines upon the screen, the length of these lines marking the amplitude of the vibration. The impression of wave-motion has totally disappeared."

* How has this been proved?

"The most familiar illustration of the interference of sound waves is furnished by the *beats* produced by two musical sounds slightly out of of unison. These two tuning-forks are now in perfect unison, and when they are agitated together the two sounds flow without roughness, as if they were but one. But by attaching to one of the forks a two-cent piece, we cause it to vibrate a little more slowly than its neighbour. Suppose that one of them performs 101 vibrations in the time required by the other to perform 100, and suppose that at starting the condensations and rarefactions of both forks coincide. At the 101st vibration of the quickest fork they will again coincide, the quicker fork at this point having gained one whole vibration, or one whole wave upon the other. But a little reflection will make it clear that, at the 50th vibration, the two forks are in opposition; here the one tends to produce a condensation where the other tends to produce a rarefaction; by the united action of the two forks, therefore, the sound is quenched, and we have a pause of silence. This occurs where one fork has gained *half a wave-length* upon the other. At the 101st vibration we have again co-incidence, and, therefore, augmented sound, at the 150th vibration we have again a quenching of the sound. Here the one fork is *three half-waves* in advance of the other. In general terms, the waves conspire when the one series is an *even* number of half-wave lengths, and they are destroyed when the one series is an *odd* number of half-wave lengths in advance of the other.* With two forks so circumstanced, we obtain those intermittent shocks of sound separated by pauses of silence, to which we give the name of beats."

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* In regard to this experiment, we remark that the primary cause of the sound is admitted to be the vibration of the metal fork; the primary cause of the quenching of the sound, also, is admitted to be the unequal number, owing to the variation in the rapidity, of the vibrations of the two prongs respectively. It does not appear, therefore, that any proof, or even that any evidence, in favor of the undulating theory is afforded beyond the negative eviden

Page 54. " In the undulatory theory, what pitch is to the ear, colour is to the eye. Though never seen, the lengths of the waves of light have been determined Their existence is proved *by their effects*, and from their. effects also their lengths may be accurately deduced. This may, moreover, be done in many ways, and, when the " " different determinations are compared, the strictest harmony is found to exist between them. The shortest waves of the visible spectrum are those of the extreme violet; the longest those of the extreme red; while the other colours are of intermediate pitch or wave-length. The length of a wave of the extreme red is such that it would require 36,918 of them placed end to end to cover one inch, while 64,631 of the extreme violet waves would be required to span the same distance.

Now, the velocity of light, in round numbers, is 190,000 miles per second. Reducing this to inches, and multiplying the number thus found by 36,918 we obtain the number of waves of the extreme red in 190,000 miles. *All these waves enter the eye and hit the retina at the back of the eye in one second.* The number of shocks per second necessary to the production of the impression of red is, therefore, four hundred and fifty-one millions of millions. In a similar manner, it may be found that the number of shocks corresponding to the impression of violet is seven hundred and eighty-nine millions of millions. All space is filled with matter oscillating at such rates. From every star waves of these dimensions move with the velocity of light like spherical shells outwards. And in the ether just as in the water, the motion of every particle is the algebraic sum of all the separate motions imparted to "

in this instance is not antogonistic to, or irreconcilable with, the theory. The same remark may be likewise applied to the preceding experiment, which may be termed a very striking subjective illustration of *an explanation*, assisting to make that explanation clearly understood, but which does not afford any demonstration or even evidence that the explanation itself is sound, further than shewing it to be in certain particulars, or when regarded from a certain point of view, not antagonistic to the observed phenomena.

"it. Still, one motion does not blot the other out; or, if extinction occur at one point, it is atoned for at some other point. Every star declares by its light its undamaged individuality, as if it alone had sent its thrills through space.

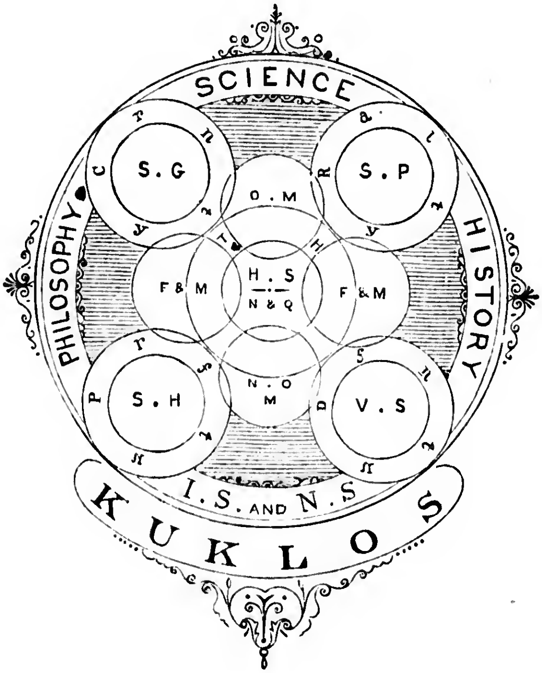
The principle of interference applies to the waves of light as it does to the waves of water and the waves of sound. And the conditions of interference are the same in all three. If two series of light-waves of the same length start at the same moment from a common origin, crest coincides with crest, sinus with sinus, and the two systems blend together to a single system of double amplitude. If both series start at the same moment, one of them being, at starting, a whole wave-length in advance of the other, they also add themselves together, and we have an augmented luminous effect. Just as in the case of sound, the same occurs when the one system of waves is any *even* number of semi-undulations in advance of the other. But if the one system be half a wave-length, or any *odd* number of half wave-lengths in advance, then the crests of the one fall upon the sinuses of the other; the one system, in fact, tends to *lift* the particles of ether at the precise places where the other tends to depress them; hence, through their joint action the ether remains perfectly still. This stillness of the ether is what we call darkness, which corresponds, as already stated, with a dead level in the case of water."

The explanations of the undulatory theories of light and sound contained in the foregoing quotations, sufficiently exhibit the present teaching on the subject. It may be here remarked that the explanation as given by each of the three teachers from whom we have quoted, differs in some essential particulars from that given by each of the other two. Dr. Lardner states, comparing the optical to the acoustic form of the theory, that the ether takes the place of the air, and that the ether "transmits the vibration exactly as the atmosphere transmits the vibration of a sounding body." Prof. Tyndall states as "a fundamental difference," first discovered by Young, that "the vibrations of the air are longitudinal" and "those of the ether transversal," which is particularly defined to mean that every individual particle of air oscillates to and fro in the direction of propagation, and that every individual particle of ether makes a small excursion to and fro across the line of propagation. Leslie writing in the Encyc. Brittan. (as quoted page 31) gives an explanation of the acoustic form of the theory, differing so essentially from the others that it might be more properly considered a distinct theory; the particles of air are supposed by him to conduct the impulse by impact of each particle on the next, the analogy to the waves of the liquid and the supposed alternating condensations and rarefications are put aside and the impact transmission of the impulse through the air is apparently similar to that which Dr. Lardner supposes to take place through solids and liquids which conduct the impulses or vibrations resulting in sound.

We are now prepared to consider the objections to the undulatory theory of light.

*There is, however, another question which, although not directly belonging to the undulatory theory of light, is closely connected with it, and is yet distinct enough to claim independent consideration. As it appears desirable to give attention to it before proceeding to expressly challenge the teaching on the general subject, and as we do not wish to divide or complicate the main argument, the investigation of the case will here follow as an appendix to part the first of this supplement. The question alluded to is . . the amount of Solar light (and radiant heat) received by a planet, in any definite time, relatively to the distance of the planet from the sun.**

* This question involves, and to some extent, includes other cases; e. g., the probable distance of the fixed stars as an inference from their comparative brightness.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APPENDIX.

It is now thought that the quantity of light and heat received by a planet from the sun is inversely as the square of the distance of the planet. We challenge this doctrine as unproven, and allege the fact to be that the amount of solar light and radiant heat received by the planet is inversely as the distance of the planet from the sun; that is, in simple and not in quadratic proportion. We do not propose now to demonstrate the proposition, but merely to indicate the argument.

Lardner's Natural Philosophy.

Light (910.) "*Methods of comparing the Illuminating power of Light.*—If two luminaries, having equal luminous surfaces at equal distances from the same white opaque surface, placed at the same angle with the rays, shed lights of equal brightness on such surface, it follows that their absolute intensities must be equal. If on the contrary, two such luminaries so placed produce different degrees of illumination on the same surface, their absolute intensities must be different, and must be in the proportion of the illuminations they produce. If in this case that luminary which produces the more feeble illumination be moved towards the illuminated object until its proximity is increased, so that it produces an illumination equal to that of the other luminary, then the absolute intensity of the two luminaries will be as the squares of their distances. This may be demonstrated as follows:—

"Let B. express the brilliancy of the illumination produced by the two luminaries. Let S. express the common magnitude of their luminous surfaces. Let I. and I'. express their intensities, and let D. and D'. express those distances which render their illuminations equal; we shall then have for the one $B = \frac{I \times S}{D^2}$ and for the other $B = \frac{I' \times S}{D'^2}$ consequently we shall have $\frac{I}{D^2} = \frac{I'}{D'^2}$ and consequently, $I : I' :: D^2 : D'^2$."

It is, perhaps, superfluous to point out that since no reason whatever is given why the square of the distance should be substituted for the distance itself, the foregoing formula has no value whatever in the sense of demonstration. We have the statement that "the absolute intensity of the two luminaries will be as the squares of their distances." This statement may be the expression of a prejudice; of a mere baseless opinion, or it may be of a conclusion based upon actual experiment and observation: it appears without support or reference, and the formula of itself can certainly not substantiate or strengthen it in any degree.

Herschel's Outlines of Astronomy.

(592.) "What renders these elements so remarkable is the smallness of the perihelion distance.* Of all comets which have been recorded this has made the nearest approach to the sun. The sun's radius being the sine of his apparent semi-diameter (16′1″) to a radius equal to the earth's mean distance = 1, is represented on that scale by 0·00466, which falls short of 0·00534, the perihelion distance found by taking a mean of all the foregoing results, by only 0·00068, or about one-seventh of its whole magnitude. The comet, therefore, approached the *luminous* surface of the sun within about a seventh part of the sun's radius! It is"

* The comet here spoken of, is the great comet which appeared in the spring of 1843; of which a full and very interesting account is given in the above work.

"worth while to consider what is implied in such a fact. In the first place, the intensity both of the light and radiant heat of the sun at different distances from that luminary increase proportionally to the spherical area of the portion of the visible hemisphere covered by the sun's disc. This disc, in the case of the earth, at its mean distance has an angular diameter of 32′ 1″. 1. At our comet in perihelio the apparent angular diameter of the sun was no less than 121° 32′. The ratio of the spherical surfaces thus occupied, (as appears from spherical geometry), is that of the squares of the sines of the fourth parts of these angles to each other,* or that of 1 : 47042. And in this proportion are to each other the amounts of light and heat thrown by the sun on an equal area of exposed surface on our earth and at the comet in equal instants of time. Let any one imagine the effect of so fierce a glare as that of 47,000 suns such as we experience the warmth of, on the materials of which the earth's surface is composed."

It will be understood, from what has gone before, that we do not accept as reliable the positions attributed to this and to other comets relatively to the sun; but, for the purpose of simplifying this argument, we will assume the place of the comet to have been as supposed in the foregoing; and, taking that assumption, our computation would be as 121°32′ : 32′ 1″ :: the amount of light and heat received by the comet in that position : the amount of light and radiant heat received by the earth. The result of which gives us, as the proportion

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* We would suggest that this can scarcely be the meaning which Sir John has intended to express. The "ratio of the squares of the sines of the fourth parts of the angles" *to each other*, is a simple quadratic proportion; quite the same as the ratio of the squares of the sines of the angles, or of the squares of the angles themselves *to each other* respectively. But it would appear that Sir John had some sort of geometric complex quadratic proportion in mind at the time of writing this.

about 227 suns, in place of the 17,000 suns obtained on the quadratic *hypothesis*.

Outlines of Astronomy.

(816.) "If our sun were removed to the distance expressed by our parallactic unit (art. 804), its apparent diameter of 32′ 1″·5 would be reduced to only 0″·0093 or less than the hundredth of a second, a quantity which we have not the smallest reason to hope any practical improvement in telescopes will ever show as an object having distinguishable *form*."

(801.) "Radius is to the sine of 1″ as 206265 to 1. In this proportion then, at least, must the distance of the fixed stars from the sun exceed that of the sun from the earth. Again, the latter distance, as we have already seen (art. 357), exceeds the earth's radius in the proportion of 23984 to 1. Taking, therefore, the earth's radius for unity, a parallax of 1″ supposes a distance of 4947059760, or nearly five thousand millions of such units: and lastly, to descend to ordinary standards, since the earth's radius may be taken at 4,000 of our miles, we find 19788239040000 or about twenty billions of miles for our resulting distance."

(348.) "The greatest apparent diameter (of the sun) corresponds to the 1st of January or to the greatest angular velocity, and measures 32′ 36″·2, the least is 31′ 32″; and corresponds to the 1st of July."

(358.) "An object placed at a distance of 95,000,000 miles, and subtending an angle of 32′1″, must have a real diameter of 882,000 miles."

The data thus furnished by arts. (801,) (348,) (358,) are quoted here for the purpose of checking the computation given above from art. (816), and which, apparently, presents an extraordinary discrepancy. On examination it becomes evident that the decimal point has been misplaced, and that the quantity should read ·00093″; or less than the thousandth of a second, instead of the hundredth as stated. However, we have, at the end of supplement B, furnished a rough computation on parallactic data, of the probable mean distance of a number of the comparatively less distant stars. That distance so obtained is 952,942 times the distance of the sun from the earth. On repeating the foregoing computation with this distance, we have, 952·942 : 1 :: 32′ 1″ : ·00020159″ or about the $\frac{2}{10000}$th part of a second. Be it noted that, notwithstanding the extremely small apparent magnitude of the diameter as thus represented, the stars, of which this distance is estimated to be the mean, are very distinctly visible to the unassisted eye; and not only so, but stars which must be unquestionably at very much greater distances are also quite distinctly visible without the aid of a telescope.

We will now briefly examine the case on its own merits. Fig. 10. (Pl. 4.) Let *S.* represent the sun; and *P.* a planet, at any definite distance as shown at (*a.*); at double that distance as at (*b.*); and at four times that distance as at (*c.*)

If we assume that the quantity of light received by the planet at (*a.*) is proportional to the angular visible area (*i.e.*, the apparent area) of solar surface; and if we represent the definite quantity received when at the place (*a.*) by x., then, if the planet be removed to the place (*b.*), at twice the distance, the angular visible area (apparent area) of the solar surface will have decreased to the one-half; and, consequently, the amount of light received by the planet will be now represented by $\frac{x}{2}$. And again, if we suppose the planet removed to the place (*c.*), the apparent solar area will have diminished to the one-fourth of the apparent area in the first position of the planet at (*a.*); and, consequently, the amount of light now received will be represented by $\frac{x}{4}$. Now, if we suppose the planet to have orbital revolution around the sun, controlled by gravitation, then the angular velocity of the planet's motion at the distance (*b.*) will be twice as great as at the distance (*c*.), and half as great as if at the distance (*a*.) from the sun. It will therefore follow that the total amount of light received during a complete revolution would be the same at whatever distance the planet might be from the sun; but, in the same definite time, the quantity received would be the one-half and the one-fourth respectively, if the distance of the planet were to be increased from (*a*.) to (*b*.), and then from (*b*.) to (*c*.).

But it is alleged that the sun radiates light in all directions alike, a part being intercepted and received by planets, and a very large proportion being radiated into space. And it would be inferred, as a consequence, that our assumption does not apply to the actual case. How has it been ascertained that the sun radiates light into space, and in every direction alike? Gravitation is also an influence which is communicated from the sun to the planet, or is intercommunicated between them; and it may also be said to be emitted by the sun. Is, then, the sun supposed to emit or radiate gravitation into space? Or, is it only emitted in the direction in which there is an aggregated mass of matter, to receive and reciprocate that influence? If the latter, then, supposing we dismiss all foregone conclusions and prejudice, does it appear so certain that the influence which causes light may not to be in the same case?

NOTE.—*We have not forgotten that a burning candle radiates light and heat to all directions, or that other luminous and incandescent bodies of the same description behave in like manner—a fact which is probably the basis of the supposition that the sun radiates equally in all directions; but it must be remembered that the candle or other radiating body, is surrounded by bodies which are recipients and in some degree reciprocators of the radiation.**

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* We are mindful that a red-hot globe radiates heat in all directions, and might be easily misunderstood to do so equally in all directions; but what is the actual result if examined by experiment? Four globes are suspended in the same apartment, at equal distances from each

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PLATE IV

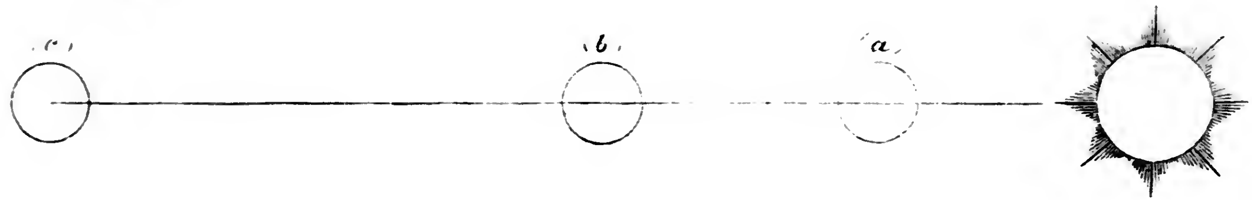

FIG. 10.

FIG. 13.

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We find in Prof. Tyndall's work, "Heat as a Mode of Motion," the following, which will assist in contrasting and making apparent the distinction between the two assumptions, viz: that of a general dispersion of light or heat from the radiant body, and that of a concentration of the light or heat from the radiator upon one or upon any number of recipients; only it must be carefully noted that according to the last assumption, if the number of recipients be innumerable or very numerous, so as to completely surround the radiating body, and to occupy every radial direction from that body, the apparent effect or result will be the same as by the first assumption.

(334.) "The intensity of radiant heat diminishes with the distance, in the same manner as that of light. What is the law of diminution of light? Each side of this square sheet of paper measures two feet; folded thus, it forms a smaller square, each side of which is a foot in length. (See Fig. 11.) The electric lamp now stands at a distance of sixteen feet from the screen; and at a distance of eight feet, that is, exactly midway between the screen and the lamp, I hold this square of paper.

other, of which *A.* is very hot, *B.* less hot, *C.* somewhat cooler, and *D.* the coolest. It is known that *D.* obtains a larger quantity of the heat radiated by *A.* than either of the others; whereas if the radiation of *A.* was equal in all directions, *C.* and *B.* would receive equal shares. (It may be said that B. and C. receive equal shares and return the difference to A. or transfer it to other bodies. But that is, at present, an assumption.) We are also aware that the light (and heat) from a radiating body, such as a candle, is alleged to decrease inversely as the square of the distance, and that this conclusion is supposed to have been experimentally established. But has not the experiment been tried without sufficiently careful consideration as to the required conditions? Put the luminous (or incandescent) radiating body in the focus of a good concave parabolic reflector, so that the rays will all be directed in parallel lines in the one direction, ... will the light or heat from the radiating body be found to decrease inversely as the square of the distance, if the experiment be so conducted?

If, for example, *C.* Fig. 14, be four times as far from the emitting body as *A.*, will the photometer or thermometer, if removed to *C.*, indicate only the $\frac{1}{16}$th the quantity of light o heat shown by it when at *A.*? And so on.

" The lamp is naked, unsurrounded by its camera, and the rays, uninfluenced by any lens are emitted in straight lines on all sides. You see the shadow of the square of paper on the screen ; let us measure the boundary of that shadow, and then unfold the sheet of paper, so as to obtain the original large square. You see, by the creases, that it is exactly four times the area of the smaller one. This large sheet, when placed against the screen, exactly covers the space formerly occupied by the shadow of the smaller square."

(335.) "On the small square, therefore, when it stood midway between the lamp and the screen, a quantity of light fell which, when the small square is removed, is diffused over four times the area upon the screen. But, if the same quantity of light is diffused over four times the area, it must be diluted to one-fourth of its original intensity. Hence, by doubling the distance from the source of light, we diminish the intensity to one-fourth. By a precisely similar mode of experiment, we could prove that, by trebling the distance, we diminish the intensity to one-ninth; and by quadrupling the distance we reduce the intensity to one-sixteenth: in short, we thus demonstrate the law that the intensity of light diminishes as the square of the distance increases. This is the celebrated law of inverse squares, as applied to light."

(336.) "But it has been stated that heat diminishes according to the same law. Observe the experiment which I am now about to perform before you. Here is a narrow tin vessel, *M. N.* (Fig. 12), presenting a side, coated with lamp black, a square yard in area. The vessel is filled with hot water, which converts this large surface into a source of radiant heat. I now place the conical reflector on the thermo-electric pile, *P.*, but, instead of permitting it to remain a reflector, I push into the cone this lining of black paper, which fits exactly, and which, instead of reflecting any heat that may fall obliquely on it, effectually cuts off the oblique radiation."

Fig 14

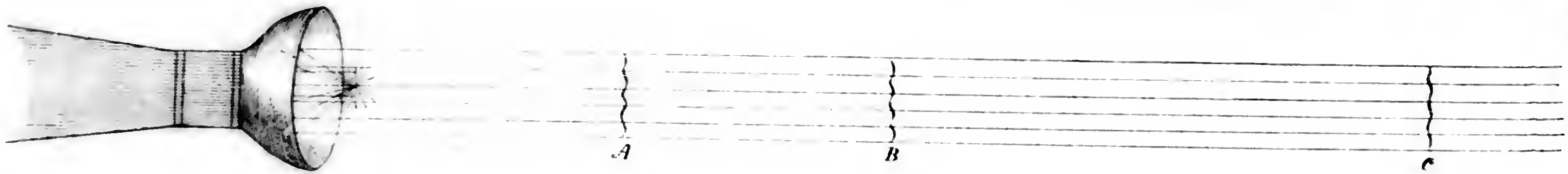


Fig 11

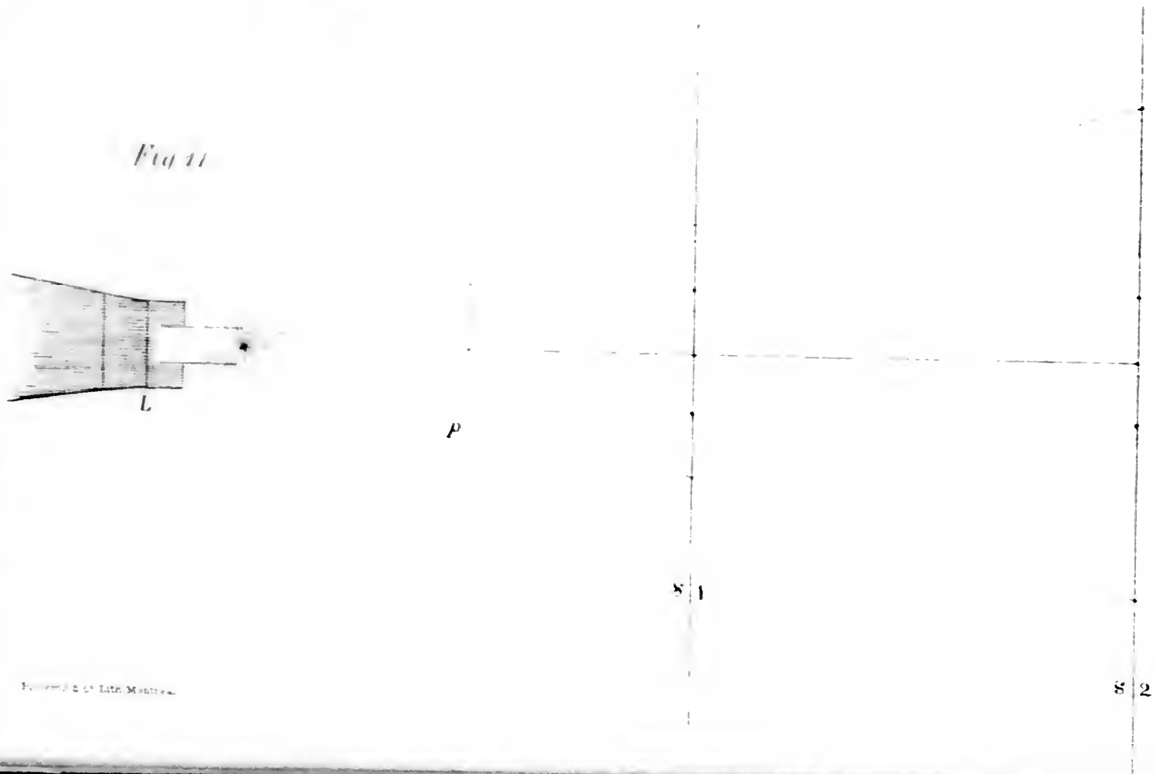
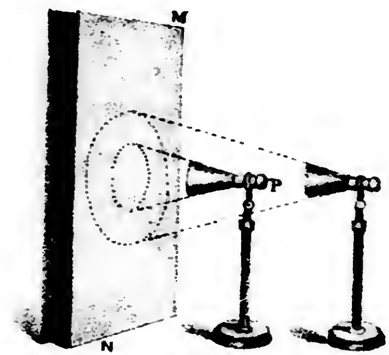


Fig 12.



"The pile is now connected with the galvanometer, and its reflector is close to the radiating surface, the face of the pile itself being about 6 inches distant from the surface."

(337.) "The needle of the galvanometer moves; it now points steadily to 60°, and there it will remain as long as the temperature of the radiating surface remains sensibly constant. I will now gradually withdraw the pile from the surface, and ask you to observe the effect upon the galvanometer. You will naturally expect that, as the pile is withdrawn, the intensity of the heat will diminish, and that the deflection of the galvanometer will fall in a corresponding degree. The pile is now at double the distance, but the needle does not move; at treble the distance, the needle is still stationary; we may successively quadruple, quintuple—go to ten times the distance, but the needle is rigid in its adherence to the deflection of 60°. There is, to all appearance, no diminution at all of intensity with the increase of distance."

(338.) "From this experiment, which might at first sight appear fatal to the law of inverse squares, as applied to heat, Melloni, in the most ingenious manner, proved the law. I will here follow his reasoning. Imagine the hollow cone in front of the pile prolonged; it would cut the radiating surface in a circle, and this circle is the only portion of that surface whose rays can reach the pile. All the other rays are cut off by the nonreflecting lining of the cone. When the pile is moved to double the distance, the section of the cone prolonged encloses a circle exactly four times the area of the former one; at treble the distance, the radiating surface is augmented nine times; at ten times the distance the radiating surface is augmented 100 times. Now, the constancy of the deflection proves that the augmentation of the surface must be exactly neutralized by the diminution of the intensity. But the radiating surface augments as the square of the distance, hence the intensity of the" "heat must diminish as the square of the distance; and thus the experiment, which might at first sight appear fatal to the law, demonstrates that law in the most simple and conclusive manner."

The two assumptions might be also examined by an experiment of this kind. A hot copper globe, at any very considerable definite temperature, being suspended in an apartment, the thermo-electric pile, fitted with a large condensing cone, is to be placed at a certain distance from it and the effect noted. A hollow hemispherical cover of diathermanous material (glass, for example) is to be applied over the copper globe, so as to partially enclose the globe and to leave only the one side of it exposed. Directly in front of the uncovered side, that is, in the direction in which the uncovered side looks, and at the same distance as before, the thermo-electric pile is to be stationed, and the effect again noted. (See Fig. 13, Pl. 4.) Now, assuming that the radiant heat received by the pile in the last case will be (considerably) greater than in the first, we have, then, to consider whether unoccupied space may not be negatively diathermanous—that is, have the effect in a negative sense, only much more perfectly (*i. e.*, quite perfectly), which a coating of diathermanous and non-radiating material would have. The supposition may be otherwise expressed, viz., that unoccupied space negatively refuses to receive or to convey (conduct) radiant heat or light—meaning thereby, that mere space has no positive capacity of itself to receive or convey the radiant heat or light.*

* The experiment, as proposed above, is for the purpose of illustration rather than as a test; but by exposing the pile for some considerable definite time, such as an hour, in each case, and noting the average and final effect, the experiment might be made to furnish some evidence towards a solution of the question.