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XIV. The experimental study of Huygens's secondary waves

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of the measurements is about 0·1 Å.U. ; it will be seen that the measurements of Rutherford and Royds are in good agreement.

Brief glances at the spectrum when the jar and spark-gap discharge is sent through the vacuum-tube indicate that the spectrum remains unaltered.

These experiments were made with the aid of the radium loaned to Prof. Rutherford by the Austrian Academy of Sciences. To Prof. Rutherford I am also indebted for the use of the apparatus and methods for purifying the emanation.

Physical Laboratories,
Manchester University.

XIV. *The Experimental Study of Huygens's Secondary Waves.* *By* C. V. Raman, *M.A.**

[Plate III.]

IN the Phil. Mag. for Nov. 1906 (pp. 495–498), I published a note on the diffraction-bands formed when a rectangular aperture is held very obliquely in a parallel beam of light. I showed that the bands cease to be of the same symmetrical type as the fringes formed when a rectangular aperture is held normally. They are not equidistant, the band-width increasing progressively from one side of the pattern to the other. Further, the number of bands visible on one side of the pattern is limited. The photographs of the effect published with this paper (Plate III.) exhibit these features.

Further observation of the diffraction-bands on the spectrometer, made by the methods I described in the paper referred to (*i. e.* of observing through the telescope the image of the slit of the instrument formed by light reflected very obliquely at the face of a prism, or by light passing through a rectangular aperture cut in a thin sheet of metal and held very obliquely on the table), elicited the following : it was found that the bands on one side of the pattern were fainter than those on the other, the difference becoming very large as grazing incidence was approached. This feature is visible on all the three photographs in the Plate. The effect is inexplicable on the ordinary (non-analytical) theory of diffraction.

* Communicated by the Author.

The illumination at any point in the pattern is, as deduced by the ordinary method, proportional to

$$\sin^2 \frac{\pi a}{\lambda} (\sin i - \sin \theta) \Big/ \frac{\pi^2 a^2}{\lambda^2} (\sin i - \sin \theta)^2,$$

a being the aperture, λ the wave-length, and i, θ being the angles of incidence and diffraction respectively. Plotting this expression against θ, it is seen to be the ordinary symmetrical curve $\sin^2 x/x^2$ with its abscissæ distorted but its ordinates the same: (1) the maxima of illumination in corresponding bands on either side of the central one ($i = \theta$) are equal: (2) the illuminations at corresponding points on either side of the diffraction-pattern

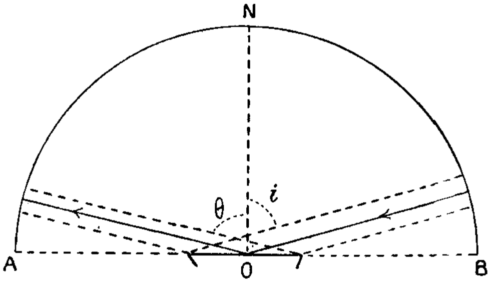
$$(\overline{\sin i - \sin \theta_1} = \overline{\sin \theta_2 - \sin i}),$$

are equal: (3) as the largest value of θ admissible is $\frac{\pi}{2}$, it follows that the curve of illumination at this point drops suddenly to zero; in other words, there is a discontinuity in the illumination-curve at this point. *All three results are contradicted by observation.* As has been stated above, the bands on the side nearer to the limiting plane $\theta = \frac{\pi}{2}$ were found to be fainter than those on the other side and the illumination at points in the diffraction-pattern decreased to zero as the limiting plane was approached.

The diffraction-fringes were observed through a nicol; there was no relative change in the illumination at different points in the pattern as the nicol was rotated, and at very oblique incidences no change at all.

An explanation of the effect was sought for on the following lines: each element of the reflecting surface may

Fig. 1.



be supposed to send out hemispherical secondary wavelets (fig. 1) and the illumination in the diffraction-pattern may be determined by integrating the effects of these secondary waves. If the amplitude of the disturbance in a secondary wave in the direction in which the diffraction-pattern is formed varies rapidly with the obliquity, such variation would have to be taken into account and we should have an explanation of the difference between the observed result and that predicted by the ordinary theory. In no diffraction-experiment so far known, with apertures of ordinary size, has the variation of the amplitude with the obliquity, in a secondary wave, manifested itself. In the well-known Fresnel-Arago Circular-disk experiment, the fact that as the disk is approached the illumination along the axis of the disk decreases, cannot be taken to be an obliquity effect, it being more or less entirely due to the large increase in the effect of minute irregularities in the rim of the disk or of minute inaccuracies in its setting, as the latter is approached. Some authorities have gone so far as to deny that an obliquity-effect is possible at all. The present paper will show that this last view is erroneous. In the case considered in this paper, if we assume that the effect of an element at O (fig. 1) of the reflecting surface is zero at points on the lines OA, OB and a maximum in the direction ON, the rate of variation with respect to θ of the amplitude in the secondary wave ANB would be a maximum in either of the directions OA, OB, and zero in the direction ON. If plane waves of light are incident on the reflecting surface at a very oblique angle, the diffraction-pattern (as observed in a telescope focussed for infinity) is formed in the neighbourhood of the direction OA, and the variation of the effect of an element with θ, the angle of diffraction, would have large effects. The intensity in the diffraction-pattern would be zero in the direction OA, and at a point at which $\theta > i$, would be less than at the corresponding point at which $\theta < i$.

The point will now be investigated mathematically. Take the case of an aperture of any shape and of dimensions large compared with λ, cut in a thin perfectly reflecting sheet of infinite extent, and let parallel waves of light be incident on the aperture at an angle i. The light passing through the aperture falls upon the object-glass (focal length f) of a telescope focussed for infinity. Let x, y be coordinates in the plane of the aperture and ξ, η in the focal plane of the telescope, y and η being parallel, and assume that the effect of an element dx, dy of the aperture is, in the focal plane, equal to

$$-\frac{A}{\lambda f}\,dx\,dy\,F(i,\theta)\sin\frac{2\pi}{\lambda}(Vt-c-P),$$

where A is the amplitude in the incident wave, c is a constant, θ the angle of diffraction, and P the path-difference of the effects at ξ, η, of the element $dx\,dy$ and of an element at the origin in the plane of the aperture. The rigorous expression for P is a little complicated, but if the angle of incidence is not so large that $(\sin i - \sin\theta)$ cannot be put equal to $\sin(i-\theta)\cos i$, P can be shown to be equal to

$$-\frac{x\xi\cos i + y\eta}{f}.$$

The amplitude of the effect at any point in the diffraction-pattern is therefore

$$-\iint\frac{\mathrm{A}}{\lambda f}\,dx\,dy\,\mathrm{F}(i,\theta)\sin\frac{2\pi}{\lambda}\left(\mathrm{V}t + \frac{x\xi\cos i + y\eta}{f} - c\right),$$

the double integral being taken over the whole of the aperture. Putting $x\cos i = p$ and $y = q$, p and q being therefore the projections of x and y on the wave-front, the above given expression reduces to

$$-\iint\frac{\mathrm{A}}{\lambda f}\,dp\,dq\,.\,\frac{\mathrm{F}(i,\theta)}{\cos i}\sin\frac{2\pi}{\lambda}\left(\mathrm{V}t + \frac{\mathrm{P}\xi + q\eta}{f} - c\right),$$

the integral being taken over the whole of the projection of the aperture on the wave-front. Now, the quantity of energy passing, per unit of time, through the obliquely held aperture, must, at any rate approximately, be equal to the quantity that would pass through an aperture identical with the projection of the first on the wave-front, cut in a screen held parallel to the waves. From this it follows that, *provided we assume* $\mathrm{F}(i, \theta)$ *does not vary sensibly* throughout the diffraction-pattern, it is equal to $\cos i$ *. This, on the assumptions made, agrees with the expression deduced by Kirchhoff in his 'rigorous' formulation of Huygens's principle

$$-\frac{\mathrm{A}}{2\mathrm{R}\lambda}(\cos i + \cos\theta)\sin\frac{2\pi}{\lambda}(\mathrm{V}t - \mathrm{R})\,dx\,dy,$$

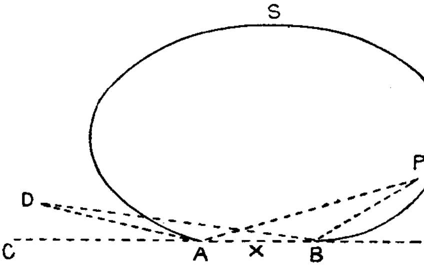
* From this and the integral given above, it appears that the diffraction-bands due to an aperture held obliquely are, at moderate incidences, identical with those due to its projection held normally: a proposition that might seem otherwise obvious, were it not for the fact that it is not true for very oblique incidences. As an instance, it can be shown experimentally that the diffraction-pattern observed when a circular aperture is held obliquely in front of a telescope directed at a point-source consists of a system of ellipses.

for in the direction of the wave-normal, $\cos i = \cos\theta$ and the expression reduces to

$$-\frac{A}{R\lambda}\cos i \sin\frac{2\pi}{\lambda}(Vt-R)dx\,dy. \quad . \quad . \quad . \quad (1)$$

The question now to be discussed is, whether we can always assume $F(i, \theta)$ to be appreciably the same in all the directions with which we are concerned, *i. e.* throughout the diffraction-pattern. Taking Kirchhoff's formula, the approximation clearly becomes inadmissible as i approaches $\frac{\pi}{2}$. In this case $\cos i$ and $\cos\theta$ are both small and a variation in θ affects the value of the expression very largely. The value of i at which the approximation ceases to represent matters fairly well depends upon the size of the aperture. θ will, in the diffraction-pattern, range from $\frac{\pi}{2}$ to i and less. The value of the factor $(\cos i+\cos\theta)$ will vary from $\cos i$ to $2\cos i$ and more. Kirchhoff's formulation of Huygens's principle thus leads us to expect that at oblique incidences we should observe some phenomena due to the variation of the obliquity, which are inappreciable in the case of normal incidence. But though Kirchhoff's formula is able to indicate this, it itself does not hold at such incidences. It will be remembered that his formula is a purely mathematical deduction holding rigorously only in the case in which the wave-surfaces are not limited by screens of any kind. When they are limited by screens and mirrors, Kirchhoff's formula does not entirely meet the physical circumstances of the case and at oblique incidences leads to results widely differing from the truth.

Fig. 2.



For example, let P be a point-source inside a surface S, such as that in the diagram, which is closed everywhere except over the opening AB. Take a point D inside the plane ABC at this point, the intensity ought obviously to be zero, D being inside the plane of the aperture. But Kirchhoff's formula leads to a different result. An element of the surface AB at X would have an effect proportional to

$$(\sin \underline{|P \times B} - \sin \underline{|D \times A}),$$

and if the angle PAB be not very large, the path-difference PA+AD−PB−BD would not be very large compared with λ and therefore there ought to be a finite effect at D. This absurd result discredits the applicability of Kirchhoff's formula to experiment, and further shows that the investigation of the correct obliquity factor has an actual tangible relation to experiment.

We now proceed to obtain a solution of the general differential equation of wave-motion in the form of a surface-integral which satisfies the requisite boundary conditions. Let S be the surface over which the integration is to be effected and r be the distance of a point in the space around from an element dS of the surface.

$$\frac{e^{-\iota kr}}{r}$$

is a solution of the symbolical equation

$$(\nabla^2 + k^2) = 0.$$

If dn be an element of the normal to the element dS, then

$$\frac{d}{dn}\left(\frac{e^{-\iota kr}}{r}\right)$$

is also a solution of the differential equation. If ϕ is an expression which is a function of the position of dS on the surface but does not contain r, then

$$\frac{1}{2\pi}\iint \frac{d}{dn}\left(\frac{e^{-\iota kr}}{r}\right)\phi \, dS \quad . \quad . \quad . \quad . \quad . \quad (a)$$

is a solution of the equation. This integral is the well-known expression for the potential of a sheet of double sources of sound, provided one of the directions of the normal n be regarded as positive and the other negative. The value of the integral at the surface itself is, on one side of it $+\phi$, on the other $-\phi$: for, regarding one of the directions of the normal as positive, the value of the integral at a point indefinitely near the positive side of the surface

$$= -\int \frac{d}{dr}\left(\frac{e^{-\iota kr}}{r}\right) \phi r\, dr \cos\theta$$

$$= -\phi \mathrm{N} \int_{\mathrm{N}}^{\infty} \frac{d}{dr}\left(\frac{e^{-\iota kr}}{r}\right) dr, \quad . \quad . \quad . \quad . \quad . \quad (b)$$

where N is the indefinitely small distance of the point from the nearest element of the surface and θ is the angle between n and r.

$$= \mathrm{Lt}_{\mathrm{N}=0}\, \phi \mathrm{N} \frac{e^{-\iota k\mathrm{N}}}{\mathrm{N}}$$

$$= \phi.$$

In the particular case in which S is an infinite plane and ϕ is constant over the whole of it, the expression (b), instead of being an approximation true in the limit (N=0), is perfectly rigorous for all values of N and expression (a) reduces to

$$\pm \phi \mathrm{N} \frac{e^{-\iota k\mathrm{N}}}{\mathrm{N}} = \pm \phi e^{-\iota k\mathrm{N}},$$

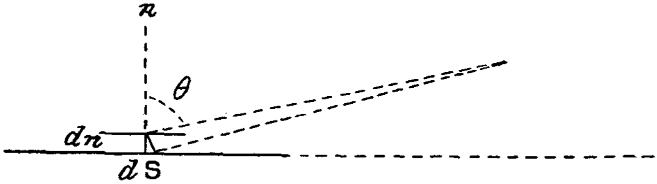
which is the velocity potential of two sets of aerial waves proceeding from the infinite plane, on opposite sides of it, to an infinite distance.

If the surface over which the integration is effected is part only of an infinite plane, the integral (a) can be written as

$$-\frac{1}{2\pi} \iint \frac{d}{dr}\left(\frac{e^{-\iota kr}}{r}\right) \phi\, d\mathrm{S} \cos\theta. \quad . \quad . \quad . \quad . \quad (c)$$

At points on that part of the infinite plane over which the integration is *not* effected, the integral (c) is zero, for (fig. 3) $\theta = \frac{\pi}{2}$ and $\cos\theta = 0$ for all such points. This part of the

Fig. 3.



infinite plane is therefore one of 'silence.' This is true whether ϕ is or is not constant over the whole of the surface of integration.

We shall now apply the solution (a) of the general differential equation to the following problems: it is understood that in each case the reflecting surface or transmitting aperture is of dimensions large compared with the wave-length.

Reflexion of plane aerial waves at an infinite rigid plane, whose position is given by $x=0$.

Let the plane waves be incident at an angle i on the positive of the plane, and the velocity-potential of the incident waves be the real part of

$$\mathrm{A}e^{\iota k(\mathrm{V}t+x\cos i-y\sin i)}.$$

Superpose upon this, the value of the integral

$$\frac{\mathrm{A}}{2\pi}\iint\frac{d}{dx}\left(\frac{e^{-\iota kr}}{r}\right)e^{\iota k(\mathrm{V}t-\mathrm{Y}\sin i)}d\mathrm{Y}\,d\mathrm{Z}\quad .\quad .\quad .\quad (d)$$

taken over the whole of the infinite plane, Y and Z being the y and z coordinates at any point on the plane.

The value of the integral at any point in the space on the positive side of the infinite plane is

$$\mathrm{A}e^{\iota k(\mathrm{V}t-x\cos i-y\sin i)},$$

and on the negative side

$$-\mathrm{A}e^{\iota k(\mathrm{V}t+x\cos i-y\sin i)}.$$

The resultant disturbance on the positive side is

$$\phi=\mathrm{A}\left[e^{\iota k(\mathrm{V}t+x\cos i-y\sin i)}+e^{\iota k(\mathrm{V}t-x\cos i-y\sin i)}\right]$$

$$\frac{d\phi}{dx}=\mathrm{A}\iota k\cos i\,e^{\iota k(\mathrm{V}t-y\sin i)}\left[e^{\iota kx\cos i}-e^{-\iota kx\cos i}\right],$$

which when $x=0$, is equal to zero.

On the negative side

$$\phi=0\quad\text{and}\quad\frac{d\phi}{dx}=0.$$

The necessary conditions are thus satisfied. The normal velocity at the plane is zero on both sides of it, and the region on the negative side of the plane is entirely screened from disturbance. The same is true even if the reflecting surface occupies only part of the plane $x=0$, for at points close to the plane, on either side of it, the result of the integration (d) is practically the same as if it were extended over infinity.

In the case last mentioned of a finite reflecting surface, the effect of the reflected waves at points not near the reflecting plane and on the positive side of it, is given by the integral (d) taken over the whole of the reflecting area. This integral may be written as

$$-\frac{A}{2\pi}\iint \frac{d}{dr}\left(\frac{e^{-\iota kr}}{r}\right) e^{\iota k(Vt - Y\cos i)} \cos\theta \, dY \, dZ, \quad . \quad (f)$$

where θ is the obliquity of the point of observation viewed from the element $dY\,dZ$. The point of interest is, that for all points on the continuation of the reflecting sheet, θ being equal to $\frac{\pi}{2}$, the value of the integral is rigorously zero and the plane is therefore one of silence. This becomes of importance experimentally when the angle of incidence is such that the diffraction-pattern is formed near this plane of silence. It is not difficult to understand why the elements of a reflecting surface should be equivalent to double sources and not to simple sources of sound: for, if the reflecting plane be replaced by an *indefinitely thin* sheet in the same position, every point of which instead of being kept fixed is obliged to follow the vibration in the incident waves, then it is obvious that these waves would be transmitted without disturbance to the far side of the plane. The effect of the reflecting plane must therefore be equivalent to that of the reversed motion of the thin sheet in a medium entirely at rest. This involves periodic *compressions* and rarefactions on one side of the plane, and simultaneous *rarefactions* and compressions on the other: *i. e.*, periodic *introductions* and abstractions of fluid on one side, and simultaneous *abstractions* and introductions on the other. This is the equivalent of a sheet of double sources.

Passage of Plane Aerial Waves through an Aperture in a Thin Plate.

This can be seen to be directly deducible from the preceding: the integral (d) would have to be taken over the reflecting plate (excluding the aperture), and the expression for the velocity potential of a system of plane aerial waves passing through an infinite medium superposed upon it. On the positive side of the reflecting sheet, the integral (d) gives the effect of the reflected waves, and since in the integration the area of the aperture is excluded, the effect of an element of the aperture in any direction on the positive side of the sheet is zero. On the negative side of the plate, the disturbance passing through the aperture appears as the difference of two quantities: if the integral (d) is taken over the whole of the reflecting sheet, including the aperture in it, this difference is zero. It follows therefore that the disturbance passing through the aperture is given by the integral (d) taken over the area of the aperture alone, with its sign reversed. It follows therefore, that considerations such as those that apply to the case of reflexion at oblique incidences apply to this also.

Light incident on a perfectly reflecting screen, the waves being polarized in a plane at right angles to the plane of incidence.

The magnetic vector ζ in the incident waves is parallel to the axis of z and to the reflecting screen. Since ζ satisfies the general differential equation and also, at the screen, the condition $\frac{d\zeta}{dx} = 0$, the expression for ζ in the secondary waves is exactly the same as that for ϕ in the preceding paragraphs. As for the other components of the magnetic vector in the secondary waves, they are zero at all points in the plane of incidence and we need not at present trouble about them.

Light incident on a perfectly reflecting screen, the waves being polarized in the plane of incidence.

The electric vector ζ in the incident waves is parallel to the axis of z and to the reflecting screen. The expression for the vector ζ in the secondary waves can still be deduced from the integral (d), if the sign of this is changed and the operand d/dx is replaced by d/dn, where dn is an element of the normal to the reflecting surface, both directions of this being regarded as positive. On the side of the screen on which the waves are incident and at points close to it,

$$\zeta = \mathrm{A}e^{\iota k(\mathrm{V}t+x\cos i-y\sin i)} - \mathrm{A}e^{\iota k(\mathrm{V}t-x\cos i-y\sin i)},$$

which is zero if $x = 0$.

On the other side, at points close to the reflecting sheet

$$\begin{aligned}\zeta &= \mathrm{A}e^{\iota k(\mathrm{V}t+x\cos i-y\sin i)} - \mathrm{A}e^{\iota k(\mathrm{V}t+x\cos i-y\sin i)} \\ &= 0.\end{aligned}$$

The other components of the electric vector in the secondary waves need not be considered here.

Apertures in Perfectly-Reflecting Plates.

The results for these cases can be deduced from the expressions for reflexion, in exactly the same way as was done for aerial waves. On the side on which the waves are incident, the effect of an element of the aperture is zero. On the other side, the z component of the electric or (as the case may be) magnetic vector is given by the integral (f) taken over the aperture and with its sign reversed.

From the integral (f) it can be seen that the obliquity-factor, for the z component of the light-vector in the secondary waves, is simply the cosine of the obliquity and is independent of the angle of incidence of the waves on the reflecting screen or aperture. Differentiating and realizing the integral (f), it can be seen that for moderate incidences it is equivalent to the expression (1), for at such incidences, the diffraction-pattern is formed in a direction in which $\cos\theta$ does not vary rapidly with θ and may therefore be put equal to the mean value $\cos i$. At oblique incidences this is no longer true. The integral of (f) in the case of a rectangular aperture (sides l, m) held obliquely in a parallel beam of light, in front of a telescope, gives for the illumination in the diffraction-pattern

$$A^2\frac{l^2m^2}{\lambda^2f^2}\cos^2\theta\,\frac{\sin^2\frac{\pi l}{\lambda}(\sin i-\sin\theta)}{\left[\frac{\pi l}{\lambda}(\sin i-\sin\theta)\right]^2}\,\frac{\sin^2\left[\frac{\pi m}{\lambda}\sin\psi\right]}{\left[\frac{\pi m}{\lambda}\sin\psi\right]^2}, \quad (g)$$

θ and ψ being the angles of diffraction, in other words, the angles made by the diffracted 'ray' with the two planes normal to the plane of the aperture. The expression deduced from the non-analytical theory is

$$A^2\frac{l^2m^2}{\lambda^2f^2}\cos^2 i\,\frac{\sin^2\frac{\pi l}{\lambda}(\sin i-\sin\theta)}{\left[\frac{\pi l}{\lambda}(\sin i-\sin\theta)\right]^2}\,\frac{\sin^2\left[\frac{\pi m}{\lambda}\sin\psi\right]}{\left[\frac{\pi m}{\lambda}\sin\psi\right]^2}. \quad (h)$$

These two expressions give, for moderate incidences, practically identical results. At all incidences, they give the same positions for the minima of illumination in the diffraction-pattern. But as regards the distribution of illumination in the pattern, and as a minor point, as regards the positions of the maxima of illumination, they give at oblique incidences very different results. The expression (h), as has already been mentioned, makes it out that the illuminations at corresponding points on either side of the central band should be equal, and that at the limiting plane $\theta=\frac{\pi}{2}$ the curve of illumination should drop discontinuously from a finite to zero value, both of which results are contradicted by experiment. The expression (g) shows that the illumination at points in the pattern on the side of the central band, nearer to the limiting plane $\theta = \frac{\pi}{2}$, is less than at the corresponding points on the farther side: and that since $\cos^2\theta$ is zero if $\theta = \frac{\pi}{2}$, the curve of illumination falls continuously to zero at the limiting plane. Both these results are verified by experiment. Photographs (1) and (2) (see Plate III.) of the diffraction-bands formed by reflexion at the face of a prism, and photograph (3) by transmission through an aperture, all exhibit these effects.

The investigation of the intensity at different points on a secondary wave, given above, is for the case of the incidence of light on a perfectly reflecting screen. It can be shown that by a suitable modification of the integral (a) it can be made to cover the case of the reflexion and refraction of light-waves at a dielectric medium, and that the obliquity-factor in these cases, as given by theory and as applicable to experiment, is $\cos\theta$. As a matter of fact the photographs (1) and (2) in the Plate are of the diffraction-bands formed by reflexion at a *glass* prism.

Similar obliquity-effects should be obtained with other forms of aperture, for example with a reflexion or transmission grating, *with wide rulings*, if it is held obliquely and if points in the field of view receive no light from the *grooves* of the grating, the only effective parts being plane portions of the grating, these being parallel to, or coincident with, its general surface. These and other considerations will form the subject of a future paper.

Summary and Conclusion.

Each element of a reflecting surface, may, when waves are incident upon it, according to Huygens, be supposed to send out into each of the two media meeting at the surface, hemispherical secondary wavelets. The amplitude of the disturbance at points on these secondary waves may be investigated mathematically, as in this paper, and shown to be a maximum at the pole of the hemisphere and zero at points on its equator. A similar result for the case of an aperture in a screen can be deduced therefrom. Observation of diffraction-phenomena at oblique incidences confirms this result. The law of variation of the amplitude of the principal component of the light-vector is the cosine of the obliquity. This may be subjected to experimental investigation, and it is hoped that if the necessary instruments are available, photometrical measurements to test this can be made.

The experiments and observations recorded in this note were made at the Physical Laboratory of the Indian Association for the Cultivation of Science, Calcutta, and formed the subject of a demonstration held at a Special Meeting of that body on the 18th of January last.

P.S. dated the 26th of Nov.—Photometrical measurements in verification of the above have been carried out. These will be dealt with in a future communication.

XIV. *The Effect of Pressure on the Natural Ionization in a Closed Vessel, and on the Ionization produced by the γ Rays.*

By W. Wilson, *M.Sc., Graduate and Hatfield Scholar of the University of Manchester* *.

THE natural ionization in gases has been very largely studied since the experiments of Geitel † and C. T. R. Wilson ‡ in 1900. Experiments have been generally made with the object of determining whether ordinary matter is radioactive or not. Wilson observed the effect of diminishing the pressure of the gas inside the electroscope, and found that for pressures of 43 to 743 mm. of mercury, the ionization was proportional to the pressure. Patterson § also studied the effect of varying the pressure and found that with large vessels (20 cms. long, 30 cms. diameter) the ionization increased with the pressure at first, but that at one atmosphere it had become sensibly constant. Strutt ‖ observed that the ionization varied for vessels of different materials; and McLennan ¶ and Burton found that it was proportional to the pressure up to seven atmospheres.

Rutherford and Cooke ** observed that the rate of leak was diminished on surrounding the electroscope with lead, thereby proving the existence of a penetrating radiation. Wood †† showed that the decrease in ionization depends both on the material of the screen and the material of the ionization vessel. He concludes that the natural ionization is due to an external radiation and its attendant secondary radiation, together with intrinsic rays from the sides of the

* Communicated by Prof. E. Rutherford, F.R.S.

† Geitel, *Phys. Zeit.* ii. p. 116 (1900).

‡ C. T. R. Wilson, Proc. Camb. Phil. Soc. xi. p. 32 (1900); Proc. Roy. Soc. lxviii. p. 151 (1901).

§ Patterson, Phil. Mag. Aug. 1903.

‖ Strutt, Phil. Mag. June 1903.

¶ McLennan & Burton, Phys. Review, No. 4, 1903.

** Rutherford & Cooke, Am. Phys Soc. Dec. 1902.

†† Wood, Phil. Mag. April 1905.

FIG. 1.

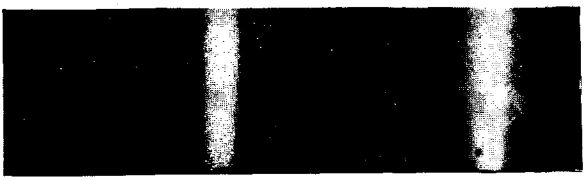


FIG. 2.

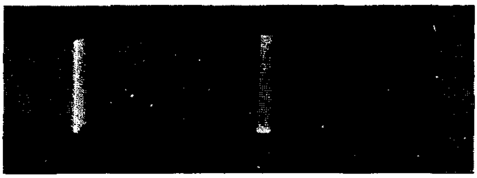


FIG. 3.