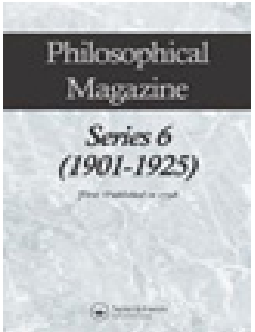

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LVI. The scattering of light in the refractive media of the eye

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for $h=0$ and $h=8$, using the equation

$$\frac{ds}{s}=(\mathrm{D}-\tan^{-1}\mathrm{D})\frac{\sec^2\mathrm{D}}{\sqrt{\tan^2\mathrm{D}-2\dfrac{h}{\mathrm{R}'}}}.$$

The error is always positive and limits the use of the formula (49) to small dips.

Values of ϕ_0 and D are interchangeable by means of Table V.

8. *Effect of a Change of Density.*

Suppose the values of the observed density given in Table I. are increased by 2 per cent. Then since the same increase occurs in n_0, p, q, k, $\sqrt{a}$, $\sqrt{b}$, $\sqrt{c}$, the values of $\triangle\phi$ and $\triangle^2\phi$ are increased by 2 per cent. Actual calculation shows that the percentage changes in γ_i and l_i are small, except for heights less than 2 km., when they may amount to an increase of +1 per cent. This is so for $\phi_0=88°$, while for $\phi_0=90°$ the changes do not exceed ·5 per cent. Hence the values of m_i will not differ from the values in Table IV. by more than 2 per cent. The formulæ of § 6 show that the changes in ϵ_i are inappreciable. The values of Q given by (48) will increase in very much the same way as the values of m, i. e. by not more than 2 per cent. This increase will therefore be about +10 in the value of Q. But the values of dQ obtained with the aid of (51), and used in the calculation of Table VII., vary from −88 to +100. Hence the refraction errors in Table VII. overshadow changes which are due to an increase of 2 per cent. in the density. Note that for $h_i<4$ km. the density increase makes the error in Chauvenet's formula less.

LVI. *The Scattering of Light in the Refractive Media of the Eye.* *By* C. V. Raman, *M.A., Palit Professor of Physics in the Calcutta University*.*

1. *Introduction.*

In his treatise on Physiological Optics†, Helmholtz has discussed the explanation of the interesting phenomena observed when a very small and intensely luminous source of light is viewed directly by the eye against a dark background.

* Communicated by the Author.

† Page 180, 1896 (German) Edition.

An enormous number of luminous streamers appear to emerge from the source, and stretch out from it in more or less exactly radial directions. Helmholtz was of opinion that these streamers were due to the diffraction of light at the irregular margin of the pupil of the eye; and this view is supported in his treatise by a description of the phenomena observed when the source of light is seen through a small hole in a metal plate placed in front of the eye so as partially or wholly to screen the margin of the pupil. Some doubt as to the adequacy of the explanation advanced by Helmholtz having been felt by me, a careful study of the effects was undertaken, the results of which are described in the present paper. The phenomena being of a subjective character, the assistance of a number of independent observers with normal vision was obtained in order to confirm my personal observations. This appeared all the more necessary, as the conclusions arrived at as to the origin of the phenomena differ from those of Helmholtz.

2. *Description of the Phenomena.*

The character of the luminous phenomena seen is widely different in the two cases in which the source emits *white* and *monochromatic* light respectively. For observing the phenomena with white light, the most suitable arrangement is to condense the light of an electric arc upon a pin-hole in a large dark screen, and to view the issuing light with the eye placed at a distance of about three or four yards from the screen. The luminous pin-hole appears surrounded in the first instance by a circular patch full of luminous streaks starting out more or less radially from it, and occasionally crossing each other. These streamers are generally white, but appear here and there tipped with streaks of colour. The circular patch is surrounded by a relatively dark ring, outside which again the streamers reappear passing radially through a luminous coloured halo * surrounding the dark ring. The halo is, in fact, made up of short sections of the streamers which, here, are strongly coloured. Outside the halo, the streamers emerge again, but are much fainter, and they form a broad and somewhat ill-defined ring of luminosity extending to a considerable angular width from the source. The inner margin of this luminous ring is greenish-blue, and the outermost visible periphery is of an orange-red colour, but some fainter fluctuations of luminosity and colour may be observed within it.

For observations with monochromatic light, a Westinghouse

* Of angular radius a little less than 2 degrees of arc.

3000 c.p. silica mercury-vapour lamp with glass dome furnishes a suitable source. The lamp is suspended immediately behind a small aperture in a dark screen and is viewed from a distance of two or three yards. A green-ray filter may be put in front of the aperture, but is not essential. An alternative arrangement for obtaining a small and powerful source of homogeneous light is to load the carbon rods of an electric arc with plenty of common salt, and to condense the light from the luminous yellow mantle of the arc upon the pin-hole in the screen. With either arrangement, the appearance of radial streamers issuing from the source as seen in white light is *not* obtained. We see, instead, a circular area round the source filled with *granular* patches of light, and outside this, a relatively dark ring, followed by a well-defined circular halo, and some faint outer rings of luminosity.

A remarkable feature which is worthy of mention is the peculiar circulatory or irregular movement which is best seen in the radial streamers surrounding a white source of light, and less clearly in the granular patches surrounding a monochromatic source of light. These movements disappear gradually when the eye is held with a fixed gaze towards the source, but start again immediately whenever any movement of the eyeball or of the eyelids occurs.

3. *Discussion of Observations.*

The effects described above obviously present a striking resemblance to the phenomena observed when light is diffracted by a large number of irregularly placed apertures or particles of uniform size, *e. g.* lycopodium dust strewn on a glass plate. Recently, De Haas * has published an elaborate study of such diffraction phenomena, and has shown that the formation of the radial streamers in the coronas surrounding a source of white light, and their replacement by a granular field in monochromatic light, may be explained by considering the interference of light diffracted by individual particles which are assumed to be irregularly distributed over the aperture. The resemblance is not merely qualitative, as some careful visual estimates made by me seem to show that the relative intensity of the streamers in the area immediately surrounding the source and in the first circular halo is about the same as that observed when a source is viewed through a glass plate dusted with lycopodium. There thus seems little

* Proc. Roy. Soc. Amsterdam, 1918, p. 1278. It may be remarked here that the phenomenon discussed in the present paper is different from the coloured haloes seen in certain pathological states of the eye and described by Tyndall in his lectures on Light, and by other writers.

doubt that the phenomena described above have to be referred to the diffraction of light by a large number of particles of more or less uniform size included in the structure of the refractive media of the eye. The peculiar movements mentioned above would then naturally be ascribed to the movements of these particles. These may be imitated by observing a source of light through a plate of glass on which a little dilute milk has been flowed. The movements of the diffracted streamers of light can then be easily seen.

Observations show that the angular diameters of the circular patch containing the streamers and of the circular haloes surrounding it are entirely independent of the aperture of the pupil of the eye. This is readily proved by altering the intensity of the source of light under observation, with the result that the aperture of the pupil automatically adjusts itself. An ordinary candle-flame at three metres distance, and the light of an electric arc at the same distance or even nearer the eye, give identical measurements for the angular widths, though the aperture of the pupil must have been greatly different in the two cases. This is exactly what we might expect if the effects are due to particles contained in the structure of the eye, but it is very difficult to reconcile with the view of Helmholtz that the phenomena are due to diffraction at the margin of the pupil. The observed effects cannot be explained if we merely postulate any arbitrary irregularities in the circular shape of the margin of the pupil. It would be necessary also to assume a regular corrugation or periodicity in the margin of the pupil*, and even such an assumption, apart from its being purely hypothetical, fails to explain the observed effects. For, with any change in the aperture of the pupil, the distance between successive corrugations should also alter and influence the observed phenomena. This is inconsistent with the observed independence of the aperture and the observed effects. We are thus led to reject the view that the diffraction at the margin of the pupil determines the phenomena seen.

It is useful in this connexion to note that the intensity of

* A useful analogue is furnished by the milling on the circular edge of a coin. In a paper on diffraction which is in course of publication, S. K. Mitra has shown that a circular disk with corrugated edges produces a coloured halo surrounding the usual Fresnel-Arago central bright spot, and the angular radius of this halo is equal to $n\lambda/2\pi a$, where a is the radius of the disk and n is the number of corrugations. A similar phenomenon is shown in convergent light by a circular aperture with a corrugated edge, but in a less striking manner. The number of corrugations remaining the same, the angular radius of the halo would vary inversely as the radius of the aperture.

the light diffracted by the pupil (supposed perfectly circular) in a direction making 30′ of arc with the source would be only $\frac{1}{3,000,000}$ of that seen in the direction of the source. (This is calculated from the formula $I \propto [J_1(z)/z]^2$, the radius of the pupil being taken to be 2 mm. and $\lambda = 5600$ A.U.) Actually, the streamers surrounding the source can be seen in directions making an angle of 200′ and even more with its direction, and it seems safe to say that their intensity half a degree away from the source is a much greater fraction of its apparent intensity than $\frac{1}{3,000,000}$.

A further test of the view that the effects are principally due to the structure of the eye and not to diffraction at the margin of the pupil, is furnished by experiments with very thin metal screens containing apertures placed in front of the pupil of the eye. Using a circular hole with smooth edges smaller than the pupil and placed in front of it, the intensity of the streamers surrounding the source of light is reduced, but does not vanish. When the screen is turned about an axis normal to its plane, the hole being continually kept in front of the pupil, the streamers of light seen in the field remain visible and fixed in position, showing that they are due to the structures of the eye through which the light passes, and not to the margin of the pupil, or the edges of the hole. Another and probably more convincing demonstration is obtained by using a *square* aperture smaller than the pupil of the eye and placed in front of it. (This may easily be contrived with the aid of four Gillette blades forming the four sides of a very small aperture.) In this case, the effect due to diffraction at the boundaries of the aperture is very clear and marked, but can be shown (on rotating the aperture in its own plane) to be entirely distinct and separate from the phenomena now under discussion.

The angular diameters and intensities of the haloes are such as to suggest that we are dealing not with *one* but with *two* sets of structures contained in the refractive media of the eye, averaging in size about 13 μ and 7 μ respectively. The structures of the latter (smaller) size are indicated by the outermost halo, which appears to be composite in character and due to the superposed effect of the two sets of particles. These structures in the living eye are presumably to be localised in the cornea and in the vitreous humour, as histological evidence of the existence of cellular structures in these bodies is available. Upon this question, however, the author does not venture to express any opinion.

Calcutta,
April 22nd, 1919.