# DEFLECTION DISK AS A VISION-INFLUENCING PHENOMENON

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In 1665 when the Italian physicist GRIMALDI recorded his observation of the light deflection disk, he could have hardly been aware of the importance his discovery would one day attain in the image production theory underlying the designs of our optical instruments. The phenomenon he described was one of the first things to furnish a solid ground of interpretation for the undulatory nature of radiating energy to be explained and understood. The subsequent dispute, long-winded and impassioned, between the adherents of NEWTON's corpuscular theory and HUYGHEN's wave-theory settled, as we know, in favour of the latter. Numerous have been the views proposed since then and our present day approach and interpretation of optical phenomena rest on a combination of the theories arguing for the corpuscular and the undulatory nature of light propagation. The image produced by an optical instrument to some extent varies according to structure, size and light distribution of the deflection disk. Any ray-transmitting device, let it be a telescope, a microscope or a simple magnifier, can be regarded as an optical instrument only inasmuch as it is used in connection with the eye since the two together constitute an integral optical system. Consequently, in the construction of every optical instrument due regard must be paid to the function and the visual ability of the eye. The psychological responses to visual impressions, varying individually and due to observation either with the naked eye or through an optical instrument, are hereby left provisonally out of consideration.

The light deflection disk observed by GRIMALDI belongs to the class of reflexion phenomena described by FRAUNHOFER. The convergent rays of a light beam proceeding towards a point $C$ give rise to an undulatory movement spreading radially in every direction, with $C$ as its point of origin. The light distribution around that point depends on the circumscription of the spherical waves and on the slit shape. Assuming a narrow slit with a beam of parallel rays passing through it, and a screen at some distance to intercept the light; what appears on the screen is a system of concentrical coloured rings around a bright nucleus situated in the slit axis, with the rings growing rapidly darker as their distance from the centre increases. Let $D$ stand for the slit diameter,

$\lambda$ for the wavelength, $t$ for the screen distance and $x$ for the ring radius; the luminous intensity is then expressed thus:

$$H = \frac{\pi \cdot x \cdot D}{\lambda \cdot t}$$

and its variations are represented by the known function diagram curve. The size of the deflection disk, expressed in terms of degrees, is determined by the angle between two imaginary straights originating in the centre of the slit and forming a triangle with the radius of the innermost dark ring as its base. Hence:

$$r = \frac{1{,}22 \cdot \lambda}{D}$$

or, if $D$ is expressed in millimetres:

$$r = \frac{138''}{D} \, .$$

The demarcations between the dark and the light portions of the disk produced by the luminous rays, whether achromatic or monochromatic, are hazy rather than distinct; the radius of the first dark ring is, therefore, determined as shown in Fig. 1.

To observe the deflection disk in a supermagnified state through a telescope presupposes the atmosphere to be, as it hardly ever is, entirely clam and clear. The slightest turbulence is apt to distort the disk past recognition. Much more simply and conveniently than with a telescope can the disk be demonstrated with a lycopodium filter placed before the objective, the latter having been focused to produce a clearcut image of the well-illuminated slit on either the projection screen, or the ground-glass screen of the camera. However, the photographic reproduction of the disk obtained in that way (see Fig. 1) greatly differs from the direct visual impression called forth by a distant luminous source of small extension. The unaided eye, when fixed on a single small spot of radiance in an otherwise entirely dark surrounding, gets the impression as if a multitude of short broken rays would spread forth in every direction under constant changes of position. This phenomenon, called *ray crown*, only presents itself to the eye and is irreproducible by the telescope and the photographic camera. The pattern indicated by way of instruction in Fig. 2 has been traced by subsequent retouch. The rings seen in the photograph are fairly well distinguishable as far in extent as the third; but the fourth ring already defies representation under normal times of exposure and any attempt to make it visible would involve an overexposure past reproducibility of the bright nucleus. Copies and enlargements are rather troublesome to take of the negatives and the brilliant nucleus usually appears confluent with its environments.

The described deflection disk probably plays a certain part in the image production of every corrected optical system. It is assumed that the lens of the eye projects a similar kind of deflection disk on the retina. The human eye, however, is far from what may be described as a corrected optical system, to say nothing of the various vision-modifying influences to which the luminous rays are exposed while they pass across the cornea, the vitreous humour, the pupil, the eye lens and the vitreous body. Changes in shape, diameter and light distribution of the deflection disk are due to eye accommodation and to dilatation or contraction of the pupil and have been illustrated graphically

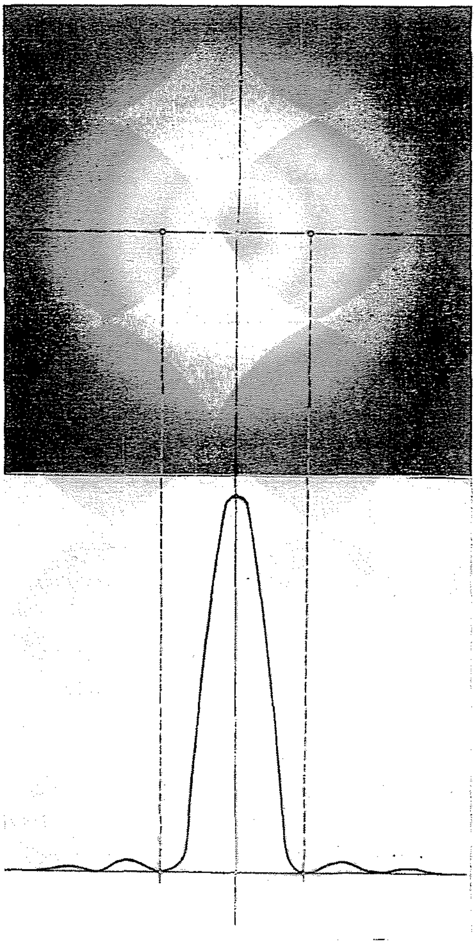

*Fig. 1.* Deflection disk with function diagram curve representing changes in light distribution

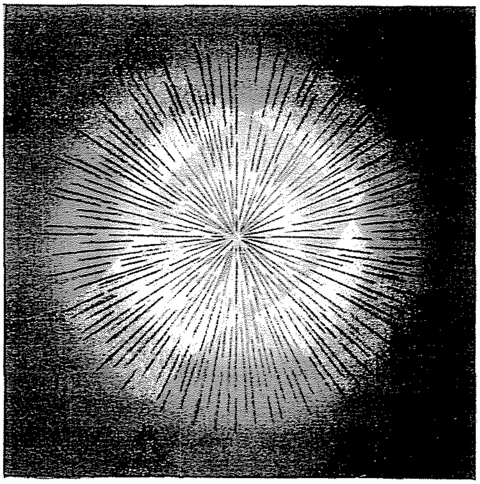

*Fig. 2.* Same as in Fig. 1 but calling up the impression presenting itself to the naked eye. The radially spread pattern is due to the structure of the eye lens. The ray crown, irreproducible by the camera, has been traced by subsequent retouch

by Ove—Müller—Ree in empirically designed figures. Astigmatism, regular and irregular, is furthermore largely responsible for changes in shape of the deflection disk appearing on the retina.

The structure of the human eye lens itself accounts to a certain measure for the difference in design between the disk perceived visually and the one shown in the photograph. Searching for the cause of that difference, Helmholtz discovered that the eye lens is divided into a number of sectors, amounting in most individuals to six, each of which presents a greated pattern with its system of parallel lines arranged so as to cut the mid-radius at right angles. The minute interstices of the grating modify the shape of the deflection disk and this change explains why a luminous source, as far as it can at all be considered punctual, never appears to the eye as punctual. The described structure of the eye lens exerts a certain influence on the process of image formation and through it on vision itself. It is well to emphasize that *vision* in this context means the *act of seeing* which presupposes the possession of a stock of experiences and can by no means be regarded as a congenital ability, in clear distinction to the *act of looking* as a primary faculty inherent even in the newborn child.

The point we propose for discussion is the analysis of certain interesting phenomena which result from the structure of the eye lens and deserve some attention, on account of the importance they have attained in the realm of fine arts, in general, and of painting in particular.

We have already seen that the deflection disk is easy to demonstrate by means of a lycopodium filter, which consists of a fine dispersible powder of vegetable origin made up of extremely small spherical lycopodium seeds, some 30 $\mu$m in diameter. This powder is deposited in an evenly distributed thin layer on one side of a smooth glass plate, previously coated with a very fine film of vaseline which keeps the lycopodium securely fixed to it. The spread-out substance is covered with a second glass plate cautiously set on it lest an occasional slip should crease the layer or make it uneven, and the two plates are held together round their edges by means of adhesive tape. The optical filter obtained in that way, unelaborate as it is, will do as an implement for the purpose of experiment and demonstration.

The deflection disk arising on the retina owes the changes of its shape to the reticular construction of the eye lens. Small luminous sources, *e. g.* stars or distant terrestrial lights appear to the naked eye in the dark not as tiny points or small-diameter disks but as asterisks with radially extending arms varying in number from one beholder to the other. It was stated that the eye lens is divided into six sectors, each including a system of parallel lines arranged perpendicularly to the mid-radius. The optical grating formed by these sectors makes the image of a punctual source of light extend in six main directions. The arms of the asterisks appear to perform movements agreeing, in direction

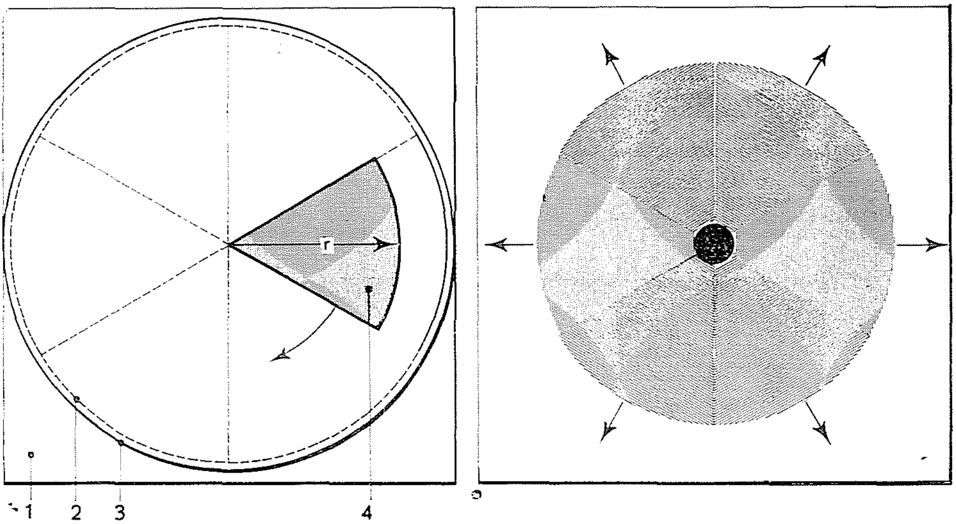

*Fig. 3.* Optical filter suitable for the photographic representation of the ray crown

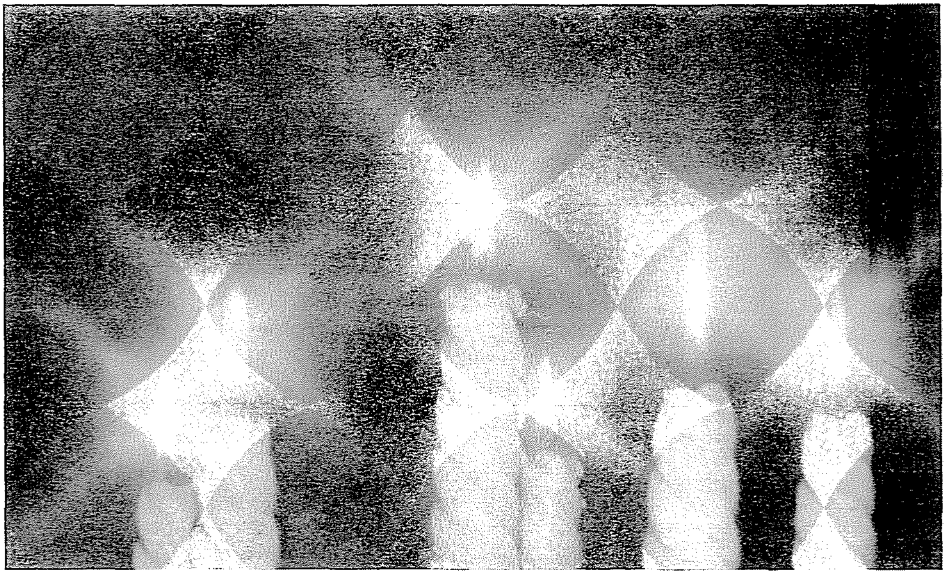

*Fig. 4.* Candle-flame exposure taken through a bright-illumination slit with a four-sector optical filter as shown in Fig. 3

and angular velocity, with the turns of the beholder's head. The phenomenon which immediately presents itself to the visual sense is amenable to photographic reproduction if the asterisk is brought to sight, as the deflection disk was before, by some sort of optical filter *e. g.* by one made as follows (Fig. 3).

Vaseline is spread in a thin layer, as was described before, over a glass plate (1) corresponding in size to the diameter of the camera objective. A circular sheet of white paper divided into six sectors (2) is placed under the glass plate and another (3), with the area of one cut out sector (4), is carefully set over it. The upper sheet is gradually turned round and in each position of the blank sector one finger is gently over the vaseline passed at right angles to the mid-radius. The region around the centre where the parallel lines appear somewhat mis-shapen, is covered with a small piece of circular black cardboard. The grating obtained in that way, again not an absolutely perfect one, offers the advantage of being reproducible and permits the layer thickness to be altered. A filter of this type, only with four sectors instead of six, has been used in photographing the candle flames in Fig. 4. Occasional asymmetry or differences in length and radiance between the arms of the asterisks may be due to variations in thickness and distribution of the vaseline layer or to position faults of the sectors or to inequalities in the interstices of the manually prepared grating. The radially disposed streaks of light appearing on the ground-glass screen of the camera betray the position and follow the turnings of the filter on the objective, and can be adjusted according to the photographer's individual taste. Such a turn has the consequence that one arm of the asterisk dims while the other grows brighter. The observer after a short practice will be able to determine the filter position at which the image is going to appear symmetrical. The distance between the luminous source and the objective matters a great deal. Light distribution is at its best if the luminous source lies in the optical axis. It is, therefore, recommended to use a mirror-reflex camera which permits the position of the filter to be checked while the exposure is taken.

Fig. 1 and Fig. 2 represent slits brightly illuminated. Much the same patterns are obtainable in various degrees of intensity from other current types of luminous source, say from a burning candle. The closer the camera is brought to the object, the more lengthened in direction of the flame axis does the disk or the asterisk appear. Constriction of the diaphragm aperture reduces the disk diameter or the lengths of the asterisk arms. As to selection of the exposure period, there is so much room in photography for personal taste and imagination that no hard and fast rules can be offered. Nature herself is the safest guide to go by and the picture will be the better, the more faithfully it reproduces the phenomenon as seen by the naked eye. By way of guidance it should be mentioned that the candle photos attached to the present paper (*viz.* all except Nos. 1 and 2) have been taken with an antireflexion-coated

Tessar objective, relative aperture 1 : 4.5, focal length 21 cm, on Agfa Isopan F glassplate negative, size 9 by 12 cm, sensitivity 17/10 DIN, exposure period 1/5 sec. Periods shorter or longer than that result either in under-exposure with the asterisk arms curtailed and the candle-flame contrasts accentuated, or in over-exposure respectively, with the arms lengthened and the flame appearing on soft-paper magnifications as if merged into the surrounding ray crown.

Fig. 5 shows a lycopodium-filter exposure of the candle-flame group, not in agreement with the natural eye-sight impression. Closer to it, in point of fidelity, is Fig. 6, made with a twelve-sector filter. The fact, strange as it may appear at first, can hardly be called into question at the sight of this picture that man's spontaneous carving for symmetry is at variance with nature's aversion to it.

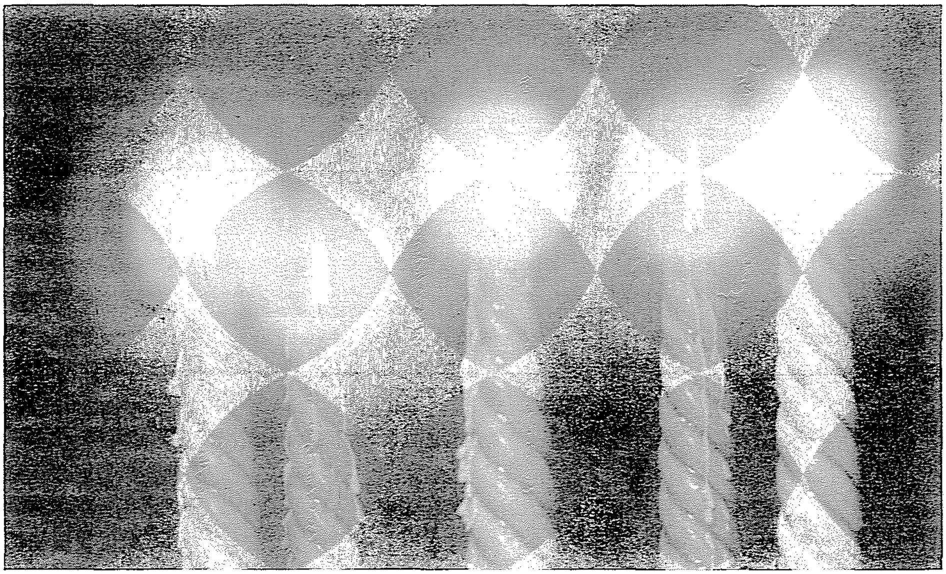

*Fig. 5.* Lycopodium-filter exposure of candle-flame group

Familiarity with the here-discussed phenomenon dates back to a considerable time. Painters made use of it with more or less success; designers in their representations of the candle flame hinted at it by tracing the diagonals of an upright square. The object represented as a mere physical phenomenon in Fig. 6 makes an artistic element of picture composition and comes to life the moment it is placed in a surrounding apt to evoke illusion. The candle-light scene in picture 7 conveys the evening atmosphere of an interior. Its aesthetical judgment is a question we are here not concerned with. But it merits attention

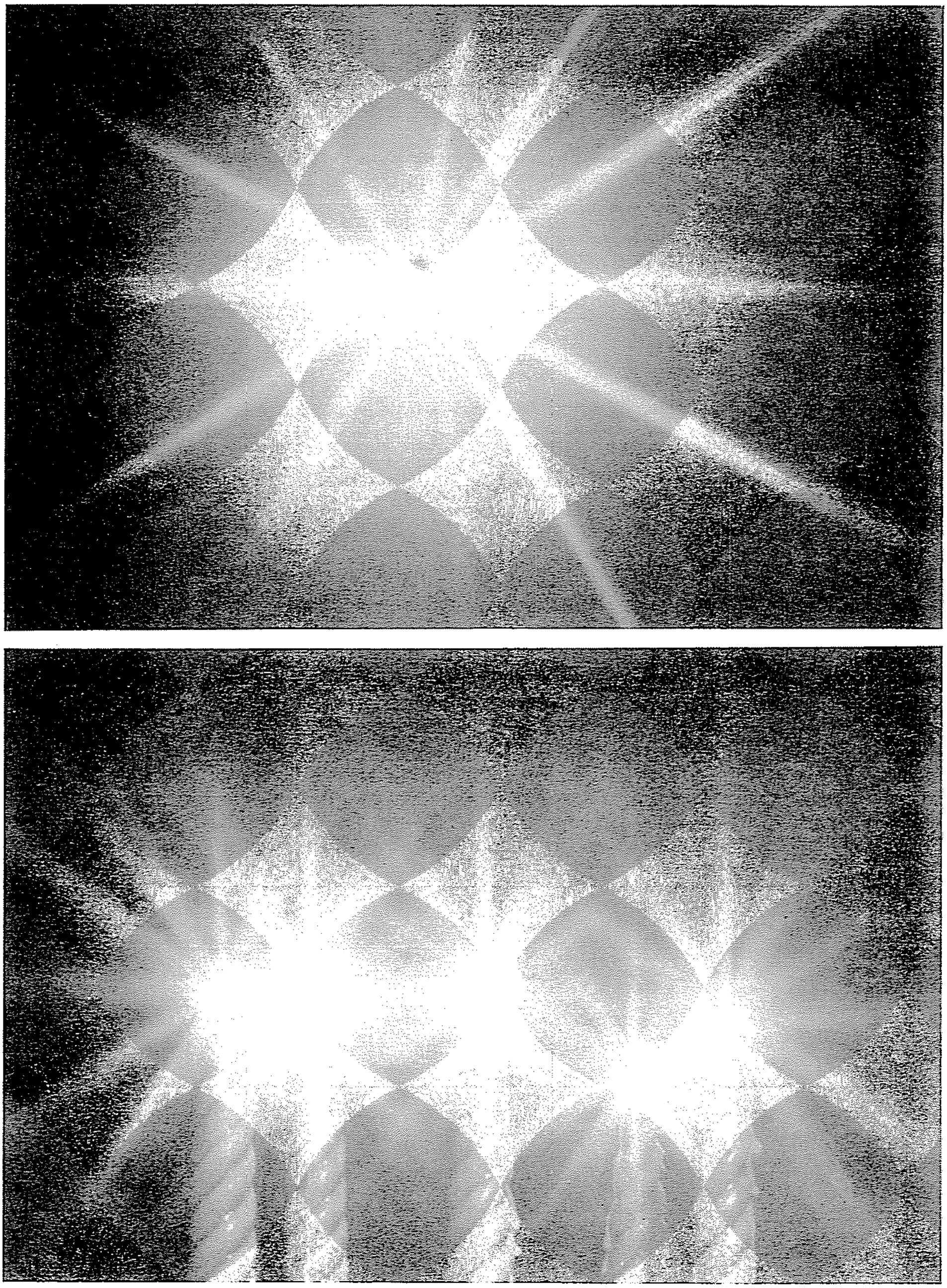

*Fig. 6.* Candle flame photographed with a 12-sector filter. The picture gives a more natural impression than Fig. 5

that the portion of space embraced and sharply reproduced by the objective is wider than what the human eye would be able to take in at a single glance. Not, unless the flames were situated in the line of sight or close to it, would direct eye vision obtain a similar impression of the scene, even then with the image definition diminishing towards the edges of the field of vision.

So much about the general features of the ray crown as a long known visual phenomenon; greater importance attaches to the role it plays in the construction of optical instruments. The quality of a telescope, a microscope, etc. depends, apart from its optico-geometrical dimensions, on the resolving power and the contrast ratio. In modern instruments these two are closely correlated with the visual function of the eye which, in turn, is strongly influenced by psychological motives.

Before the rays of a luminous source reach the lens as the chief image-producing part of the eye, they pass through the cornea, the vitreous humour, the vitreous body, etc. and probably suffer some slight change from each of them. The optical function of the eye lens is a question not fully elucidated yet. The more we succeed in throwing light on that function, the more probably will we be able to achieve that the images produced by our optical instruments should resemble in quality and light distribution those presenting themselves on the retina. The ray crown is one of the proofs to remind us thereof. For a long time FRAUNHOFER's interpretation of the deflection disk was accepted as sufficient for explaining physiologically the structure of the image produced by the eye lens. Recent optical researches and their bearings on modern instrument construction urgently called for a revision of the entire problem to which the right answer is still outstanding. Intervening psychological motives as well as doubt about the ways how the organic parts within the eye ball perform their functions add to the difficulty of the question.

Neither the optico-geometrical conditions of the eye nor the undulatory nature of light propagation suffice for offering an adequate explanation of the visual process. Not until the question how a picture arises on the retina has been fully settled, will it be possible to assimilate the design of an optical instrument to the structure of the eye.

Obviously, the mechanism operative in producing the deflection disk in a corrected optical system does not apply without further qualification to the visual function of the eye. Leaving aside the still not quite unsolved function of the eye lens, it seems safe to state that eye accommodation, frequent changes in size of the pupil aperture and irregular astigmatism, in particular, are responsible for the fact that the deflection disk on the retina is largely subject to variations in diameter, shape and light distribution.

The measure of resolving power depends on diameter, shape and light distribution of the deflection disk. This holds true both for the optical instrument and for the eye and, although each of them has a separate optical system,

*Fig. 7.* Candle-light scene suggestive of evening atmosphere, with apparent ray-crown as presenting itself to the naked eye

they are to be examined and discussed together. In designing an optical instrument, the engineer should not ignore the peculiar character of the eye function which exerts its influence on the ray path, no matter how well corrected the optical system was from where the rays issued. The binocular, among other devices, testifies to the presence of these psychological vision-modifying influences. The lower the distortion factor of an instrument the better is the image it produces: the adoption of this axiom in the design of earlier binoculars resulted in selecting their optico-geometrical dimensions so as to keep the tangential distortion ratio as low as 1 or thereabouts. But experience showed that the high-fidelity image obtained under such conditions is accompanied by certain disagreeable visual effects which are traceable back to psychological motives and trouble the observer especially when his look-out is from a vehicle under progress. Consequently, improvement of the visual performance of the binocular has been achieved paradoxically enough by an increase of the distortion factor.

The effects of these psychological motives probably extend over the resolving capacity of the eye. The criterion of RAYLEIGH's limit of anatomical resolving power needs a revision, since POLYÁK's histological examinations of the eye revealed that each deflection disk affects more than 30 receptors at the same time. The intricate structure of the retina is still far from being explored. Little do we know about the behaviour and correlation of the single receptor groups, non more about the changes occurring in them under the influence of light. Not until we have come to know the visual mechanism of the eye in every detail, can we increase the resolving power of our instruments and improve upon their aiming, reading and focussing accuracies.

## Summary

The deflection disk is discussed as a vision-influencing phenomenon attributable to the undulatory nature of light propagation. Changes in its appearance due to the physiological structure of the eye lens are demonstrated by a few experimental presentations of it. The author attaches importance to these changes which he thinks may furnish a basis for improvements in the designing of optical instruments.

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