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ON ENTOPTIC VISION;

OR,

THE SELF-EXAMINATION OF OBJECTS WITHIN THE EYE.

BY

PROFESSOR W. F. BARRETT, F.R.S.

[PART I.]

[Authors alone are responsible for all opinions expressed in their Communications.]

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VII.

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[Part I.]

[Read June 20; Received for Publication June 23, 1905; Published March 9, 1906.][1]

§ 1.

Most people have observed, and many have been needlessly alarmed at, the semi-transparent objects like notes of interrogation, or pearly strings, which occasionally are to be seen moving across the retina of the eye. These are the so-called *muscæ volitantes*, and are due to shadows thrown on the retina by the minute *débris* of cells and of smaller vessels which are floating in the vitreous humour of the eye, and perceived when they pass close to the retina. They come and go, often with the state of health, and, as a rule, need cause no anxiety.[2] If instead of a general illumination of the eye a divergent pencil of rays from a point of light near the eye be allowed to enter, the shadows become sharper, owing to the absence of penumbra, and under such conditions these and other small opacities, in the line of vision, at any part of the eyeball, can be seen from their shadows on the retina. A point of light can be readily obtained from any luminous source, by using a

[1] This paper has been unavoidably delayed in publication.

[2] These shadows are called *muscæ volitantes* ('flies flitting') because the shadow flits away as the gaze is directed to it. From remote times these *muscæ* have been the subject of frequent observation and discussion. The learned Jesuit Deschales wrote an essay on the subject in the sixteenth century. When the eyeball is kept motionless, the *muscæ* appear to be slowly descending; owing to the fact that the shadow when projected from the retina is inverted, the *muscæ* are therefore *ascending*, and hence are somewhat lighter than the vitreous humour in which they are floating.

short-focus convex lens, or by reflection from either surface of a silver spoon, or, still better, by a pin-hole in a piece of card or metal held close to the eye. With this very simple arrangement anyone can make a self-examination of any small opacities that may exist within the field of vision in either of his eyes.

Looking at a lamp or a bright surface through a pinhole in a card held close to the eye, the circle of light that is seen is not, however, the enlarged image of the pin-hole, but is the shadow cast by the circular aperture of the iris; it is in fact a magnified image of the pupil of the eye, and can be seen to vary in size with the degree of illumination, as the pupil contracts or expands, when a light is brought near to or removed from the eye. It is a sharp shadow, as the source of light from the pin-hole is practically a point, and hence any irregularity in the edge of the iris is clearly seen, as is any obscurity, however small, in the path of the rays.

A pencil of rays emanating from some luminous *point* is called *homocentric* light, as the rays have the same centre of divergence; the smaller the pin-hole aperture, or the point of light, the more perfectly homocentric is the luminous pencil, and the sharper and more detailed becomes the shadow of any small object.[1] By such means not only can minute opacities in the path of the rays be perceived, but objects which only slightly differ in transparency or in refractive power from the medium in which they are suspended, can be detected, if the vision of the observer be not seriously impaired.

§ 2.

This method of self-examination of obscurities which lie in the path of the rays within the eyeball is termed *entoptic* observation (ἐντός, within, and ὀπτικύς); a term first given by Prof. Listing of Germany, who published an important paper on the subject sixty years ago.[2] Two years previously Sir David Brewster had drawn attention to the subject in a valuable investigation, wherein he

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[1] The term *Stenopæic*, or *Stenopaic* (Gr. στενός, 'narrow,' ὀπή, 'opening') is usually employed to denote a screen with a small aperture. *Stenŏpic* would be a briefer and better term. If the botanists had not already used the word for another purpose, a *micropyle* (Gr. μικρός, 'minute,' πύλη, 'gate'), or micropylic screen, would have been more expressive.

[2] Listing, *Beitrag zur physiologischen Optik.* Göttingen, 1845.

showed how measurements of the actual size of the obscurities could be made.[1] Brewster, however, only refers to the *muscæ volitantes*. This was followed by a lengthy and excellent paper on Entoptic Phenomena, by Dr. MacKenzie, published in the Edinburgh Medical and Surgical Journal for July, 1845 (vol. lxiv., pp. 38, *et seq.*). The subject was then taken up by the famous Dutch physiologist, Donders, who largely added to the value of entoptic observation as a method of diagnosis of the eye. In conjunction with his pupil, Doncan, Donders gave admirable drawings of minor obscurities observed in the different parts of the eyeball, and discusses the whole subject in his well-known treatise on the eye.[2] A little later, Dr. Jago, of Cornwall, published two papers on the subject in the Proceedings of the Royal Society, and another in a medical Review, which, however, are more concerned with the medical aspect of the subject.[3] The substance of these essays, with many additional observations, was issued by Dr. Jago in 1864 in a small work entitled *Entoptics*.[4] Finally, Helmholtz devotes a chapter in his classical work, *Handbuch der Physiologische Optik*, to the consideration of the subject, though he does not add any fresh information.[5] After this the subject appears to have

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[1] Brewster, *Trans. Roy. Soc. Edinburgh*, 1843, vol. xv., p. 377. See also an article, presumably by Sir D. Brewster, published in the *North British Review* for November, 1856.

[2] An English edition of this work was published by the New Sydenham Society in 1864 (vol. xxii.), the excellent translation being made by the late Dr. W. D. Moore, of Dublin. The book is entitled *On the Anomalies of Accommodation and Refraction of the Eye, with a preliminary Essay on Physiological Dioptrics*, by F. C. Donders, M.D. The reference to entoptic observation will be found at pp. 197 *et seq.* See also a paper by Donders, in *Nederlandsch Lancet*, 2nd series, 1847, pp. 365 *et seq.*

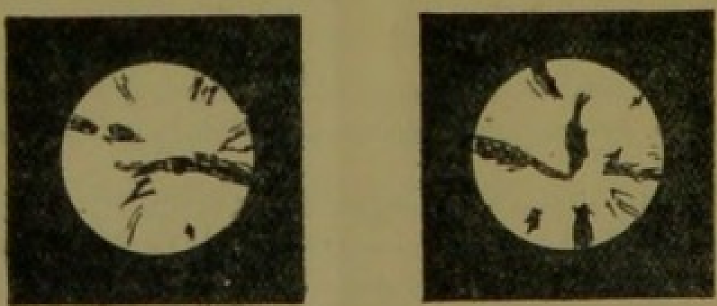
[3] Jago, *Proc. Roy. Soc.*, 1855, vol. vii., p. 208; vol. viii., p. 603, also *Medico-Chirurgical Review*, 1859.

[4] *Entoptics* by J. Jago, M.D., Churchill, 1864. This excellent brochure by Dr. Jago is very little known, and is not referred to by any writer on physiological optics that I have consulted. It had entirely escaped my search in compiling the Bibliography of this subject until quite recently, when the Rev. Dr. Abbott, S.F.T.C.D., found it for me in the Library of Trinity College, Dublin. Curiously enough, Dr. Jago, like other investigators of entoptic vision, misses the important point of the value of this method in the examination of cataract.

[5] There is unfortunately no English translation of this great work. The French edition is entitled *Optique Physiologique*, and the reference to entoptic vision will be found in sect. 15, p. 204, of that edition.

received but scant attention, owing, doubtless, to the discovery of the ophthalmoscope; and, in recent years, entoptic diagnosis of the eye has been almost completely overlooked, even by ophthalmologists.[1]

It is, therefore, not surprising that, in common with many others, I was wholly unaware of the foregoing investigations when my attention was called to entoptic observation by a curious discovery of a defect in my own vision which I noticed some twelve months ago. Looking at a bright sky through a pin-hole in a piece of card held close to the right eye, I was surprised to find the disc of light on the retina obscured by a dark shadow of fixed and definite shape, resembling the letter L reversed (⅃). The left eye also presented a shadow when the pin-hole was placed before it, only in this case it was a fainter and straight horizontal bar half way across the disc. Using a very fine needle-hole in a thin sheet of metal, held close to the eye before a good light, the obscurities were seen in great detail, revealing the structure of some partially opaque tissues in the body of each eye. Fig. 1 shows a rough sketch of these obscurities made at an early stage.



LEFT. RIGHT.

FIG. 1.

Upon consulting the eminent Dublin oculists, Dr. Arthur Benson and Dr. C. Fitzgerald, Surgeon Oculist to the King, the unpleasant fact was revealed that there was incipient cataract in each eye, more developed in the right than the left, and to this cause the shadows which I saw were presumably due. Dr. Fitzgerald carefully drew the shape of the opacity that he had observed, by means of the ophthalmoscope, in each eye. These

[1] Since this paper was read, Dr. Ettles, of London, has drawn my attention to a paper on entoptic vision by Dr. Darier, entitled "De la possibilité de voir son propre crystallin." *Annales d'Oculistique*, vol. cxiv., September, 1895, p. 198.

drawings in rough outline exactly corresponded with what I had previously drawn in much more minute detail from entoptic observation, only the figures I had drawn were taken from inverted images of the opacity in each lens. These drawings, and the reason for this inversion, will be given in Part II.[1]

These results led me to make a series of entoptic observations at stated intervals, and ultimately to the construction of a simple instrument for the more convenient drawing and measurement of what is observed. This instrument I propose to call an *Entoptiscope*, and it will be described in Part II., as some improvements I have recently made are now in process of construction. I hope that this instrument may prove a convenient and useful addition to the means already employed for the diagnosis and pathological study of the eye.

§ 3.

It may be asked how entoptic observation can reveal obscurities in the crystalline lens, when, as is well known, if an ordinary lens be partly covered or cut away, or a small opaque object be interposed near it, or a fly walk over the lens, no shadow of the object nor any injury to the image is seen at the focus of the lens. But both theory and experiment show that this is not the case when the image is out of focus; a blurred shadow of any opaque object in or near the lens is now seen, and this shadow becomes distinct and sharp, because free from penumbra, if the lens be illuminated by a light from a point, such as a pin-hole aperture. A simple experiment with a photographic camera will illustrate this. Under ordinary circumstances the diaphragm in front of the lens is not seen on the focussing screen; but throw the screen out of focus and allow a beam of sunlight passing through a small aperture in a piece of card to illuminate the lens, and the image now seen on the focussing screen will be that of the diaphragm and will alter in size with it. The shadow of a fly walking on the lens

[1] I wish to acknowledge my indebtedness to Dr. Charles Fitzgerald for first drawing my attention to the chapter on entoptic observation in Donders' treatise on the eye; and also for the very kind interest which both he and Dr. Benson have taken in this investigation.

will now be clearly depicted on the focussing screen, but will disappear as soon as the image of the pin-hole is once more focussed on the screen. All this is well known and readily explicable, but the exactly similar results that occur in our own eye are not so well known. When the illuminated pin-hole is placed at such a distance from the eye as to be within the power of accommodation of the eye, usually a distance of about 9 inches or a foot, a sharp image of the pin-hole is focussed on the retina, and no shadow of any small object in or near the crystalline lens can be perceived. When, however, the pin-hole is brought close to the eye, accommodation fails to focus its image on the retina, and the shadow of any object in the path of the rays will be clearly seen, and the more sharply the smaller the pin-hole; whilst the circle of light seen on the retina is now not the magnified image of the pin-hole, but the shadow of the iris diaphragm of the eye, as has been already stated.[1]

To those who, like myself, suffer from presbyopia, and have lost the power of accommodation for near objects, entoptic observation can be carried on with a large pin-hole, say, 1 mm. in diameter, or any bright spot of light placed at a considerable distance from the naked eye; in my case up to 20 inches. Though the entoptic shadows are now smaller, they are darker and less detailed, and hence their outline can be more easily drawn under such circumstances. To exclude extraneous light, a sliding brass tube, blackened inside, can be made to screw over the pin-hole aperture, so that the observer can adjust the length of this tube, through which he views the aperture.

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[1] Entoptic observation was evidently not known in Shakespeare's day. I am indebted to my friend Canon Elliott for drawing my attention to the following apt quotation :—

> *Cassius.* "Tell me, good Brutus, can you see your face?
> *Brutus.* No, Cassius ; for the eye sees not itself,
> But by reflection by [from] some other things.
> *Cassius.* 'Tis just ;
> And it is very much lamented, Brutus,
> That you have no such mirrors as will turn
> Your hidden worthiness into your eye,
> That you might see your shadow."
>
> *Julius Cæsar*, Act i., sc. 2.

Of course if the presbyopic observer puts on his spectacles, the distant pin-hole is now focussed on the retina, and entoptic observation ceases until the aperture is brought so close to the eye that even with spectacles its image cannot be formed on the retina. *Ceteris paribus* the same thing holds true with myopic vision; hence spectacles of any kind are of no use in entoptic observation, and may entirely destroy the effect sought for.

§ 4.

As the anterior principal focus of the eye may be taken as 14 mm. distant from the cornea, when the pin-hole is placed at this distance, the divergent cone of rays entering the eye will be rendered parallel, and hence the shadow of any object in or between the crystalline lens and the retina will be practically of the same size as the object itself. Obviously, when the illuminated pin-hole is placed nearer to, or further from, the eye than the anterior focus, the shadows will be respectively larger or smaller than the object.[1]

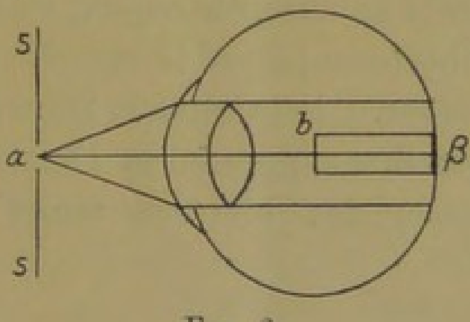

FIG. 2.

This is shown in the accompanying diagrams, where fig. 2 represents the luminous point *a* (or stenopaic screen *s*, *s*), placed at the anterior focus, the enlarged entoptic object *b* throwing the shadow β; the rays being parallel within the eyeball, the area of the shadow is the same as that of the object. In fig. 3 the luminous point *a* is placed nearer to, and in fig. 4 further from, the eye than the anterior focus *f*; in the former the rays will diverge as if proceeding from the virtual

[1] The effect of accommodation, it is true, renders the position of the principal focus of the eye slightly variable; and, in the case of looking at a pin-hole near the eye, the principal focus would be somewhat less than that given as accommodation comes into play. The pin-hole, however, should not be looked *at* but looked *through*, and the eye focussed on the distant surface on which the projected image is depicted.

focus f', and the shadow β will, accordingly, be larger than b; in the latter the rays will converge, and would meet, if prolonged, in the conjugate focus f'; accordingly, the shadow β is somewhat smaller than the object b. Hence, in estimating the actual magnitude of any obscurity within the eye it is desirable to place the pin-hole diaphragm at the position of the anterior focus, a little over half an inch (14 mm.) from the surface of the cornea.

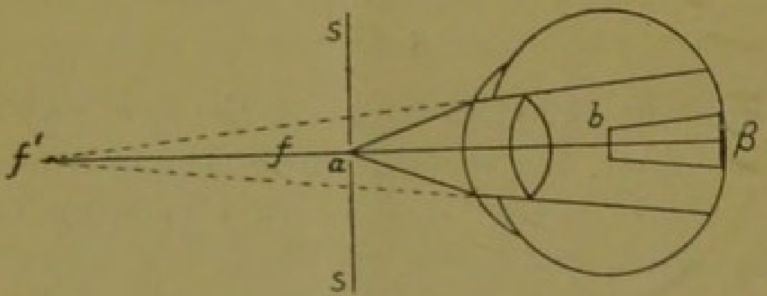

Fig. 3.

Not only the actual size of a microscopic object within the eye can be thus found, but, as will be shown presently, its exact distance from the retina can be determined.

In order to delineate an entoptic object, and estimate its magnitude, the method hitherto employed is one of considerable difficulty to an untrained observer. It is what is known as the method of double vision, and was first suggested by Donders. The procedure is familiar to microscopists; one eye views an object through

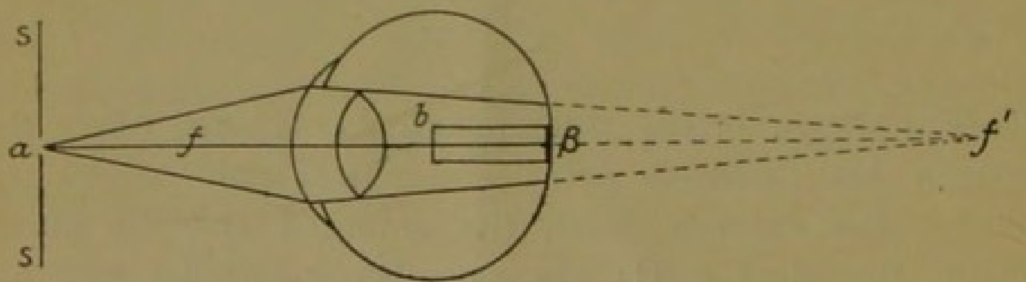

Fig. 4.

a microscope, whilst the other eye looks at a sheet of paper on which the projected image of the microscopic object is seen, and can be sketched with a little practice. Placing an object of known dimensions, such as a finely divided scale, under the microscope, the linear magnifying power of the microscope is found by comparing the actual size of a scale-division with the width apart of the pencil-marks (seen with the other eye), which are placed at the magnified image of a scale-division. Obviously, if the magnifying power of the microscope is known, the actual size of a microscopic object can be thus found. In like manner an entoptic object can be sketched, and its magnitude estimated, one eye looking through the illuminated pin-hole screen, and the other eye viewing the pencil and sheet of paper on which the enlarged image is drawn; the distance of the paper from the eye being measured, the magnification is the ratio of this distance to the distance of the retina from the optical centre of the eye (16 mm.). But, owing to the difficulty of getting the plane of the image to coincide with the plane of the paper, this method is only feasible to a practised observer. A much simpler and more accurate method of drawing the entoptic image, and one requiring no skill, forms an essential feature of the new Entoptiscope to be described in Part II. Moreover, the actual magnitude of the entoptic object is also found at once by the Entoptiscope without any difficulty.

§ 5.

There are two interesting facts in connexion with entoptic observation which require a brief explanation. On looking through a minute aperture in a card held close to the eye, it will be noticed that an object, such as a pencil-point, can be seen with perfect distinctness, even when brought within an inch or two of the eye, *i.e.*, far within the limit of clear vision; and this notwithstanding that the observer may be hypermetropic or presbyopic. The fact is well known, and is sometimes used for enabling very small print to be read with ease. The accompanying diagram, fig. 5, will help to explain this anomaly. If a small object *a*, *b*, be placed near the eye, the screen with pin-hole aperture *SS*, in the first instance being removed, the pencil of rays from the object reaching the eye at m^1, m^2, would be refracted and encounter the retina at *g*, *h*, and *i*, *f*; the prolongation of these rays would unite at β and α, when a clear inverted image of the object would be formed and perceived, if the retina were at that distance. As it is, however, a blurred and wholly indistinct image is formed on the actual retina, the cross-section of the cone of rays from the points *a* and *b* being shown at *g*, *h*, and *i*, *f*. These are *the circles of diffusion* corresponding to those points, and so with every other point of the object. If now a stenopaic screen, *SS*, be interposed, the luminous cone which enters the eye is restricted to the pencil of rays from the minute area of the pin-hole; and, consequently, all the sections of the cone up to its apex, *i.e.*, the area of the circles of diffusion, are proportionately diminished, so that where the retina intersects the cone of rays, this section has become practically a point; the circles of diffusion (which are areas of confusion of the image) have vanished; and a sharp image of *a* is formed at *f*, and of *b* at *g*. Moreover, *the magnitude of the retinal image is greater than before*, coinciding, as will be seen, with the exterior boundary of the rays.

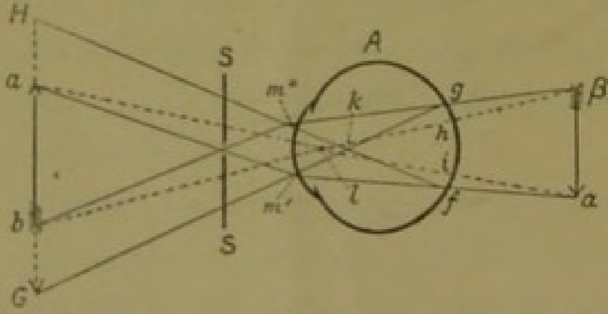

Fig. 5.

If the screen *SS* were removed, lines drawn from *g* and *f*, passing through the nodal point *k* of the eye, determine the direction in which the retinal image would be seen projected from the eye, and an inverted magnified image of the object *a*, *b*, would therefore appear at *G*, *H*. Owing to the large visual angle subtended by an object held near the eye, a microscopic object, such as a transparent scale, divided into fifths of millimetres, can be clearly seen when held close to the eye, and viewed through a very minute aperture in an opaque screen. The amount of light reaching the eye through a minute aperture is, of course, very small; but if the light be sufficiently good, this simple method affords an excellent way of seeing minute objects, or of reading well-illuminated small print, when a lens is not at hand, or spectacles are inadequate.

If, instead of holding a small object on the far side of the pin-hole screen *SS*, it be held between the screen and the eye, a *shadow* of the object, and not an inverted, lenticular image, will be thrown upon the retina. This shadow will be erect, corresponding to the position of the object, but will be projected from the retina as an inverted image; thus if a pin, with the head upwards, be held between the screen and the eye, an enlarged image of the pin with the head downwards will be seen. In like manner any obscurity within the eyeball, when revealed by pin-hole vision, is seen completely inverted laterally as well as vertically, though, as with the pin, the shadow of the obscurity on the retina is not inverted.

§ 6.

The fact that in *ordinary* vision we see things erect, though the retinal image is inverted, presents no real difficulty. The mind does not contemplate the retinal image as a photographer views the inverted image of a landscape when focussing his camera. In fact, we are wholly unconscious of the existence of the retina, or of the size or position of the retinal image, except from experiments on eyes other than our own.[1] Visual perceptions are always referred to a position in space external to our eye, and are projected outwardly by our mind along the "line of visible direction," as Brewster termed it. Now, this line is almost exactly coincident with a straight line joining any point in a visible object external to the eye, *if seen by direct vision*, with the corresponding image of that point on the retina. These lines necessarily cross each other at k, fig. 5, which is the *centre of visible direction* in the eye. The inverted image, therefore, gives rise to the perception of an erect object and *vice versa*.

The centre of visible direction k, fig. 5, may be taken as coinciding with the optical centre of the eye. The optical centre of a thin lens is such that all rays not remote from the axis passing through it are undeviated by the lens; but every lens, or system of lenses, of which the two faces are not in the same medium, as is the case with the eye, has two geometrical points which replace the optical centre of an infinitely thin lens. These two points are termed *nodal points*; and these in the eye lie so close together that

[1] Or by means of a mirror and ophthalmoscope a skilled observer can use his own eyes as if they belonged to some one else.

they do not sensibly differ from a single point. This is situated on the optic axis close to the posterior (the inner) face of the crystalline lens, about 7 mm. from the surface of the cornea, and 16 mm. from the retina.[1] At this point, the object O and its retinal image i subtend the same angle, and their relative magnitudes are in the direct ratio of their relative distances D and d from this point, or,

$$\frac{i}{O} = \frac{d}{D}.$$

Hence, as $i = \frac{d}{D} O$, the retinal image formed of a metre-stick held 1·6 metre from the nodal point (*i.e.*, 1593 mm. from the cornea) will be exactly 1 cm. long.

What determines the lines of visible direction in the case of entoptic phenomena opens up some interesting questions in relation to vision, which I propose to consider in a subsequent note.

§ 7.

Assuming that the perception of entoptic objects near the retina, *when no stenopaic screen is used*, follows the same law of projection as that of external objects—and experiments indicate that this is the case—an obscurity 1 mm. in diameter near the retina will be perceived as an inverted image 1 cm. in diameter at a distance of 16 cm. from the nodal point, or 15·3 cm. from the cornea. Hence, the linear magnitude x, of an obscurity within the eye, is to the linear magnitude of the projected image S, as the distances d and D of the nodal point from the retina and from the projected image respectively, or

$$x = \frac{d}{D} S.$$

It is, therefore, quite easy for anyone to determine for himself, without using instrumental appliances, the magnitude of any small obscurities within the eye. For example, the *muscæ volitantes*, which float near the retina, throw shadows that are

[1] The position of the nodal point is deduced from the curvatures and indices of the refractive media of the eye. Dunders and Helmholtz placed the nodal point 15 mm. from the retina of a normal eye; but recent determinations of the refractive index of the lens, &c., give a value more nearly like that obtained by Dr. Young a century ago.

perceptible without using homocentric light. They can, if present, readily be seen upon looking at the sky or any illuminated surface, such as a sheet of white paper placed at a convenient distance from the eye. Keeping the head and eyeball as far as possible motionless, the observer can mark with a pencil on the sheet of paper the length and breadth of the projected image of one of these muscæ. For this purpose the paper can be about one or two feet (30 or 60 cm.) from the eye, so as to be within easy reach of a pencil held by the observer. If the image is too small at this distance, the paper can be placed further off, and the size of the projected image judged by marks previously made on the paper. Knowing the distance of the paper, the length and breadth of the retinal shadow is to that of the projected image as the distance of the nodal point of the eye from the retina (viz. 16 mm.) to the distance of the sheet of paper from the nodal point, or practically from the eye. Thus, in the case of a particularly persistent and large musca I recently noticed in my right eye, the length of the projected image of the filament was about 150 mm., and its breadth 2 mm., the sheet of paper being 60 cm. from the eye. Accordingly the retinal shadow was

$$\frac{16}{600} \; 150 = 4 \text{ mm. long,}$$

and $$\frac{16}{600} \; 2 = 0{\cdot}053 \text{ mm. broad.}$$

As this musca was very near the retina, its actual size was practically the same as the above.

In making this experiment one eye must be shut, and the eye used should be partly closed so as to give a sharper and darker shadow. Looking through an aperture made in a piece of card with a stout needle, gives a much better result, as already explained: here, however, the magnification of the image follows another law, as will be explained below. In this case the head can be rested on a support—such as the left hand, with elbow on the table—the eye being a foot or so from the sheet of paper, and the perforated card held or fixed close to the eye; excellent drawings and measurements of the reticulated and cellular structure of the muscæ, with the knots and loops of their filaments, can thus be made. Their mobility is at first very provoking, but they are much steadier when the head is bent over the illuminated sheet of paper lying on a table, than when the head is erect and the paper vertical.[1]

We owe to Sir David Brewster the first determination of the magnitude of these muscæ and the first suggestion as to finding their distance from the retina.[2] He used two lights placed at a distance from the eye: a double shadow of a particular musca was thus thrown on the retina; the lights were then moved closer together till the projected images touched. Measuring the distances of the lights apart and their distance from the eye, and the angle subtended by one of the images of the musca, enabled him to deduce its size and distance from the retina. The nodal point of the eye was taken by Brewster as 0·524 of an inch from the retina, a little less than its true value; the width of the musca he found to be 0·0012, (1/820th) of an inch; this corresponds to 0·03 mm., and its distance from the retina 1/85th of an inch, equal to 0·3 mm.; but their distance varies, and is often further from the retina than this.

§ 8.

When entoptic objects are seen by means of a minute illuminated aperture, or stenopaic screen, and projected on to a surface behind the screen, the magnification of the shadow of the pupil

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[1] This is due to the fact that in the former case the muscæ slowly ascend and therefore keep in the line of sight; in the latter they move across and disappear out of the line of sight. The range of their motion is limited owing to the fact that the vitreous humour is divided up by a kind of cellular structure. Many papers and treatises have been written on the subject of the muscæ; occasionally the muscæ appear fixed in position; these are considered symptomatic of the beginning of mischief in the eye, but as a rule they are indicative only of digestive or other slight bodily derangement. In my own case, however, mobile muscæ have certainly increased both in size and persistency since the development of cataract in my eyes, and are worse in the right eye, in which cataract is more advanced. It is curious to note how they begin to appear and float into the line of sight when searched for.

[2] *On the Optical Phenomena, Nature, and Locality of Muscæ Volitantes, with Observations on the Vision of Objects placed within the Eye*, by Sir David Brewster, D.C.L., F.R.S., Transactions Royal Society of Edinburgh, vol. xv., p. 374, 1843. Brewster unfortunately gives no details of his experiment, nor data upon which he founded his calculation; but in an article on Entoptic phenomena in the *North British Review* for November, 1856, I find these data are supplied. The article is evidently by Brewster himself, and is one of considerable interest.

and of any obscurity within the eyeball *does not follow* the usual law of projected images stated above. Singularly enough, this important fact seems to have escaped observation hitherto, and I must reserve for a subsequent paper the series of measurements I have made that demonstrate the law in this case.[1] This law the Entoptiscope not only determines with precision, but also enables one accurately to investigate other obscure phenomena in the psycho-physiology of vision, such as ocular parallax, &c.

It will be obvious from an inspection of fig. 5 (p. 52) that when entoptic objects are seen through a stenopaic screen, if the lines of visible direction crossed at k, the nodal point of the eye, then :—(i) the rays would again cross at the pin-hole aperture, and the image would be re-inverted (that is, it would be seen upright); but this is not the case; and (ii) the enlarged image would be projected on to the surface of the stenopaic screen and its apparent magnitude

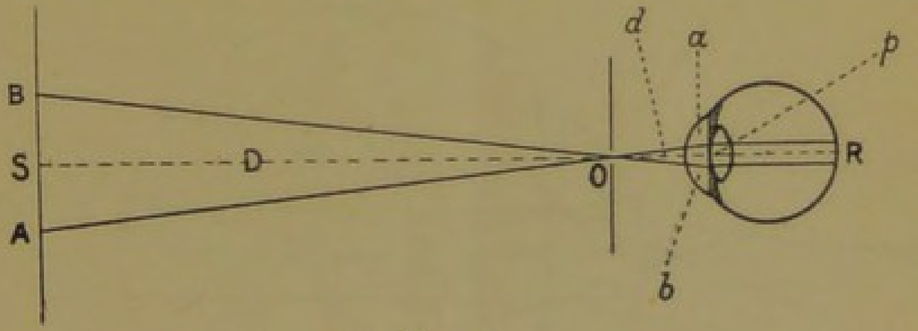

FIG. 6.

would follow the usual law, but neither of these is the case. In fact, the path of the projected shadow corresponds to the path of the incident-rays crossing at the pin-hole aperture only. This is shown at O in fig. 6. Hence the magnification is, as might be inferred *a priori*, in the direct ratio of the distance d of the pin-hole from the pupil to its distance D from the illuminated screen S on which the shadow is projected. The pupil p forms the base $a\,b$ of the cone of rays on one side, and the projected image of the pupil $A\,B$ forms the base of the cone of rays on the other side. When O is at the anterior focus of the eye, the retinal

[1] Even Helmholtz and Donders, and more recent authorities on physiological optics such as Tscherning (*Physiologic Optics*, Eng. Trans., p. 304), appear to have overlooked the obvious considerations stated in the next paragraph, and accordingly have given an incorrect formula for calculating the size of entoptic objects.

shadow R is the same size as the entoptic object, and hence the linear magnitude x of the pupil, or of the obscurity within the eye, is to that of its projected image S, as d is to D, or,

$$x = \frac{d}{D} S.$$

The *area* of x to that of S is of course as $d^2 : D^2$.

These measurements are easily made with the Entoptiscope, nor does a slight deviation of the pin-hole from the anterior focus make any sensible error.

§ 9.

The distance of entoptic objects from the retina, as Listing has shown, can be ascertained by noting the relative parallactic displacement of the shadow which occurs upon moving the eye.[1]

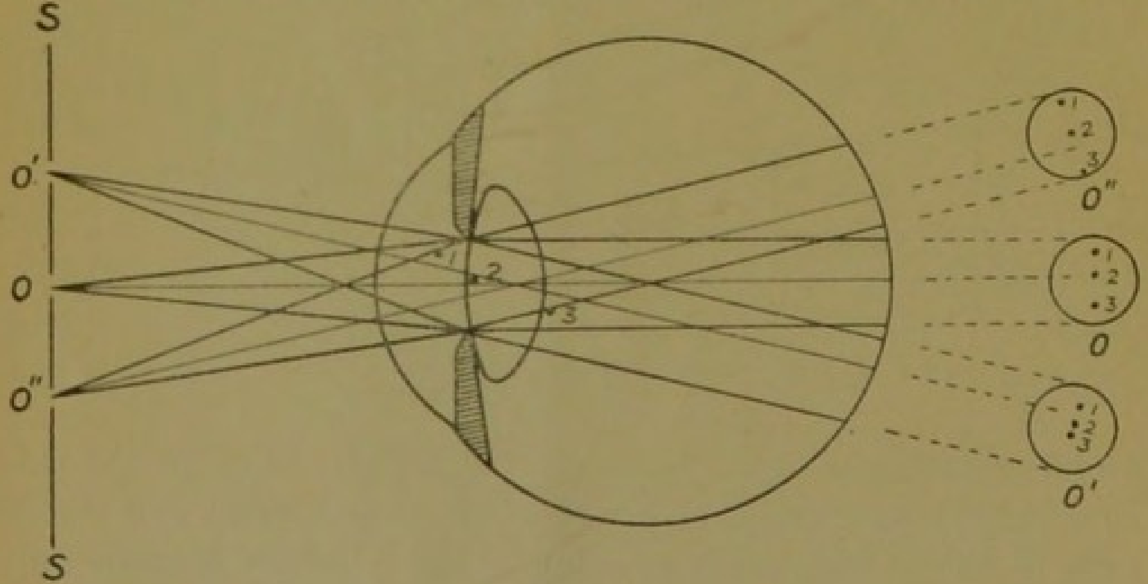

Fig. 7.

This will be readily understood from an inspection of fig. 7, which is accurately drawn to scale. Within the eyeball let us suppose that three entoptic objects exist: No. 1 between the pupil and cornea; No. 2 in the crystalline near the plane of the pupil; No. 3 in the vitreous; therefore nearer the retina than No. 2. The eye is first directed to the central spot of light or opening O in a stenopaic screen. The shadows of the three entoptic objects fall on the retina, and are seen as in the central projection. If now the eye be turned to view first the upper light or opening O', and

[1] Listing, *Beitrag zur physiologisehen Optik.* Göttingen, 1845.

then the lower opening O'', the shadows are seen on the retina displaced as shown in the upper and lower projections. The entoptic object No. 2 in the plane of the pupil has not changed its position, but No. 1 in front of the pupil, and No. 3 behind, have both been displaced, but *in opposite directions*. Obviously this displacement or parallax is greater as the distance from the pupillary plane is greater, and thus the position of an obscurity within the eye can be found by the observer with a certain degree of accuracy.

This method, however, is not applicable to moving objects like the muscæ, and in any case requires a considerable amount of skill on the part of the observer. Brewster's method is better, and was improved upon by Donders by using two adjacent openings in a

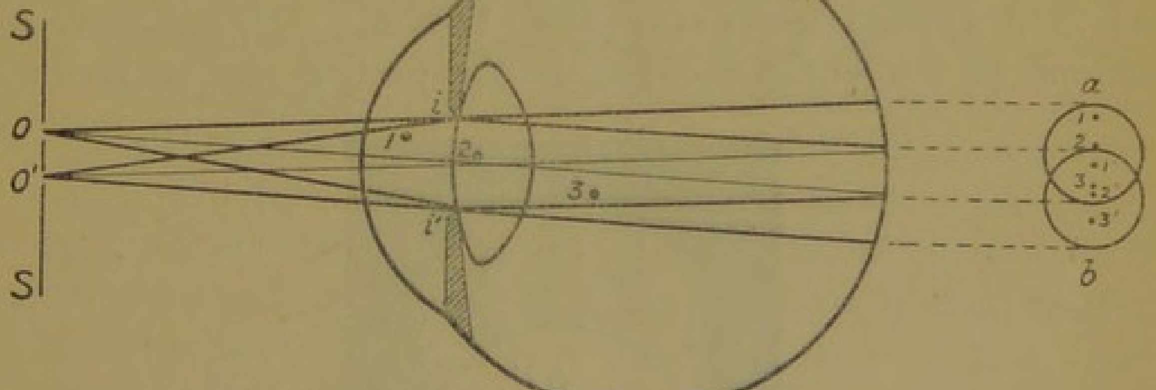

FIG. 8.

stenopaic screen: each aperture about 0·1 mm. in diameter and about 2 mm. apart.[1] Two overlapping images of the pupil are now seen as shown in *a b* (fig. 8). The closer the pin-holes are together, the more the circles overlap; the distance apart of the centres of the two circles exactly corresponding to that portion of the double image which does *not* overlap: and this distance, when the entoptic rays are parallel, is proportional to the distance between the pupil and the retina. If now an entoptic object, such as No. 2 (fig. 8), lie in the plane of the pupil, its doubled shadow will be as far apart as the images of the pupil, *i.e.* as the centres of the two circles. On the other hand, the doubled

[1] *Nederlandsch Lancet*, 2nd Series, D. 11, 1847. *Archiv. f. physiologische Heilkunde*, viii., 1849. *Accommodation and Refraction of the Eye*, by F. C. Donders, 1864, p. 203.

shadow, if the object lie in front of the pupil, as No. 1, will be further apart than the centres of the two circles, and if between the pupil and the retina, as No. 3, the shadows will be closer together. It is now only necessary to find the breadth of the part of the circles which do not overlap in order to find the relative position of an obscurity in the eyeball. For the distance apart S of the duplicate shadow is in the same ratio to the distance R of the entoptic object from the retina, as the distance apart C of the centres of the two circles is to the distance P of the pupillary plane from the retina; or

$$\frac{S}{R} = \frac{C}{P} \quad \text{hence} \quad R = \frac{S}{C} P.$$

Now the distance P, of the pupil from the retina in a normal eye, may be taken as 19 mm., in a myopic eye about 21 mm., and in a hypermetropic eye about 17 mm. Hence the exact position of the entoptic object in the eyeball can be located.

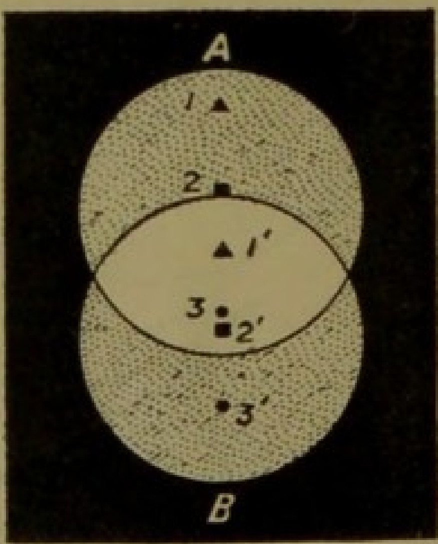

Fig. 9.

This is more clearly seen in fig. 9, where A and B are the overlapping images of the pupil; and the obscurities, in the order of their distance from the cornea, are diagrammatically represented by a triangle, a square, and a circle. As both figs. 8 and 9 are accurately drawn to scale, by using a pair of compasses, the reader can verify the law above stated. In connexion with the Entoptiscope to be described in Part II., I will show how this measurement can be made in actual practice; and will also describe another and very simple method I have recently devised, which enables an unskilled observer to make an approximate estimate of the position of the obscurities.

§ 10.

By making a large artificial eye, and using a brilliant point of light, it is possible to illustrate in a lecture-room the whole of the principles of entoptic observation and measurement. This was shown at the conclusion of the paper, a small arrow painted on a strip of thin glass or mica being used to represent the obscurity within the eye and placed in different positions in the imaginary eyeball; the shadow of this object being thrown on a ground-glass screen to represent the retina. The source of light was an electric lamp the rays from which passed through an orifice (about a mm. in diameter) in an opaque screen placed before the artificial eye. When the ground-glass screen was moved out of focus, the sharp shadow of the arrow was seen wherever it was placed in the eyeball. The effect of varying the size of the orifice in the opaque screen upon the visibility of the shadow of a small object, held at different parts of the eyeball, can thus be strikingly demonstrated to an audience.

With two closely adjacent pin-holes two partly overlapping circles of light were thrown on the screen; the distance apart of the double shadow of the object thus caused was seen to be exactly the same as the distance apart of the centres of the two circles, when the object was in the plane of the pupil; but this distance diminished in proportion as the object approached the retina. In fact, the exact distance of the object from the artificial retina could thus be readily determined in a lecture experiment.

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ON ENTOPTIC VISION.

[PARTS II. AND III.]

BY

W. F. BARRETT, F.R.S.,

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(PLATES III. & IV.)

[Authors alone are responsible for all opinions expressed in their Communications.]

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1906.

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Letter Entoptics

6, De Vesci Terrace,
Kingstown,
Co. Dublin.

May 2/06

Dear Dr Tweedy,

I take the liberty of sending you Part 2 of my paper, on p. 79 you will find a reference to the experiment you were good enough to show me you had made long ago.

With the Author's compliments.

ROYAL COLLEGE OF SCIENCE,
DUBLIN.

The instrument will be exhibited at the forthcoming Soirée of the Royal Society on May 9th.

ON ENTOPTIC VISION.

BY W. F. BARRETT, F.R.S.

VIII.

ON ENTOPTIC VISION.

Parts II. and III.

PART II.—THE ENTOPTISCOPE AND ITS APPLICATIONS.

By W. F. BARRETT, F.R.S.,

Professor of Experimental Physics, Royal College of Science for Ireland.

(Plates III., IV.).

[Read, November 21, 1905; Received for Publication, November 24, 1905; Published May 2, 1906.]

§ 1.

In the present paper the instrument which I have devised for viewing, delineating, and measuring entoptic objects will be described, and some experiments with, and applications of, the Entoptiscope will be given, though its practical use must be left in the hands of the ophthalmic surgeon.

In this instrument, instead of the troublesome method of double vision referred to in Part I., the observer *looks through* the pin-hole orifice on to a brightly illuminated ground-glass screen, placed upon what corresponds to the stage of a microscope. By this means the magnified image of the entoptic object is projected upon the ground-glass below, and the shadow can easily be traced with a pencil. An important feature of this arrangement is that the pencil-point appears to be exactly in the plane of the projected shadow, so that no difficulty is experienced in making a tracing. The observer, especially if presbyopic, will be astonished to find, on looking through the minute orifice, how distinctly he sees the sharp point of the pencil, or of any small object in the field of view, albeit far within the limit of clear vision of his unaided eye. This is due to the homocentric pencil of rays through the pin-hole orifice, and has already been explained in Part I., § 5.

The first form of my Entoptiscope is shown in Plate III., fig. 1, and consists of a pair of vertical brass pillars supporting a head-rest, which can slide from side to side so as to bring either eye vertically over the pin-hole contained in the revolving diaphragm of the eye-piece. This diaphragm has pin-hole apertures varying in diameter from 0·1 to 2·5 of a millimetre, and a pair of pin-holes each 0·1 mm. diameter, and 2 mm. apart, so that by revolving the diaphragm either a single aperture of any given size or a double aperture can be successively brought before the eye. Figs. 1 and 2 show the diaphragm *A* in plan and elevation (the orifices are shown enlarged); the object of the double aperture will be seen later on; an eye-cup screws on to the upper part of the eye-piece (fig. 2).

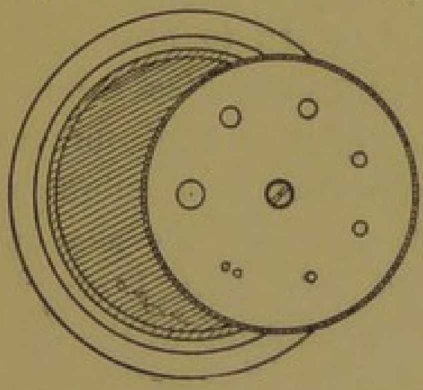

Fig. 1.

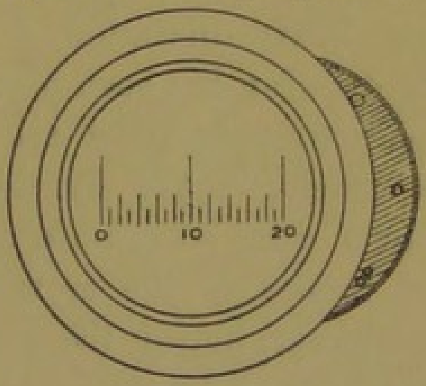

Fig. 3.

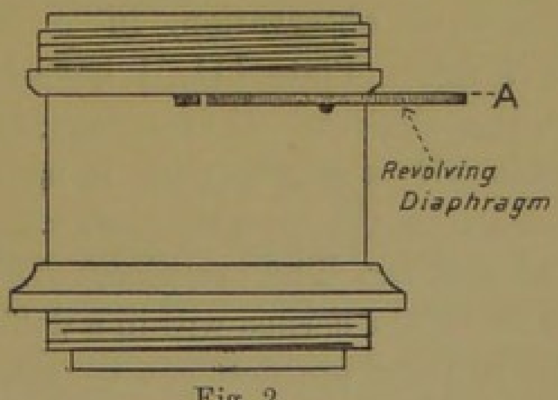

Fig. 2.

Below the pin-hole eye-piece is a transparent scale (fig. 3), divided into fractions of a millimetre; the shadow of this scale falls upon the eye of the observer, and is thence projected much magnified upon the ground-glass stage below, along with the shadows of any opacities seen in the eye. At the base of the instrument (Plate III., fig. 1) is a concave mirror, which can be adjusted so as to illuminate the eye-piece brilliantly, using the light of the sky or that of a lamp. A sharply-pointed and hard pencil is used by the observer to trace the image seen on the ground-glass stage; and, as stated, pencil-point, scale, the image of the pupillary disc, and the projected shadow of the opacities in the eye are all seen in the same plane with perfect clearness. Hence, if the head and eye are kept steady, the drawing or tracing is made with ease even by an unskilled observer. The only difficulty consists in the contraction and an apparent dilatation of the pupil; the former occurs even in uniform light during accommodation, when the attention is concentrated in the act of drawing. This difficulty, however, is overcome by keeping the eye fixed for a few moments on the pencil-point before the tracing is made, or by dilating the pupil artificially when a careful drawing is required. The latter, a curious elusive dilatation, I will return to presently (see § 8). After the drawing has been made the ground glass can be removed, and a photographic print taken, which is kept for comparison with the tracing made by the observer at a subsequent time. In my own case, so minute and clear are the shadows of the darkened tissues of the crystalline lens, that I can detect the slightest change, noting the gradual extension of the opacity, and could watch week by week the effect of any remedy if such were known.

For convenience of observation, in a later form of the apparatus, shown in fig. 2, Plate III., I have hinged the vertical pillar *P*, so that the observer, when using the instrument, may incline it to suit himself; a single pillar is used in order to leave the hand free to draw on the ground-glass stage *G*, which carries a supporting hand-rest *R*. The eye-pieces *EE* have shaped cups to fit the eye and bring the cornea within a definite distance of the pin-hole. In this way the pin-hole can be placed at the anterior focus of the eye (about half an inch from the cornea), for the reason already explained in Part I.; and the stage is placed at a fixed distance so as to give a definite magnification.

It is important in using the Entoptiscope that the observer should be comfortably seated and completely at ease; he should have his hands free and not be troubled to keep one eye closed; it is much better in fact to keep both eyes open. This is done in using either of the instruments shown on Plate III.; in the smaller one the shaped sliding head-rest keeps all light from reaching the eyes except through the single revolving diaphragm; in the larger there are two revolving diaphragms, one (shown at *D*) for each of the eye-pieces *EE* (these are also shown at *DD* in fig. 4, p. 66). The eye that is not under observation is kept in complete darkness by turning *D* until the index marks *O*; at this position there is no aperture in the diaphragm; thus either eye can be occluded with ease. The apertures are numbered in order of their size, No. 1 being less than a tenth of a millimetre in diameter, No. 2 larger, No. 3 larger still, and so on. The mirror *M* is plane and not concave, and made sufficiently large to cover the whole of the ground-glass stage *G* with a flood of light reflected from an adjoining incandescent gas lamp or other source of light. As the mirror is carried by the stage and moves with it, the illumination of the field remains unaltered in adjusting the inclination of the pillar to suit the observer. The pillar, stage, and mirror move with stiff friction round the centre *A*, and can be clamped in any position by turning a milled-head screw. In order to prevent any shifting of the observer's head, and to avoid fatigue, a hinged and padded head-rest *H* is fixed in such a position that the forehead rests comfortably upon it. The head-rest is also made to rise or fall, and can be clamped at any elevation to suit the observer.

§ 2.

As the distance between the two eyes varies in different persons, the exact adjustment of the pupil to the pin-hole is accomplished by an ingenious device suggested to me by the remarkably skilful mechanician, Mr. M. Lambert, to whom I am indebted for the admirable construction of the instrument from the rough plans I gave him. This device is shown in fig. 4 (p. 66), and consists in gearing the arms supporting the eye-pieces, so that an automatic adjustment and exact centring occur directly the observer places his eyes in position. Incidentally this arrangement, by means of the scale on the sector *S*, affords a most perfect method of ascertaining the exact pupillary distance of the two eyes, thus replacing the spectacle "trial-frame," or sliding callipers, usually employed for this purpose by the oculist.

As it is obviously an advantage that the oculist should retain a record of the obscurities delineated from time to time by the patient, and photographic printing of the drawing on ground glass involves a little trouble, a direct tracing on paper can be made by the patient.[1] For this purpose the ground glass *G*, Plate III., fig. 2, is lifted out of its clips, and a piece of clear plate-glass of the same size is substituted. On this a piece of tracing-paper cut to the exact size is held by the spring-clips *S*, *S*. The tracing paper is ruled as shown in fig. 5; the object of this is to enable the image of the pupil to be drawn more easily, by making the intersection of the cross-lines the centre of the projected image of the right or left pupil.

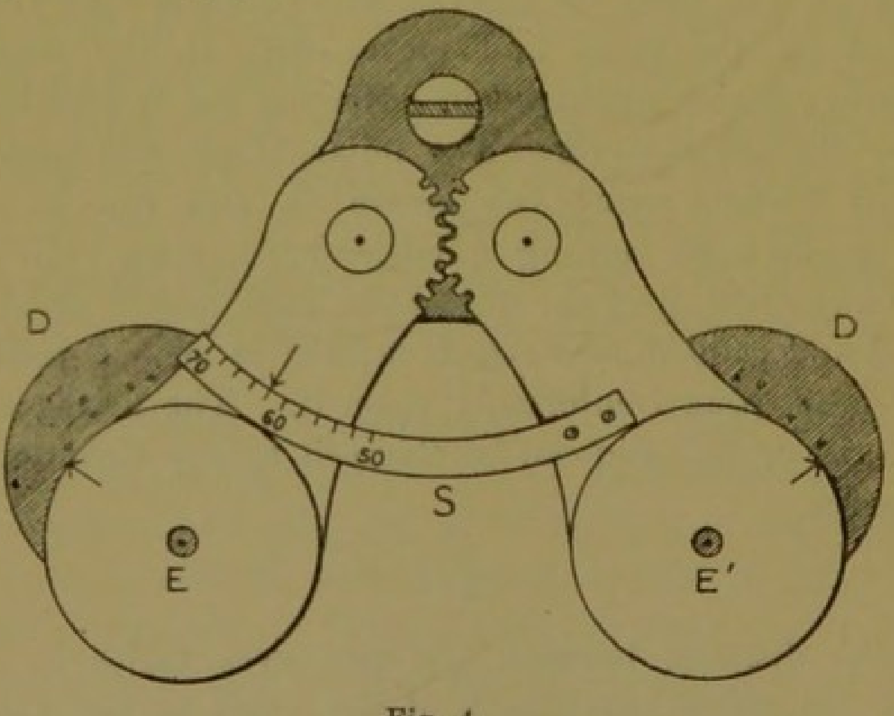

Fig. 4.

It is convenient to know the exact retinal area shadowed by the obscurities at any given time, so that the rate of progress, or amendment, of the defect can be determined. This is accomplished by having the tracing-paper printed in very faintly-ruled 5 mm. squares, such as are shown in part on the right hand of fig. 5. Upon counting the squares covered by the drawing of

[1] There is also a disadvantage in a photographic print of the tracing on ground glass, that it *laterally* inverts the shadows that are drawn, unless the print be taken through the glass, when it is of course less sharp; moreover the tracing-paper can be at once named and dated, and stuck in the practitioner's case-book for future reference.

the shadow which the patient has made, the oculist at once knows (see § 3) the exact area of the entoptic obscurity, or of the pupil, as shown by the dotted circles in fig. 5. A supply of tracing-paper, properly ruled and cut the right size, is provided with the instrument.[1]

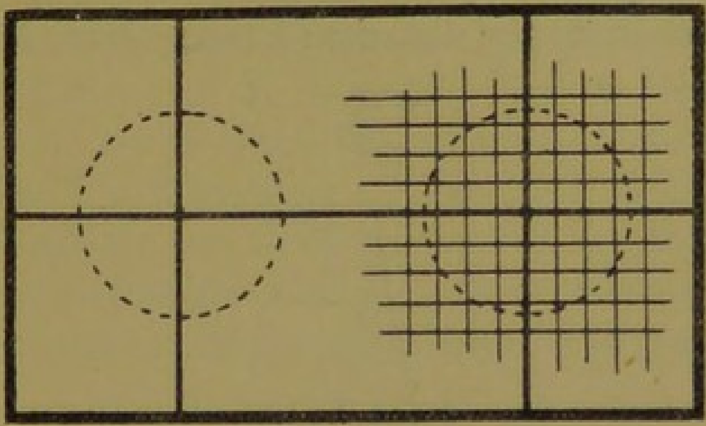

Fig. 5 (*reduced one half*).

§ 3.

It is certainly astonishing that such an instrument as the foregoing does not appear to have been devised hitherto. Perhaps no instrumental appliance was thought necessary for entoptic observation, which has fallen into disuse since Helmholtz's discovery of the ophthalmoscope. In fact, Donders remarks: "Now that Helmholtz's ophthalmoscope is in our hands, the importance of the entoptic mode of examination for diagnosis is thrown completely into the shade."[2] With all deference, I venture to think Donders' statement will be found to be inaccurate. It is a remarkable fact that neither Donders nor Helmholtz depicts the entoptic observation of cataract, nor dwells upon the special value of this method in the diagnosis of this defect in vision. Drawings are given of what they and their pupils saw; but these are only of minor defects in the eye. Even in the lengthy article on Ophthalmology in the *Encyclopædia Britannica* and in several text-books on this subject, I can find no reference to entoptic observation. It is obvious that whilst the ophthalmoscope has been of inestimable value to the

[1] The Entoptiscope can be obtained from the well-known opticians, Messrs. Curry and Paxton, 195 Great Portland Street, London, W.

[2] Donders, *Accommodation and Refraction of the Eye*, p. 204.

profession, it has its limitations, especially when there is any opacity in the anterior parts of the eye; and I imagine that cases may frequently occur when the Entoptiscope can alone enable a correct diagnosis to be made by the ophthalmic surgeon.

In order to save calculation, the distance from the glass stage, on which the image is projected, to the pin-hole aperture, can be made five or ten times the distance of the aperture from the pupil

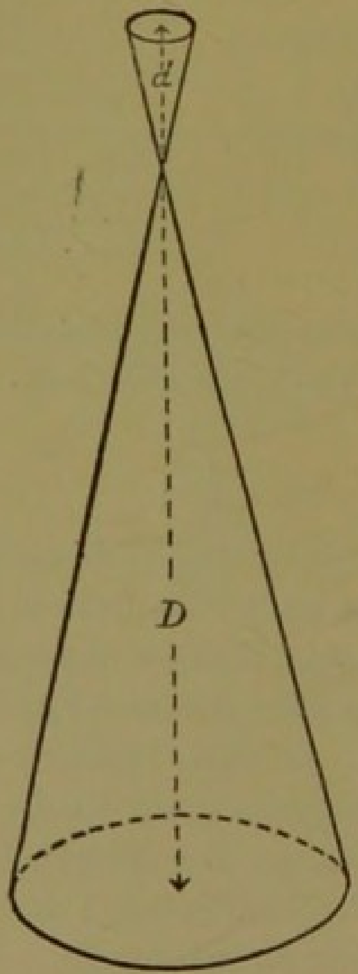

Fig. 6.

of the eye; the linear magnification is thus five or tenfold; and the exact area of the entoptic obscurity is accordingly 25 or 100 times less than the area of the image drawn by the patient.

In ordinary vision, the magnitude of the image of an object on the retina is to the size of the object in the ratio of the distance of the nodal point of the eye from the retina (viz., 16 mm.) to that of the distance of the nodal point from the object. This law also holds true of entoptic vision when the shadows on the retina can be seen by a general illumination of the eye. Helmholtz, Donders, and all recent authorities on physiological optics, so far as I know, assume the same law holds true when a stenopic screen[1] (*i.e.*, a pin-hole diaphragm) is used, and the entoptic shadow is seen projected through the pin-hole aperture on to a surface beyond. But, as I have explained in Part I., § 8, this is *not* the case, and could not be the case, for the reasons I there adduced. Careful measurements which I have made show, as might be expected, that the magnification is in the ratio of the distance d of the pin-hole from the pupil, to the distance D of the pin-hole from the ground-glass stage or other surface on which the image is projected, as shown in fig. 6. Hence, if the shadow on the retina be the same size as the object (as occurs when the pin-hole is at the anterior focus of the eye), the linear magnitude x, of any obscurity within the eye, is known when that of the projected image S is measured, for

$$x = \frac{d}{D} S.$$

As the pupil is approximately 3 mm. from the cornea, this amount must be added to the distance d of the orifice from the eye.

§ 4.

But the use of the Entoptiscope is not confined to the detection and delineation of opacities in the eyeball. The circular image the observer notices on the stage is not an enlarged view of the orifice through which he is gazing, but, as already mentioned, it is a magnified image of his own pupil. The iris limits the divergent cone of rays entering the eye, and its shadow is sharply depicted on the retina. Hence any irregularities in the iris are at once detected, and can be readily traced by the patient, and the exact size of the pupil accurately determined. *Pupillometry*, as it is called, is one branch of ophthalmology; and the ease, expedition, and accuracy with which it can be accomplished by means of the Entoptiscope will, I hope, render this instrument, in the hands of oculists, a useful means of supplementing the usual external methods of observation of the pupil. Even among the limited number who have so far used the Entoptiscope, I have been

[1] As 'stenopaic' screen (see Part I., p. 44, footnote) may mean either a narrow slit or a small pin-hole in a screen, I shall use the word 'stenŏpic' to signify the latter only.

struck with the deformation of the pupil occurring and drawn in one or two cases, though the defect was not conspicuous externally to any casual observer.

It is also interesting to note the wide variation in the size of the pupil among different people, under the same degree of illumination and with similar accommodative contraction. The average normal pupil is rather less than 4 mm. in diameter; and a difference in diameter of a fraction of a millimetre is easily registered by the Entoptiscope. For the purpose of measurement it is better not to attempt to trace the whole circle of light seen on the stage, but simply to make a pencil-mark at the extremities of any diameter of the circle, and measure the width apart of the pencil-marks by a pair of compasses. A transparent millimetre-scale can of course be placed on the stage, or the eye-piece micrometer-scale can be used, and the diameter of the circle read off directly; but for an inexperienced observer the pencil-marks I find more satisfactory. The diameter of the pupil being obtained, if it be a normal or fairly circular pupil, it is a great help to draw on the ground glass, or tracing-paper, a circle of this diameter, with the cross-lines of fig. 5 as the centre of each circle, using for this purpose a compass or a coin of the right size. This enables the patient to make his drawing of any entoptic objects with more ease and leisure; still better is it to use as a guide an opaque diaphragm, with a circular aperture of the right size, laid on the stage. Or a movable opaque screen can be used, having two apertures—one corresponding to each eye, and each about 2 cm. diameter. As the magnification of the pupillary image depends on the distance of the screen from the pin-hole, by making this screen with a sliding-tube, to enable it to move up or down the pillar of the instrument whilst it is kept parallel to the stage below, a position will be found by the observer when the diameter of the aperture in the screen exactly corresponds with the area of the image of his pupil; the screen is then kept in this position whilst the drawing is made below.

§ 5.

I have already mentioned in Part I. that it was the discovery of a small permanent obscurity in both of my eyes, before any opacity was detected by the ophthalmoscope, that led me to devise the Entoptiscope; and I will now give a recent tracing I have made of these obscurities. Fig. 1, Plate IV., is a reproduction of the shadows seen by means of the Entoptiscope, respectively, in my right and my left eye. That these obscurities are due to cataract—that is to say, to partial opacity of the crystalline lens or its capsule—there is no doubt, as will be evident from the careful drawing of the appearance presented in the ophthalmoscope (fig. 3, Plate IV.), which was kindly made for me by the eminent oculist Dr. C. Fitzgerald, of Dublin. As already explained in Part I., § 5, entoptic observation inverts both laterally and vertically the shadows on the retina, whereas the opacity is seen without inversion in the ophthalmoscope. A comparison of the two sets of drawings must therefore be made after the complete inversion of one or the other. This has been done in fig. 2, Plate IV. Dr. Ettles, of London, was good enough to spend some time in making as minute a drawing as was possible of the cataract in my right eye; and a copy of his drawing is given in fig. 4, Plate IV.[1] The much greater detail shown by entoptic observation is obvious; but the entoptic drawing in fig. 1, Plate IV., gives no idea of the wonderful structural detail which the observer sees. The minutest change in the opacity is clearly visible; and, as I have said, the effect of any therapeutic treatment of cataract, if such should ever be found worthy of trial, could be rigorously tested. It is, of course, desirable that the Entoptiscope should be kept in the hands of the profession; otherwise nervous people would be apt to alarm themselves needlessly by its use. In my own case, if a personal reference will be pardoned, I have found the periodic examination of my own eyes a matter of considerable, if not very exhilarating, interest, inasmuch as the slow progress of the cataract, and the curious way in which it spreads, can be watched up to the inevitable end. The only inconvenience so far felt has been due to the increasing astigmatism, which, as I believe is usual, augments with the development of cataract.

---

[1] I met Dr. Ettles at the Royal Society Conversazione last year, where he was exhibiting that fine instrument the Ettles-Curties Ophthalmometer, and was struck with his scientific enthusiasm and all too rare knowledge of entoptic phenomena.

Another and by no means unimportant use of the Entoptiscope by the oculist will be found in the certainty with which it will enable him to dispel alarm in very many cases where a patient, from perceiving some obscurities such as the *muscæ volitantes* in his field of view, imagines he is about to lose his sight. Looking through the Entoptiscope, if any muscæ are present, they will be conspicuously seen slowly moving over the illuminated stage; not only will their characteristic appearance and mobility enable the oculist to make an immediate diagnosis, but their actual size and position in the eyeball can be accurately determined. Fifty years ago, Sir David Brewster pointed out the value of entoptic observation in such cases. He remarks: "Few symptoms appear so alarming to nervous persons as the *muscæ volitantes*; and that these fears can be dispelled by the application of a recondite property of divergent light which has only been developed in our own day is one of the numerous proofs which the progress of knowledge is daily accumulating, that the most abstract and apparently transcendental truths in physical science will, sooner or later, add their tribute to supply human wants and alleviate human sufferings."[1]

As the muscæ occur nearer the retina than the lens, their shadows can be seen, as is a matter of common experience, without the use of a homocentric pencil of rays. Hence a very simple method, which I referred to, but did not describe, in Part I., § 9, suggests itself for ascertaining approximately the relative position of any obscurities within the eyeball. This consists in gradually increasing the size of the aperture in the eye-piece of the Entoptiscope. Accordingly, a graduated series of orifices is made in the revolving diaphragm of the eye-piece. Upon rotating the diaphragm so that these orifices, from the minutest to the largest, successively come into view, the observer will note a corresponding disappearance of obscurities in the order of their distance from the retina. Finally, with the largest aperture, whilst the definite shadow of even advanced cataract is lost, the far smaller shadows of muscæ, or any obscurity very near the retina, still remain. The fears of a patient, if groundless,

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[1] *North British Review*, November, 1856.

can be thus set at rest at once. Retinal defects, if existing, are of course still seen, but are easily distinguished from obscurities in the eyeball, and can be examined by retinoscopy.

§ 6.

In order to find the *exact* position within the eyeball of any obscurity, two methods were fully described in Part I. The best method is that of employing two minute and closely-adjacent apertures in the diaphragm; two overlapping images of the pupil are thus produced, together with duplicated shadows of the obscurities. As was fully explained in Part I., § 9, when the path of the rays within the eye is parallel, the distance apart S of the duplicated shadow is in the same ratio to the distance R of the entoptic object from the retina as the distance apart C of the centres of the two overlapping pupillary discs is to the distance P of the pupil from the retina, or

$$R = \frac{S}{C} P.$$

The distance P in a normal eye is 19 mm. As C corresponds to the portion of the circles which do *not* overlap, a comparison of that distance with S can at once be made. If the entoptic object be near, or on the cornea, its duplicate shadow SS is seen further apart than C; if it be on the anterior face of the crystalline, $SS = C$; if on the posterior face, SS is rather smaller than C; if near the retina, SS is seen well within the overlapping part of the circles, and much smaller than C; in this case the duplicated shadows SS are, in fact, quite close together.

Fig. 7, p. 74, is a careful tracing I have made of the obscurities seen in my left eye with a double aperture; the distance C corresponds to the distance apart of the centres of the two circles. If the reader will take the trouble to measure the distance asunder of any of the prominent duplicate obscurities, he will find that distance exactly equal to C; hence these opacities lie on the anterior face of the lens in the pupillary plane. A small *musca* near the retina is shown, with its double shadow close together at m. Owing to the superposition of the two discs of light, the overlapping part will be noticed to be brighter than the other portions of the duplicated pupillary disc.[1]

The observer will probably notice that on first looking through the Entoptiscope the two circles of light barely overlap; but, as the pupil dilates in the subdued light, the overlapping rapidly increases, soon reaches a maximum, and becomes steady, if the illumination remains unchanged. This is due to the fact that, as the pupil dilates, its projected image enlarges, and the double images or discs of light therefore encroach on each other. Hence, before making any measurements, a moment or two should elapse to allow for the dilatation of the pupil. The duplicating of the image of the pupil is a very delicate method of measuring changes in its magnitude.

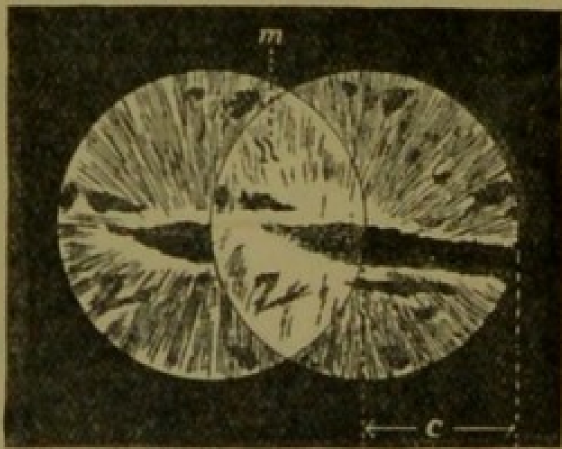

Fig 7.

§ 7.

As the Entoptiscope is designed chiefly for the use of the ophthalmic surgeon, it would be the presumption of ignorance on my part if I entered into its clinical use. But there are several interesting phenomena connected with vision which, I venture to think, will render the instrument of value in physiological and psycho-physical demonstration and research. To some of these I will now briefly allude.

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[1] This drawing of the obscurities in my left eye I made nearly six months later than that shown in fig. 1, Plate IV.; the slow growth of the cataract is thus seen; the principal addition is the smaller bar parallel to and below the large pen-like horizontal obscurity: the field is darker, and a few additional spots are also scattered about.

The observer, having adjusted the inclination of the instrument to suit his convenience, moves the mirror until a brilliant and uniform light covers the ground-glass stage. A shaded lamp, or incandescent gas-mantle, or a couple of incandescent electric lights, or the bright light of the sky, can be used as the source of light. It is, however, preferable to employ a constant source of light, such as the incandescent mantle placed at a given distance from the mirror. Both eyes should be kept open, and buried up to their sockets in the eye-cups, the head-rest being moved until the forehead is comfortably supported.

(1). When the observer's eyes are adjusted in the eye-cups, and the brightly lighted stage seen through the smallest apertures in each eye-piece, the graduated sector, as already stated, at once indicates the exact distance between the pupils, if this is required.

(2). One of the revolving diaphragms is then turned to *O*, to occlude whichever eye is not under observation. Even without a transparent scale in the eye-piece or on the stage, the observer can readily note the well-known fact that light falling on one eye causes *both* pupils to contract simultaneously. This 'consensual reaction,' as it is termed, and its rate, can be accurately studied with the Entoptiscope. It is only necessary to open suddenly the largest aperture in front of one eye, keeping the smallest aperture before the other, when the contraction of *both* pupils will be seen. Still better, if the stage be dimmed by altering the mirror, an electric lamp brought close under one eye, with the largest aperture open, though not seen by the other eye, nevertheless causes a vigorous contraction of its pupil. The scale, or the ruled squares on the tracing-paper, enables the contraction to be measured, whilst the periodic time of the consensual reaction can be determined by opening and closing the large aperture in front of the electric lamp.

(3). The change of the pupil, during accommodation, has already been mentioned. This 'accommodative contraction,' as well as the direct light reaction in the pupil, is strikingly seen in the Entoptiscope. Turn both diaphragms to *O*; then, after a few moments in darkness, open an aperture in one eye-piece. The contraction of the pupil from light-reaction is first seen. If a pencil-point be now brought in the field of view on the stage and looked at, accommodation takes place, and the pupillary disc will be seen to contract; the pencil may be suddenly raised near the eye-piece, when a further contraction occurs, owing to the convergence of the eyes that now takes place.

Other causes which give rise to pupillary contraction or dilatation, such as an emotional disturbance, fright, pain, and the action of certain drugs, &c., can be studied more readily, and their effect more accurately measured by the Entoptiscope than in any other way. A magnified view can also be obtained of a slight rhythmic contraction of the pupil (said to be seen by some, though I have not noticed it), which appears to be connected with respiration and the systole of the heart.

§ 8.

(4). One of the most striking phenomena observed with the Entoptiscope is the extraordinary displacement of the projected image of the pupil which takes place when it is seen first by *direct* and then by *oblique* vision. This change in the position of the image, due to a change in the point of view, is not the ordinary parallactic displacement; for this does not occur in the Entoptiscope, but is, I find, an *ocular parallax* due to the structure of the eye. The position of an object when seen by direct vision becomes apparently displaced when it is seen by indirect vision, that is when the pencil of rays from the object is oblique to the visual axis. This displacement increases with the obliquity of the rays falling on the pupil, and therefore with the angular magnitude of the cone of rays entering the eye. Hence, if the object were at an infinite distance, it would vanish; hence also the larger the area of the pupil the greater the ocular parallax; if the pupil were a point, it would disappear. I must reserve to a subsequent paper the explanation and discussion of this obscure subject, together with the series of measurements I have made in connexion with it.[1] It will be sufficient here to describe a few experiments on this parallax which can be made with the Entoptiscope.[2]

[1] In this I have been aided by my assistant, Mr. Warwick, A.R.C.Sc., to whom I am also indebted for several of the drawings in this and the previous paper.

[2] A paper "On the Law of visible position in single and binocular vision,"

(*a*). Look through one eye-piece; bring a pencil-point as at *b*, fig. 8, to the very edge of the projected pupillary disc, looking directly at the pencil. Without moving the pencil or the head, turn the eye to the opposite edge *a* of the pupillary disc; the pupil will appear to have suddenly expanded to *b′*, as shown by the dotted lines; and the pencil will, therefore, be now seen well within the disc; but when again the eye turns to *b*, the disc resumes its first position on that side, and the side *a* correspondingly expands.

(*b*). Now shift the pencil outside the disc, between *b* and *b′*, as shown by the dot, so that it cannot be seen if directly searched for; when, however, the eye is turned away from it to *a*, instantly it reappears; this occurs equally well at either side of the disc, with either eye. This paradoxical effect of *seeing an object when you look away from it, and not seeing it when you look directly towards it*, is

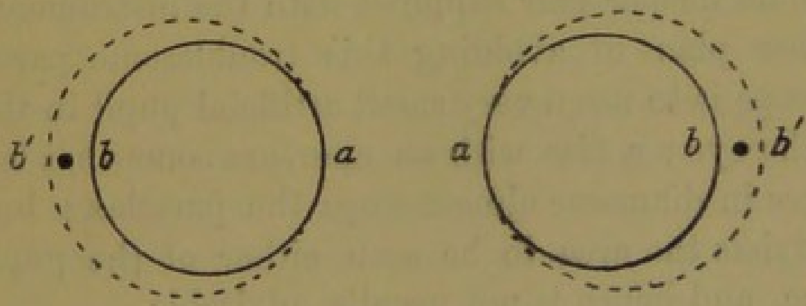

Fig. 8.

not due to the image falling on the blind spot, for it occurs, as I have said, at either side of the disc, or at any portion of the retina oblique to the axis of vision.[1]

By making pencil-marks at the limiting points at which the pencil is seen by direct and oblique vision, the magnitude and

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published by Sir David Brewster in the Trans. Roy. Soc. Edinb. for 1843, vol. xv., p. 349, contains the first reference I can find to ocular parallax, which Brewster appears to have observed in cases of oblique incidence in ordinary vision. Subsequently Listing investigated the matter, *Beitrag zur Physiologischen Optik*, 1845, pp. 14 *et seq.*, and gave the probable explanation (see next footnote).

[1] The *cause* of this ocular parallax I will discuss in a subsequent paper. Brewster assigns it to the fact that the eye is not a homogeneous refracting medium; Listing to the fact that the centre of rotation of the eyeball does not correspond to the optical centre or nodal point of the eye. Helmholtz (*Optique Physiologique*, p. 748) agrees with and develops Listing's view, but is unaware of Brewster's earlier discovery and explanation. None of those, nor any later authorities, however, appear to have noticed the remarkable effect of this parallax in entoptic observation with a stenopic screen.

angular value of the parallax can be easily determined. It is this ocular parallax which gives rise to the mysterious and elusive dilatation of the pupillary disc that so puzzles the observer when, in using the Entoptiscope, he begins to trace the outline with a pencil. By keeping the eye always fixed on the pencil-point, and not allowing it to be beguiled by a furtive wandering of the axis of vision, a perfect tracing can be made. Diminishing the angle subtended by the projected image—which can be done by increasing the distance between the pin-hole and the eye—lessens the parallax. For in the Entoptiscope the greater the magnification, the greater the ocular parallax; with distances of the pin-hole from the eye and to the stage respectively of 25 and 125 millimetres, or 1 to 5, an image is given of sufficient magnitude and having very little parallax. For this purpose the eye-cups are made detachable, and a second deeper pair supplied with the instrument.

Another plan of avoiding this troublesome parallax in the Entoptiscope is to use a very small artificial pupil in the eye-piece, close to the eye; a disc with an aperture somewhat less than two millimetres in diameter almost stops the parallax; but this very much restricts the area to be seen either of the pupil or of the crystalline, and hence is not usually advisable.

§ 9.

(5). Upon winking the eyelids, transverse striæ will be perceived on looking through the Entoptiscope, due probably to minute wrinkles in the epithelial layer of the cornea. If one eyelid be winked frequently, as happens in using a telescope or microscope for some time, striæ are formed which remain for some hours, and give rise to a marked defect in vision. The presence of tears also gives rise to long striæ from their prismatic action on the pencil of rays. Rubbing the cornea causes the roughening of the epithelial layer, which gives rise to a peculiar ribbed or mottled appearance in the field of view of the Entoptiscope, but this soon disappears. Dr. Thomas Young was, I find, the first to notice and depict this so long ago as 1801 (see footnote [1], next page). Helmholtz gives some excellent drawings of these entoptic appearances (*Optique Physiologique*, p. 208).

(6). But more important is the study of the structure of the crystalline lens as seen in the Entoptiscope. The observer will probably notice a star-like figure radiating from the centre of the field of view. This is due to slight differences in refractive power of the fibrous tissue separating the sectors into which the crystalline is known to be divided. This star-figure is sometimes bright, as shown in Plate IV., fig. 5, sometimes dark, the difference being due to the fact that the refraction of the fibres is in some eyes greater, and in some less, than that of the surrounding portion of the crystalline. In his wonderful paper on the "Mechanism of the Eye," published in the Philosophical Transactions upwards of a hundred years ago, Dr. Thomas Young gave a drawing of the radiating structure of the human crystalline, exhibiting ten main radiations, and finer striæ within.[1] These finer radiations are well seen in the crystalline as revealed by the Entoptiscope. Donders and Helmholtz both give several drawings of the lens seen by its entoptic image. Bright spots, due to higher refrangibility, are frequently seen on the crystalline and are shown in Plate IV., fig. 5; these are termed "pearl-spots," and, in some cases, similar dark spherules are seen, due to the lower refrangibility of their structure.[2]

The eminent oculist, Mr. J. Tweedy, President of the College of Surgeons, London, published in the *Lancet* for December, 1871, p. 776, drawings of the human crystalline, showing its stellate structure, which he was the first to observe in the eyes of several patients by means of intense oblique illumination. Mr. Tweedy was good enough to show me his original drawings which are more detailed than the published reproduction.

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[1] *On the Mechanism of the Eye*, by Thomas Young, M.D., F.R.S., Phil. Trans., 1801. This classical research was published when Young was only twenty-eight years old, and contains a number of remarkable discoveries, such as accommodation being due to change in curvature of the crystalline, &c., often attributed to later investigators. No one, however, appears to have noticed that Young was the first to discover entoptic vision. He gives excellent drawings (figs. 32 and 33 in his paper) of the radiating structure of the crystalline and the mottled surface of the cornea when rubbed, as seen when "a minute lucid point such as the image of a candle in a small concave speculum was held very near the eye."

[2] A magnifying glass is required to see them in Plate IV., fig. 5, which has been reduced from a drawing made by Donders.

Listing and subsequently Donders classified the various entoptic appearances seen in the crystalline and the anterior part of the eye. Excellent drawings of these are given by Donders, and more especially by Helmholtz.[1] But, as already remarked, it is surprising that none of these eminent men noticed the great value of entoptic observation in the case of cataract. I cannot lay claim to the first discovery of this, for, though it was independently observed by myself, Dr. Darier, of Paris, appears to have been the first to draw a cataract thus observed some ten years ago. In a paper he published in a French journal, Dr. Darier says he accidentally noticed an obscurity in one of his own eyes when he viewed a point of light; he was thus led to make an arrangement, consisting of a concave lens and a distant candle, for the better examination of his crystalline.[2] This arrangement he called an *autophakoscope*; unfortunately, he appears to be quite unaware of the literature or the theory of entoptic observation, and also of the generally accepted terminology; he gives, however, some drawings of what he observed, and is convinced of the value of the method in ophthalmology.

It does not, however, need any instrumental appliances to see one's own crystalline lens. Various simple methods of doing so were mentioned in Part I., § 1. One of the best and simplest is a point of light reflected from some portion of the polished rim of a pair of spectacles worn by the observer, especially when a bright source of light is behind the observer. The homocentric pencil of rays thus obtained enables entoptic phenomena to be well seen, so that if the observer has used the Entoptiscope, and is familiar with what he is to look for, he can readily see his own crystalline, any opacities within his eye, and the changes in the magnitude of his pupillary disc by merely looking at one of the brilliant spots of light reflected from the rim of his own spectacles.

(7). Reference has already been made in § 5 to the ease with which the Entoptiscope enables the *muscæ volitantes* to be seen and their position in the eyeball found. In this case No. 2 or No. 3 pin-

[1] See Donders, *Accommodation and Refraction of the Eye*, p. 200; Helmholtz, *Optique physiologique*, pp. 208 *et seq.*

[2] "De la possibilité de voir son propre crystallin," par M. le docteur Darier. *Annales d'Oculistique*, September, 1895, vol. cxiv., p. 198. See *Note* on p. 83.

hole aperture and the shortest eye-cups should be used, in order to give a large retinal illumination, and the pillar of the Entoptiscope should be fixed vertically, so that the eye looks directly downwards. The muscæ will now be seen nearly stationary, for being rather lighter than the vitreous humour they will slowly ascend, and thus their motion being in the line of sight their shadows will not be displaced, but become clearer as they approach the retina. Dr. Jago, in his "Entoptics," gives some careful drawings he made of different types of muscæ. Helmholtz, in his "Physiological Optics," also gives some excellent drawings of the muscæ, and divides them into four or five groups according to their appearance. More recent writers have also depicted and investigated the muscæ, so that it is needless to dwell further on this subject. In my own case, as I mentioned in Part I., footnote on p. 56, the muscæ have increased in number, size, and persistency since the development of cataract in my eyes, and are constantly seen when looked for in the right eye, where the cataract is more advanced.

(8). The Entoptiscope also enables the "light-sense" of an observer to be tested, and the threshold of visibility of each eye determined, *i.e.* the degree of illumination which forms the lowest limit of visibility—the *lux-liminal* point, it might be termed. For this purpose the smallest aperture may be used in the case of a normal eye, or larger, in persons suffering from cataract, and a small, steady source of light (such as a night-light) is shifted to different distances from the mirror of the instrument in a well-darkened room. The limiting distance is then measured, and, as the illumination of the ground-glass stage follows the law of inverse squares, the light threshold is at once found, relatively to some standard. The "adaptation-time," or rise of sensibility when in darkness, of the eye of the observer is thus also accurately found; further the visual acuity and colour-sense, under different degrees of illumination, can be conveniently examined in this way.

(9). As was explained in Part I., § 5, a minute object can be clearly seen when held close to the eye and viewed through a stenopic screen. Under such circumstances a highly magnified image of the object is perceived from the large visual angle subtended by the object, whilst the blurring of the image on the retina is prevented owing to the circles of diffusion being reduced to mere points. The Entoptiscope not only affords a most convenient way of exhibiting this magnification of a microscopic object without the aid of a microscope, but also enables the observer to make an accurate tracing of the magnified image of the object on the ground-glass stage. If the object be placed below the pin-hole, it does not appear inverted; if above, it does; see Part I., § 5, p. 53: the nearer the pin-hole aperture is to the eye, and the nearer the object is to the pin-hole, the greater the magnification. A brilliant source of light, the smallest aperture in the diaphragm, and the shortest eye-cups should be used. More light is obtained by using the clear-glass instead of the ground-glass stage. The microscopic object, liquid or solid, can be placed in the centre of the glass diaphragm of one of the eye-cups referred to in the next experiment (10).

Mr. E. M. Nelson, Past-President of the Royal Microscopical Society, informs me, as this paper is going to press, that some years ago he exhibited to that Society the hexagonal structure of a diatom, "Triceratinum," by means of its shadow on the retina, obtained by pin-hole illumination; the hexagons measured about $\frac{1}{2500}$th of an inch (0·01 mm.). It was found necessary to use a diminished image of a pin-hole in a card, obtained at the conjugate focus of a wide-angle lens of about half-an-inch focus. The hexagonal structure of the eye of a fly, $\frac{1}{800}$th inch, Mr. Nelson found quite easy to demonstrate to an observer in this way.

(10). As the refractive index of the cornea is nearly the same, and that of the aqueous humour the same, as water, by immersing the eyes in water, refraction by the crystalline alone becomes effective. This method was employed by Dr. Thomas Young to demonstrate that accommodation was effected by a change in curvature of the crystalline.[1] The experiment can easily be made with the Entoptiscope. The pillar of the instrument is clamped vertically, and an eye-cup, fitted with a glass diaphragm below, is placed in position. The cup is nearly filled with (not quite cold) water, and the eye immersed, so that the cornea is in contact with the water. Open the largest aperture (say 2 or 3 mm. diameter): note (*a*) the focal length of the convex glass lens

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[1] *On the Mechanism of the Eye.* Phil. Trans. for 1801, p. 23.

required to be held below the aperture in order to restore clear vision; the refraction by the cornea is thus seen to be far greater than that by the crystalline ($2\frac{1}{2}$ times); this is owing to the latter being immersed in media only slightly differing from itself in refractive power. (*b*) Keeping the selected convex lens before the aperture, note that accommodation still takes place. (*c*) Changing the aperture to the smallest size, note that clear vision is now restored without the use of any external glass lens.[1] (*d*) Note, also, that ocular parallax (§ 8) still remains, though the large corneal refraction is abolished.

Immersion of the cornea in water also enables the observer, if astigmatic, to note whether any residual astigmatism is due to the crystalline lens, or whether any power of astigmatic accommodation by the lens can take place, as some think does occur.

Doubtless other applications of the Entoptiscope will occur to the ophthalmologist. One of the simplest is its use in testing astigmatism by the appearance presented by the luminous point, when the eye of the observer is gradually removed from, say, 3 to 30 inches. (See Part III. (2).) The observer will notice in this experiment how the slightest pressure on the cornea completely alters the appearance of the elliptical diffusion-spot, or other image, which the luminous point assumes in astigmatic eyes. Tscherning goes so far as to say there is no optic defect which is not shown by means of the figures presented by a luminous point.

Note.—I have to thank my friend Dr. C. E. FitzGerald for pointing out to me that Snellen and Landolt, in their classical *Handbuch der Augenheilkunde* published in 1874, vol. 3, p. 178, were the first to speak of the great importance of entoptic examination in observing the development of cataract. They add the proviso "if the patient is sufficiently intelligent." It is true all entoptic examination requires a certain degree of intelligence on the part of the observer; but I have found that a very little instruction enables any one, not hopelessly stupid, to use the Entoptiscope quite successfully.

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[1] For my own part I cannot understand why evolutionary processes did not lead to increased sensitiveness of the retina and a pin-hole eye like that of the nautilus, with a projecting cover. Such an eye would have many advantages over our own; no accommodation and no spectacles would be required; no spherical or chromatic aberration would exist, and no cataract would occur. And how did the lens originate? Only in its perfect state would it be of use; and this, we assume, could only have been the result of imperfect stages which would be useless.

PART III.—OTHER ENTOPTIC PHENOMENA.

(1). When the point of light is at a considerable distance—a stenopic screen 4 or 5 feet away, with a bright light behind, or the incandescent gas-mantle of a street lamp over 40 feet away, does very well—beautiful diffraction phenomena will be seen ; lines of light, with spectrum tints, are seen radiating in all directions from the common centre. This, sometimes called the ciliary corona, is due to the stellate fibrous structure of the crystalline lens ; and the radiations I find become very brilliant and conspicuous when the lens has the numerous small opacities which occur in the growth of cataract. A rainbow-coloured ring is often seen (though I have not noticed it) surrounding these radiations, probably due to the epithelial cells of the cornea or the fibres of the crystalline. A few grains of hycopodium dust, or other powder, scattered on a glass plate, and held between the eye and a distant point of light, give rise to exactly similar diffraction phenomena.

(2). If the stenopic screen, or other brilliant point of light, be placed at different distances from the eye, any astigmatism in the eye can be readily seen, and its meridian accurately determined by the appearances presented. Here, again, Dr. Thomas Young was the first to employ this method of observation ; and in his paper of 1801—to which reference has already been made—diagrams are given by Young, showing the various appearances of a luminous point at different distances from the eye. Tscherning, in his " Physiological Optics " (English translation, pp. 138-144), gives a series of drawings of the forms presented by a luminous point at varying distances from the eye.

I find that a narrow illuminated slit, capable of rotation through 180°, is far better for judging the amount and the exact meridian of astigmatism. Such a slit when slowly rotated from a vertical to a horizontal axis on either side also forms an extremely delicate method of judging whether spectacles to correct astigmatism have been accurately made or not. If there be any inaccuracy in the meridian or the curvature of the glasses, the slit will, in some position, appear with a faint duplicate image or ghost upon rotation.

(3). There are several other well-known entoptic phenomena which do not require the aid of the Entoptiscope or a stenopic screen for their perception. Such, for example, are the so-called Purkinje's figures: these are the shadows of the capillaries and minute vessels of the retina, which can be seen ramifying in all directions when a candle is moved to and fro on one side of, and a little below, the eye, the observer being in a darkened room, and looking straight in front; or they may be seen by moving a perforated screen to and fro in front of a lamp, or a pin-hole aperture moved to and fro when the eye is directed to a bright sky; still more easily and vividly can they be seen when a very bright spot of light is allowed to fall on the sclerotic coat of the eye, and in this case the minute detail of the arborescent form of the vessels is well seen. In any of these ways oblique illumination is obtained, and retinal sensitiveness increased, by the successive moving of the shadow through the motion of the light or of the head.[1]

(4). When the eye is directed to a bright sky or cloud, and a cobalt-blue glass or gelatine film of the right tint suddenly interposed, the *macula lutea*, or yellow spot of the eye, can be seen as a small dark patch in the field of view. The best colour to interpose is a solution of the blue oxalate of chromium and potassium; but I have found a gelatine film, tinted a purplish blue, do very well. The success of the experiment depends on the eye not being focussed on the interposed screen, but kept fixed on the distant cloud. With a stenopic screen kept in to-and-fro motion, and the tinted gelatine interposed, the actual structure of the yellow spot can be seen.

(5). Several observers have noticed that when the opened fingers are moved to and fro in front of the eye, or, still better, the above coloured screen interposed, the eye being directed to a bright cloud, a remarkable movement like the circulation of the blood is perceived in the vessels of the retina. Vierordt, in 1856, first drew attention to this. Prof. Ogden Rood independently noticed it, and published an interesting paper on the

[1] Writers on physiological optics appear to have overlooked the fact that Sir C. Wheatstone gave the first explanation of this phenomenon (*vide* British Association Report, 1832, p. 551).

subject in 1860.[1] Prof. Rood also detected the movement of small bodies which he took for blood-corpuscles, but their size, estimated from their projected shadows, was about double that of blood-corpuscles.

It is quite easy to see this phenomenon if a bright sunlit sky be looked at through a cobalt-blue glass held close to the eye. A rapid succession of bright specks like minute fire-flies are seen darting swiftly onward in numerous broken curved paths of short radius. I hope shortly to publish a note giving further particulars and the actual dimensions of these corpuscles.

Other American observers, Prof. Rogers and Dr. Reuben, in 1861, also drew attention to these streams of particles, and attributed them to moving blood-corpuscles. Helmholtz, who repeated the experiment, states that he could see the phenomenon very well with his right eye, a little to the left of the point of fixation. He came to the conclusion that the circulation of the blood and groups of corpuscles are really thus entoptically seen; but only when small obstacles in the retinal circulation occur, thus a local and temporary stoppage in the circulation takes place. An agglomeration of blood-corpuscles and a variable velocity in the flow of blood through the smaller capillaries are thus produced, which render the phenomenon visible.[2] The fact has hitherto been overlooked that Dr. Thomas Young noticed this as long ago as 1793. He found that by prolonged pressure on the sclerotic and interrupted pressure on the cornea, temporary stoppage of the circulation in the retinal vessels is produced; and the sudden return of the blood enables the branching capillaries and also the flow of the blood to be perceived.[3]

(6). It is well known that mechanical and electric stimulation of the retina give rise to luminous appearances to which the name of *phosphenes* has been given. Pressure on any small part of the sclerotic is transmitted to the retina, and causes a bright phosphene to be projected in the opposite direction to the pressure. Young describes and explains this phenomenon; and Helmholtz and

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[1] See American Journal of Science (Silliman's Journal), vol. xxx., Sept. 1860; also a second paper on the subject by Prof. Rood in vol. xxxi.

[2] Helmholtz, *Optique Physiologique*, pp. 221 *et seq.*

[3] Philosophical Transactions, 1793, p. 160.

others have discussed the subject fully.[1] The experiment is best made in a darkened room, and is readily explicable from the law that the stimulation in any way of a nerve-fibre excites only the sensation peculiar to that special group of nerves.

This, however, is to some extent a subjective phenomenon; and into purely subjective optical phenomena, such as the effects resulting from retinal fatigue, after-images, &c., I do not propose to enter.

(7). Microscopists who have worked with high magnifying powers are aware that, with excessive magnification, a peculiar spotty appearance is produced in the field. This is due to the fact that, as the magnification increases, the image of the objective, from which proceeds the light that enters the eye, becomes smaller and smaller until it is practically a luminous point. Thus a homocentric pencil of rays enters the eye; and the shadows of any dust on the eye-piece of the microscope, or of any obscurities on or within the eye, are thrown upon the retina along with the image of the microscopic object. Delicate microscopic details thus become indistinct owing to the fact that the very conditions which create high-power microscopy also create the conditions of entoptic vision. Helmholtz was the first to point this out in his paper on the "Theoretical Limits of resolving Power in the Microscope."[2] The difficulty appeared to be insurmountable until Mr. J. W. Gordon entirely overcame it by receiving the luminous point of the image of the objective carrying with it the image of the microscopic object on a little ground-glass screen. This, by scattering the light, of course, destroys the homocentric nature of the pencil, and thus gets rid of the entoptic shadows. But the magnified grain of the ground-glass screen now becomes a serious objection; this, however, Mr. Gordon entirely gets rid of by causing the little screen to be kept in rapid eccentric motion by a small electric motor. Under these circumstances eye-observation

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[1] *Optique Physiologique*, pp. 266–280. See also *Essai sur les phosphenes*, par Dr. Serre. Paris, 1853, &c.

[2] *Die theoretische Grenze für die Leistungsfähigkeit der Mikroscope*, von H. Helmholtz, Poggendorff's Annalen, 1874, p. 557. This important paper has been translated by Dr. Fripp, and is published in the Monthly Microscopical Journal, N.S., vol. xvi., p. 15, and in the Bristol Naturalists' Society Proceedings, N.S., vol. i., part 3.

or micro-photographs of objects magnified 7000 diameters exhibit a wonderful clearness and sharpness of definition, as was shown in Mr. Gordon's lecture on the subject at the Royal Institution.[1]

(8). The so-called Haidinger's brushes may be mentioned in concluding the summary of these entoptic phenomena. These are seen by some when the sky, or any brightly illuminated white surface, is viewed through a Nicol's prism. A pair of faint yellow tufts or sectors, shaped something like an hour-glass, is seen in the plane of polarization; and, at right angles, the space is filled with a faint blue light. These coloured sectors rotate as the Nicol is turned, showing that the eye can act as an analyser to polarized light. Jamin, Brewster, Helmholtz, and others have suggested various explanations of this phenomenon, which probably depends on a slightly polarizing structure possessed by the cornea or the *fovea centralis* of the eye.[2]

I cannot conclude this paper without adding my humble tribute of admiration to the amazing genius and almost miraculous range of knowledge possessed by that great Englishman, Dr. Thomas Young, the extent and value of whose discoveries in vision are not even now adequately recognised, though, from the first, Continental physicists and ophthalmologists have done him greater honour than his own countrymen.

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[1] *Vide* Journal of the Royal Microscopical Society, 1903, pp. 400 *et seq*; also Proceedings of the Royal Institution, February 17, 1905.

[2] *Vide* Brewster's *Optics*, pp. 245 *et seq.*; Helmholtz, *Optique Physiologique*, pp. 552 *et seq.*; G. G. Stokes, Brit. Assoc. Report, 1850, p. 20. Drawings of Haidinger's tufts and the exact measurement of the retinal area they cover, as seen by the author and by one of his senior students, Mr. Ledwidge, will be published shortly, as some light is thus thrown on the seat of this obscure ocular phenomenon.

EXPLANATION OF PLATE III.

PLATE III.

Fig.

1. Experimental form of Entoptiscope. Scale, one-sixth.

2. Entoptiscope for ophthalmic use or research. Scale, one-fourth.
   Vide page 64.

FIG. 1.

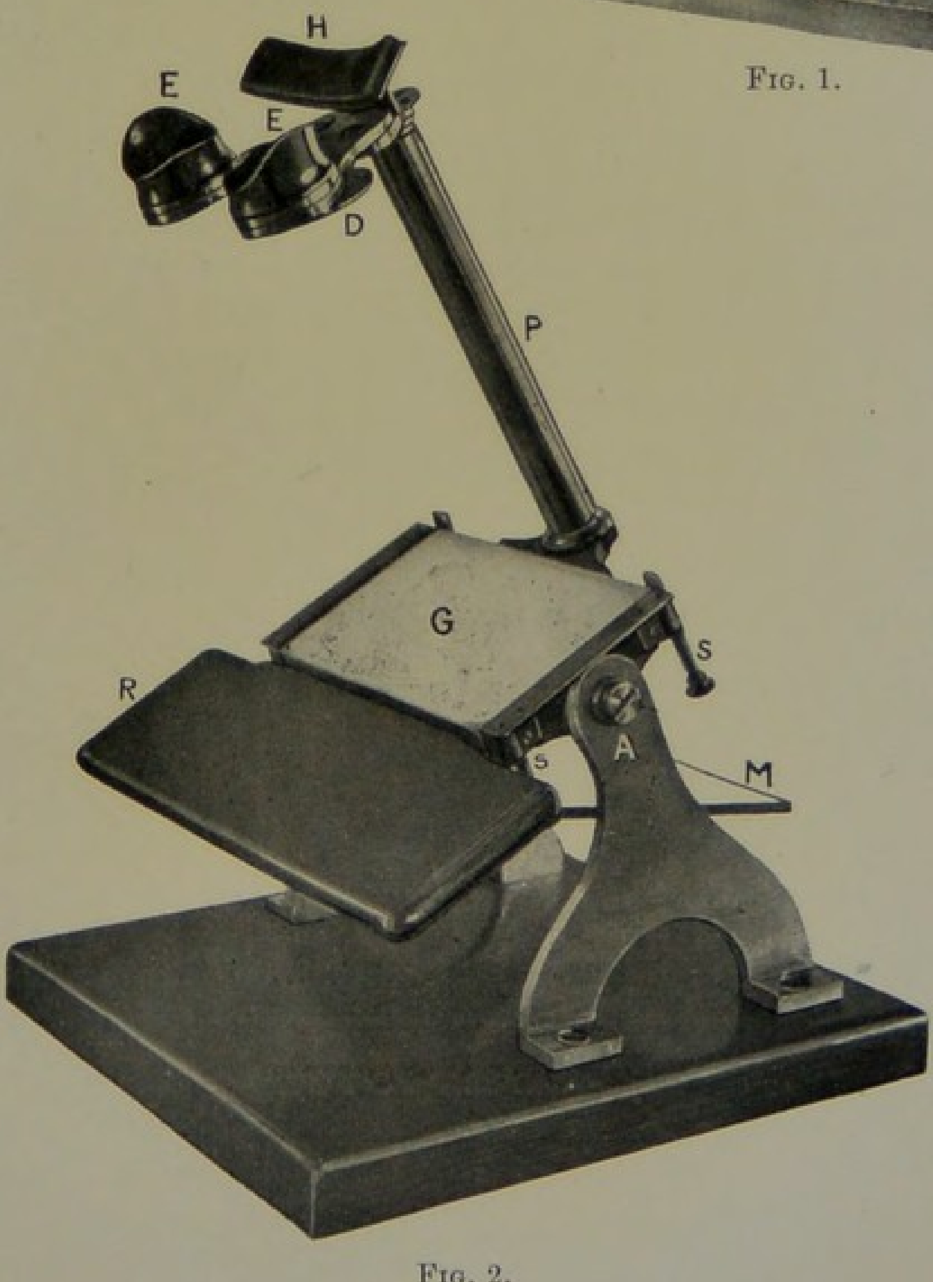


FIG. 2.

ENTOPTISCOPE.

EXPLANATION OF PLATE VI.

PLATE IV.

Fig.

1. Pupillary disc and obscurities in crystalline lens of the author's left (L.) and right (R.) eyes, as seen and delineated by the author with the Entoptiscope, showing growth of cataract in both eyes. The pupil and obscurities are magnified 7 diameters.

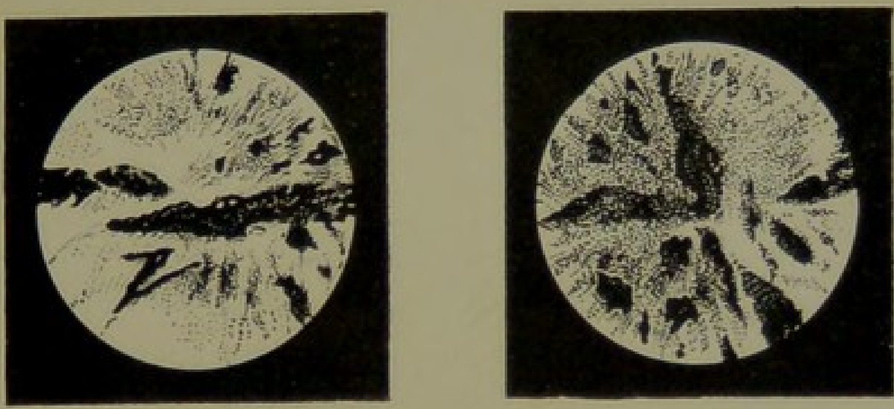
3. Drawing of the obscurities in the author's eyes as seen by Dr. C. Fitzgerald, of Dublin, by means of the ophthalmoscope, about the same date as the drawing in fig. 1.

2. The same inverted both laterally and vertically to compare with fig. 1.

4. Detailed drawing of the obscurities in the author's right eye, as seen by Dr. Ettles, of London, by means of the ophthalmoscope, for comparison with R., fig. 3.

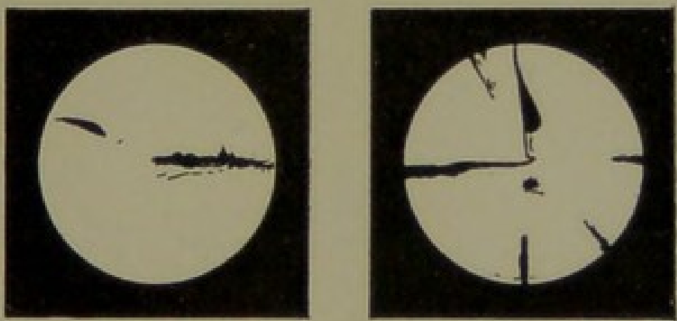
5. Entoptic view of his right crystalline lens made by Donders, the eye under a mydriatic. The normal stellate structure of the lens is here shown; most persons see in the Entoptiscope the bright star, sometimes with branching lines, indicating the structure of their crystalline.

Fig. 1.



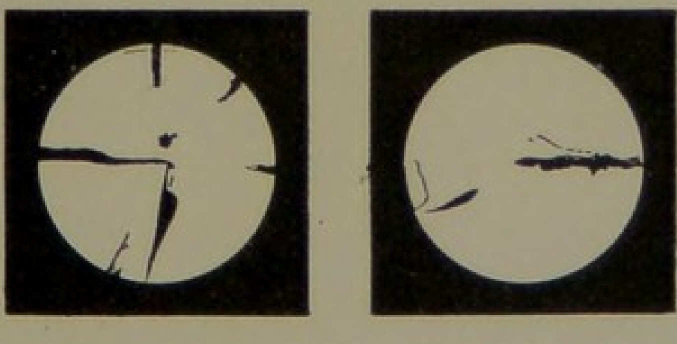
L R.

Fig. 2.



L. R.

Fig. 3.



R. L.

Fig. 4.

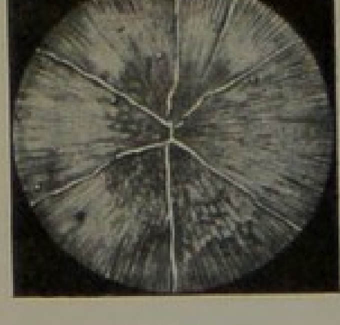


Fig. 5.