CHAPTER VIII.

ASTIGMATISM.

We have seen that the anomalies of refraction resolve themselves into two, viz., myopia and hypermetropia. But the state of refraction may vary in the different meridians of the same eye; thus, it may be emmetropic in the vertical meridian, but myopic or hypermetropic in the horizontal, or *vice versâ*. Or differences in the degree and even in the form of emmetropia may exist in the various meridians. This asymmetry has been termed astigmatism (*α*, privative, and *στιγμα*, a point), which signifies that rays emanating from a point are not re-united at a point. This peculiar defect* was first observed by Thomas Young (1793), who considered it due to some inequality in the structure of the lens, whereas Wharton Jones thought it was situated in the cornea. Donders has shown that it is of frequent occurrence, and

* For a most interesting historical account of this subject, see Donders' work, p. 539.

that many cases of congenital amblyopia are due to it, and may be cured by suitable cylindrical glasses.

But even in the normal eye the cornea does not refract equally in all its meridians, for the focal distance of the dioptric system is generally shorter in the vertical meridian than in the horizontal. On this account, fine vertical lines can be seen up to a further distance than horizontal lines, but the latter can be seen closer than the vertical lines. For this experiment horizontal and vertical lines may be drawn upon a page, or Von Graefe's wire optometer may be used.

If the stripes or lines are arranged crosswise, we are unable to distinguish both the horizontal and vertical lines with equal clearness and distinctness at one and the same distance; thus, if we can see the vertical line clearly and sharply defined, we must approach the horizontal line nearer to the eye, in order to gain an equally distinct image of it, and *vice versâ*. These facts prove that the vertical meridian has a shorter focal distance than the horizontal, and for this reason horizontal lines are seen distinctly at a shorter distance than vertical ones. For as the rays which are refracted in the vertical meridian are united in a point sooner than those in the horizontal plane, the latter give rise to circles of diffusion upon the retina in the form of small horizontal lines which do not confuse the images of horizontal lines, but interfere with those of vertical lines.

As it is of much consequence in the study of astigmatism that the reader should thoroughly understand these preliminary facts, I give the following extract and explanatory woodcuts from Donders' work. After speaking of the fact that a vertical stripe can be seen further off, and a horizontal stripe at a closer distance, he continues :—"These experiments prove that the points of the refracting meridians are not symmetrically arranged around one axis. The asymmetry is of such a nature that the focal distance is shorter in the vertical meridian than in the horizontal. In order, namely, to see a vertical stripe acutely, the rays, which in a horizontal plane diverge from each point of the line, must be brought to a focus upon the retina; it is not necessary that those diverging in a vertical plane should also previously converge into one point, as the diffusion-images still existing in a vertical direction cover one another on the vertical stripe. On the other hand, in order to see a horizontal stripe acutely, it is necessary only that the rays of light diverging in a vertical plane should unite

in one point upon the retina. Now horizontal lines are acutely seen, as I have remarked, at a shorter distance than vertical ones, consequently rays situated in a vertical plane, which are refracted in the vertical meridian of the eye, are more speedily brought to a focus than those of equal divergence situated in a horizontal plane; and the vertical meridian, therefore, has a shorter focal distance than the horizontal.

"The correctness of this view appears further from the form of the diffusion-images of a point of light. In accurate accommodation the diffusion-spot is very small, and nearly round, while a nearer point appears extended in breadth, and a more remote one seems to be extended in height. The signification of this phenomenon must be clearly understood, and appears therefore, to demand more particular explanation.

"Let us suppose the total deviation of light in the eye to be produced by a single convex refracting surface, with the shortest radius of curvature in the vertical, and the longest in the horizontal meridian. These two are then the principal meridians. Through a central round opening (Fig. 26, *v v h h*) let a cone of rays, proceeding from a point situated in the prolongation of the axis of vision, fall upon this surface; of this cone let us consider only the rays situated in the vertical plane *v v*, and the rays situated in the horizontal plane *h h*, whereof respectively the points *v v* and *h h* are the most external. After the refraction both approach the visual axis (which perpendicular to the plane of the drawing passes through *a*), *v v* does so, however, more rapidly than *h h*. Before union they therefore lie in the ellipse *A*, as in Fig. 27, and where *v v* meet in one point *B*, *h h* have not yet come to a focus. Thereupon we now find in succession *v v* already intersected, *h h* approached to one another, *C*, *D*, *E*; further, *h h* united in one point, and *v v* after intersection more

Fig. 26.

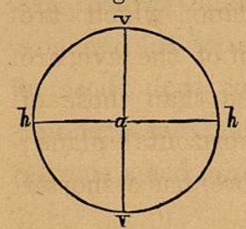
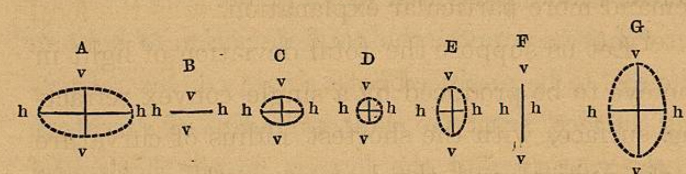


Fig. 27.

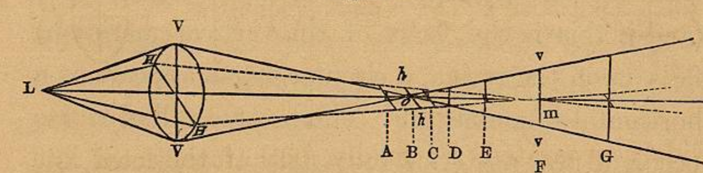


widely separated, *F*; finally, both intersected, *G*. The focus of *v v* therefore lies most anteriorly, that of *h h* most posteriorly in the axis. The space between these two points where rays

of different meridians intersect, may be called the focal interval (*intervalle focale* or Brennstrecke of Sturm). From the above figures it is now evident what successive forms the section of the cone of light will exhibit. In the middle of the focal interval, *D*, it will be nearly round, and anteriorly through oblate ellipses, *C*, with increasing eccentricity, it will pass into a horizontal line *B*; posteriorly through prolate ellipses, *E*, it will come to form a vertical line, *F*, while before the focal interval a larger oblate ellipse, *A*, and behind it a larger prolate ellipse, *G*, will be found."

The position of these figures with regard to the focal interval is shown in Fig. 28. In the cone of light emanating from *L* are depicted the rays which impinge upon the vertical meridian *V V* and upon the horizontal meridian *H H*. The former are united in *o*, the latter in *m*, so that *o m* is the focal interval.

Fig. 28.



In Fig. 28, the letters *A*, *B*, *C*, *D*, *E*, *F*, and *G* correspond to the same letters in Fig. 27. The rays which lie in the plane of the vertical meridian

$V\,V$ (in Fig. 28), are brought to a focus at o, where the rays which lie in the plane of the horizontal meridian $H\,H$, are not yet united, but form the horizontal line $h\ h$ (the *anterior* focal line). The rays $H\,H$, are united further back at m, where the vertical rays form the vertical line $v\ v$ (the *posterior* focal line). The distance between these two focal lines forms the focal interval. The anterior focal line $h\ h$, corresponds to the position of the meridian of the lowest refractive power, whereas the posterior focal line $v\ v$, to that of the meridian of highest refraction. Generally the astigmatic patient endeavours unconsciously so to regulate his accommodation that the middle portion of the focal interval falls upon the retina; in this way only a small round circle of diffusion D (Fig. 27), is formed, and the object is more distinctly seen than it would be at the anterior or posterior extremity of the focal interval. In case that the anterior extremity of the focal interval (and if this is the focus of the vertical meridian) falls upon the retina, a circular flame appears as a horizontal luminous line. The reverse will of course occur, if the posterior extremity of the focal line (if this corresponds to the focus of the horizontal meridian) falls upon the retina, for then the flame will appear as a vertical luminous line. Hence,

horizontal and vertical stripes will be sharply and distinctly seen when the diffusion-images of all the points of the stripe form respectively horizontal and vertical lines, which cover one another in the stripe; and this will be the case when the beginning and the end of the focal interval correspond respectively to the percipient surface of the retina (Donders).

Although we have hitherto assumed that the principal axes of curvature correspond with the vertical and horizontal meridians, it must be mentioned that they may deviate considerably from these. Also, that instead of the minimum of curvature corresponding with the horizontal meridian, and the maximum with the vertical, the reverse may even obtain, and the maximum curvature coincide with the horizontal meridian.

The aberration which is due to a difference in the focal distance of the two principal meridians, is called *regular* astigmatism, and depends upon the curvature of the cornea. Whereas the aberration which is due to a difference in the refraction in one and the same meridian, is called *irregular* astigmatism, and is generally caused by a peculiarity in the structure of the crystalline lens, and cannot be corrected by cylindrical lenses. It often gives rise to monocular polyopia. The two forms sometimes co-exist. The degree of regular astigmatism met with in normal eyes is generally too slight to cause any impairment of vision; but when it is more considerable, the sight is indistinct. This amblyopia is due to circles of diffusion being formed upon the retina, which cross and overlap each other. The greater the difference in the refraction of the principal meridians, the more considerable will be the circles of diffusion and consequent indistinctness of vision. If the astigmatism is at all high in degree, the acuteness of vision is much impaired, both for near and distant objects. If the eye is myopic or hypermetropic, we find that we cannot with any spherical lens produce a very decided improvement, or raise the acuteness of vision to the normal standard.

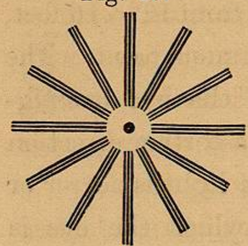
The diagnosis of astigmatism may generally be made without much difficulty; but it is necessary to follow a settled line of examination, otherwise the beginner will fall into great confusion, and waste a large amount of time. Numerous modes of discovering the presence of astigmatism, and of estimating its degree, are in use; but the following are the simplest and most practical:—

In the first place, we must carefully examine the acuteness of vision, and ascertain which number of Snellen's types the patient can see at a distance

of 20′. If the acuteness of vision is below the normal standard (if he cannot read No. xx), we must try whether it can be raised to this by concave or convex spherical lenses. If we fail in doing so, we must suspect the presence of astigmatism, and next proceed to determine the situation of the two principal meridians (*i.e.*, the maximum and minimum of curvature). This may be done by directing the patient to look at a small, distant point of light (varying from two to four millimètres in diameter, and seen through a small opening in a large black screen). The patient should be placed at a distance of from 12 to 16 feet, and directed to look at the luminous point. The latter will not appear round if the eye is astigmatic, but will be elongated in a certain direction according to the fact whether the light is nearer or further off than the point for which the eye is accommodated. Thus, if the maximum of curvature coincides with the vertical meridian, the luminous line will be horizontal if the eye is accommodated for a further point, and vertical if it is adjusted for a nearer point. Weak concave and convex lenses are then placed alternately before the eye (the latter being thus changed into a myopic or hypermetropic one), and the anterior and posterior diffusion line brought alternately upon the retina. The direction of this line will depend of course upon the direction of the principal meridian.

A better test object is, however, formed by a series of straight lines, which cross each other in the centre of a circle. For this purpose I have found Dr. Green's* test objects the best, and use them in preference to any others. He employs three figures, which can be arranged in such a manner as to amplify and check the results obtained. I have, however, found that one of the diagrams (Fig. 29) is sufficient. It consists of a circle, traversed by a set of twelve triple lines, corresponding to the figures on a watch dial; the figures being placed at the extremity of the sets of lines, as in Javal's optometer (Fig. 30). Each line is equal in thickness to the lines employed by Snellen in the construction of No. XX of his test types, and is designed to be distinctly seen at a distance of about 20′. The circle is about $12\frac{1}{2}''$ in diameter.

Fig. 29.



This test circle is to be placed at a distance of

* Vide Dr. Green's paper on "The Detection and Measurement of Astigmatism," in the American Journal of Medical Sciences, January, 1867.

20′, and if the patient can see all the lines distinctly and sharply defined (any existing myopia or hypermetropia being corrected by suitable spherical lenses), he is not astigmatic. But if only the line in one meridian appears clear and sharply defined, whilst the others are indistinct, the presence of astigmatism is proved, and the direction of the distinct line corresponds to the meridian of the highest refraction. If we now wish to discover the degree and nature of the astigmatism, and are only supplied with spherical lenses, we try the weakest concave or the strongest convex lens which, placed in a stenopaic apparatus,* enables the patient to see all the radiating lines with equal distinctness. If a concave lens is required, it is a case of myopic astigmatism, whereas, it is hypermetropic, if a convex lens is required.

If we possess a trial case of cylindrical lenses, the weakest concave or strongest convex cylindrical glass should be found, which renders all the

* The stenopaic apparatus employed for this purpose, consists of a small cylinder open at one end, so as to fit closely to the eye, the other end being furnished with a small slit, which can be readily narrowed and widened. The effect of this slit (which should be set to a width of about $1\frac{1}{2}$ or 2 millimètres), is, of course, to admit only rays in a certain direction, excluding all the others. The box of the cylinder should be made to unscrew, in order that spherical lenses may be placed in it.

radiating lines quite distinct and clearly defined. When we have found the lens which corrects the astigmatism, the patient's sight should next be tried with Snellen's test types, in order that we may accurately ascertain the degree of improvement of sight produced by it. In cases of hypermetropia, the effort of accommodation often conceals a considerable portion of the astigmatism, and may thus greatly mislead us as to its actual degree. The examination is therefore much facilitated, if the accommodation is first paralysed by atropine.

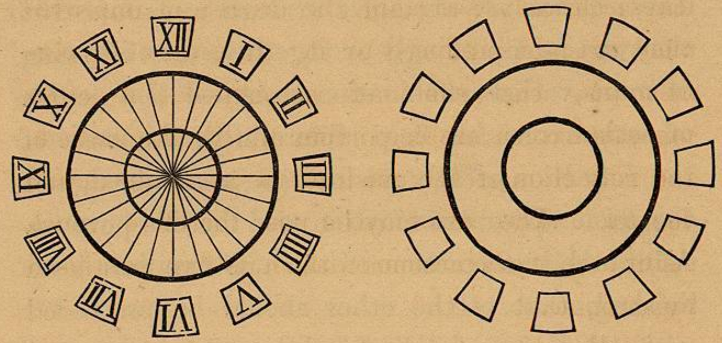
In the above modes of examination each eye is to be tried separately.

Javal has devised the following ingenious instrument for the rapid determination and correction of astigmatism.* It is in the form of a stereoscope mounted upon a stand, and is supplied with convex spherical lenses of about 5″ focus. In high degrees of hypermetropia a lens of 3″ should be employed, whereas, in high degrees of myopia we may omit the convex lenses, or substitute concave ones. Two circles are drawn side by side upon a piece of cardboard, just as in a stereoscopic plate, being at such a distance from

* "Klinische Monatsblätter für Augenheilkunde," 1865, 336. This optometer of Javal's is made by Nachet, 17, Rue St. Séverin, Paris.

each other, that the centre of each circle corresponds to the distance between the two eyes. In the one figure (Fig. 30) are drawn a series of

Fig. 30.



radiating lines, and at their extremity are placed the figures I to XII, arranged like the figures on a watch dial. If the visual lines are parallel, the two circles are fused into one image, in the centre of which lie the radiating stripes, and at the circumference the figures. On account of the parallelism of the eyes, the latter are accommodated for their far point. By means of a screw the circles are now removed further and further from the eyes, until all the radiating lines except one becomes indistinct. The direction of this one is easily identified by the figures, and its direction corresponds to the diameter of the highest refraction. Behind the ocular lens of the one eye is