arranged upon a pivot, a series of concave cylindrical lenses, so that they can be rapidly rotated in front of the eye, until the lens is found which corrects the astigmatism and indicates its degree. These lenses are arranged in such a manner that they can be used singly or together, thus allowing of most varied combinations. After the degree of astigmatism has been determined, the state of the refraction of the eye must be ascertained, and the same apparatus may be used for this purpose. After the examination of the one eye has been finished, that of the other should be proceeded with, the series of cylindrical lenses being turned over to the other side. The principal objection to this instrument is, that on account of the patient being conscious of the close proximity of the object, he does not relax his accommodation completely, and is hence not in reality accommodated for his far point, and we may, therefore, fall into error as to the degree of his astigmatism. This error is to a great extent avoided if we test him with the radiating lines at a distance, and completely so, if in a case of hypermetropia the accommodation is paralysed.

Donders has distinguished three forms of astigmatism, viz.: I. Simple astigmatism; II. Compound astigmatism; III. Mixed astigmatism.



I. Simple Astigmatism.—The state of refraction of the one principal meridian is emmetropic, whereas that of the other is either myopic or hypermetropic. If we, in such a case, turn the slit of the stenopaic apparatus in the direction of the normal meridian, the acuteness of vision will be perfect, whereas, a certain concave or convex spherical lens will be required if the slit is turned in the direction of the other meridian.

Simple astigmatism is divided into:—1. Simple myopic astigmatism (Am), in which myopia exists in the one principal meridian, and emmetropia in the other. 2. Simple hypermetropic astigmatism (Ah).—In this there is hypermetropia in the one principal meridian, and emmetropia in the other.

II. Compound Astigmatism.—In this form, myopia or hypermetropia exists in both principal meridians, but it varies in degree. If the stenopaic slit be used in such cases, it will be found that a different concave or convex lens will be required in each of the principal meridians, in order to render the acuteness of vision normal.

We must here also distinguish two forms:—1. Compound Myopic Astigmatism (M + Am).—Myopia exists in both principal meridians. 2. Compound Hypermetropic Astigmatism (H + Ah).—Hypermetropia exists in both principal meridians.

III. Mixed Astigmatism.—This is a rare form, in which the one principal meridian is myopic, the other hypermetropic. We must here also distinguish :—1. Mixed astigmatism, with predominant myopia (Amh). 2. Mixed astigmatism, with predominant hypermetropia (Ahm).

Knapp and Schweigger have pointed out that the ophthalmoscope also furnishes us with a valuable and easy diagnostic symptom of regular astigmatism. On examining in the direct method an eye affected with astigmatism, it will be found that the optic disc, instead of being round, appears elongated in one direction, and that the latter corresponds exactly to the meridian of greatest curvature. For as the focal distance is shorter in this meridian than in the other, the image must also be more magnified in this direction. If we now examine the same eye in the inverted image, the optic disc will appear elongated in the opposite direction; thus, if in the erect image the disc appears oval in the vertical direction, in the inverted, it will appear oval in the horizontal direction, and this at once proves the existence of regular astigmatism, and shows also that the vertical meridian is of greater curvature, and, consequently, has a less focal distance, than the horizontal. The comparative examination in the



erect and inverted image therefore furnishes us with a most valuable aid to diagnosis, which will often spare us the necessity of a long and intricate subjective examination.

In examining in the erect image, an eye affected with hypermetropic astigmatism, it will also be found that in order to see with equal distinctness the vessels running in different directions, the state of accommodation of the observer's eye has to undergo a change.

Mr. Bowman "has been sometimes led to the discovery of regular astigmatism of the cornea, and the direction of the chief meridians by using the mirror of the ophthalmoscope much in the same way as for slight degrees of conical cornea. The observation is more easy if the optic disc is in the line of sight and the pupil large. The mirror is to be held at two feet distance, and its inclination rapidly varied, so as to throw the light on the eye at small angles to the perpendicular, and from opposite sides in succession, in successive meridians. The area of the pupil then exhibits a somewhat linear shadow in some meridians rather than in others."*

Astigmatism is generally congenital and often hereditary; it may, however, also be acquired.

* Donders, p. 490.

The congenital astigmatism is mostly regular and dependent upon asymmetry of the cornea. In the majority of cases it is present in both eyes, although perhaps in varying degree. Donders has found that abnormal astigmatism occurs far more frequently in hypermetropic eyes than others; indeed, he even thinks that out of six hypermetropic eyes one suffers from abnormal astigmatism. The amblyopia which often exists in hypermetropia, and which cannot be remedied by spherical convex lenses, is mostly due to astigmatism. We often find that persons unconsciously correct a certain amount of astigmatism by holding their head on one side, and thus looking slantingly through their spectacles.

Acquired astigmatism is mostly caused by inflammatory changes in the cornea, which lead to consecutive flattening of the cornea, and leave behind them opacities and cicatrices; it may also be caused by irregularity in the apposition of the edges of the incision after the operation of extraction of cataract. We occasionally find that if iridectomy or iridodesis is performed in cases of opacity of the cornea, a considerable degree of amblyopia persists after the operation, although the pupil is now brought opposite to a transparent portion of the cornea. On examination, we then



find that in many of these cases this weakness of sight is due to astigmatism, and that vision is greatly improved by a cylindrical lens. Acquired astigmatism may also be caused by dislocation of the crystalline lens, more particularly if it is obliquely displaced in the area of the pupil.

The best examples of pure, regular astigmatism are furnished by successful cataract operations, for then any irregular astigmatism which may have been caused by the lens, will, of course, have been removed.

The disturbance of vision produced by even a slight degree of astigmatism is often very great and annoying, as the form and shape of minute objects (such as small letters) are so changed, that they cannot be seen with distinctness, but look blurred and confused. This is due to the fact that certain portions of a letter are yet quite distinct, whilst others are faint or unapparent. Thus the vertical lines of the letter H may appear quite dark and clear, whilst the horizontal connecting line is almost invisible. This also gives a peculiar tremulousness and uncertainty to the outline of the object. On account of the co-existence of irregular astigmatism, the patient may also be affected with monocular diplopia or polyopia.

Regular astigmatism may be remedied by the use of cylindrical lenses, which enable us to correct the anomaly of refraction in each of the principal meridians.

A cylindrical lens is the segment of a cylinder, and refracts those rays of light the strongest which strike it in a plane at right angles to the axis of cylindrical curvature; whereas the rays which pass through its axis suffer no deviation at all. In this, therefore, the cylindrical lens differs from the spherical, which refracts the rays in all planes of the segment.

Now, if in a case of simple astigmatism the one principal meridian is normal, so that rays passing through it are united exactly upon the retina, and the other principal meridian is myopic or hypermetropic, and the rays passing through it are brought to a focus before or behind the retina, we should correct this anomaly of refraction by means of a cylindrical lens whose axis corresponds to the normal meridian. The effect of this would be that the rays which pass through its axis would undergo no refraction, whereas those that pass in a plane at right angles to the axis would undergo the necessary refraction, and thus neutralize the anomaly which obtains in this meridian.

A convex cylindrical lens should be placed in



such a direction that its axis lies in the plane of the highest refracting meridian, in order that it may give to the rays which undergo the smallest degree of deflection such an increased amount of convergence as if they passed through the meridian of the greatest refraction.

The reverse obtains in the case of concave cylindrical lenses, for here the axis must correspond to the meridian of least refraction, so that the focal length of the meridian of greatest curvature may be increased, and made equal to that of the meridian of least refraction. A glance at Fig. 28, p. 193, will readily explain this.

I will now illustrate the choice of cylindrical lenses by some examples.

I. *Simple Astigmatism.*—The state of refraction of the one principal meridian is emmetropic, whereas that of the other is either myopic or hypermetropic.

1. *Simple Myopic Astigmatism* (Am).—Let us suppose that there is emmetropia in the principal horizontal meridian (the far point lying at an infinite distance, *i.e.*, $r = \infty$), but that in the principal vertical meridian there is myopia $= \frac{1}{8}$, then $\text{Am} = \frac{1}{8} - \frac{1}{\infty} = \frac{1}{8}$.

In order to correct this, a concave cylindrical lens of 8 inches focus will be required, its axis corresponding to the horizontal meridian, so that the rays of light may here pass without undergoing any refraction, and only those which pass at a right angle to the axis (vertically) be refracted, so as to neutralize the myopia which exists in the principal vertical meridian. To be quite accurate the lens should be slightly stronger ($7\frac{1}{2}$ inches focus), for $\frac{1}{2}$ an inch should be deducted from the strength of the concave lens, on account of the distance of the latter from the nodal point. In hypermetropia, on the other hand, this distance of about $\frac{1}{2}$ an inch must be added to the number of the convex lens. In slight degrees of myopia or hypermetropia (below $\frac{1}{15}$ or $\frac{1}{20}$) we may, however, omit this distance in the calculation.

2. *Simple Hypermetropic Astigmatism* (Ah).—In the horizontal meridian let there be hypermetropia $= \frac{1}{10}$, in the vertical emmetropia, then Ah $= \frac{1}{10} - \frac{1}{\infty} = \frac{1}{10}$ and the patient will require a convex cylindrical lens of 10 inches focus with its axis placed vertically.

II. *Compound Astigmatism.*—In this form, it will be remembered, myopia or hypermetropia exists in both the principal meridians, but it varies in degree.



It will be found very much to facilitate the understanding of these cases of compound astigmatism if we consider the eye to be affected with simple myopia or hypermetropia, but that there exists besides a maximum degree of this anomaly of refraction in one of the principal meridians. We have, therefore, a certain degree of myopia or hypermetropia common to the whole eye, besides a certain, special degree in one of the principal meridians.

1. *Compound Myopic Astigmatism* (M + Am).—Myopia exists in both meridians, but to a higher degree in the one than in the other.

In the principal vertical meridian let $M = \frac{1}{15}$.

In the principal horizontal meridian let $M = \frac{1}{30}$; we then have myopia $= \frac{1}{30}$, and $Am = \frac{1}{15} - \frac{1}{30} = \frac{1}{30}$, to be written as $M = \frac{1}{30} + Am\frac{1}{30}$.

In such a case a spherico-cylindrical lens is required, the one surface of which has a spherical, the other a cylindrical curvature, and its action is that of a plano-cylindrical lens combined with a plano-spherical lens, and it may be expressed by the formula for each of the refracting surfaces, united by a sign of combination.

The case which we have supposed would therefore be corrected by $-\frac{1}{30}\,s \bigcirc -\frac{1}{30}\,c$.