far point is the crux of the clinical correction of ametropia. You must be fully comfortable with the far point as a concept, so brand this completely onto your brain: the far point R belongs to the unaccommodated eye, *not* to any corrective lens. Picture R as being rigidly attached to the eye like a barnacle on an oyster; imagine that it protrudes a certain distance from the eye (front or back) as the amount and type of ametropia demands. The action of all lenses must be referred to this far point — it serves as *the* basis for understanding the action of all corrective lenses.

THE CORRECTION OF AMETROPIA

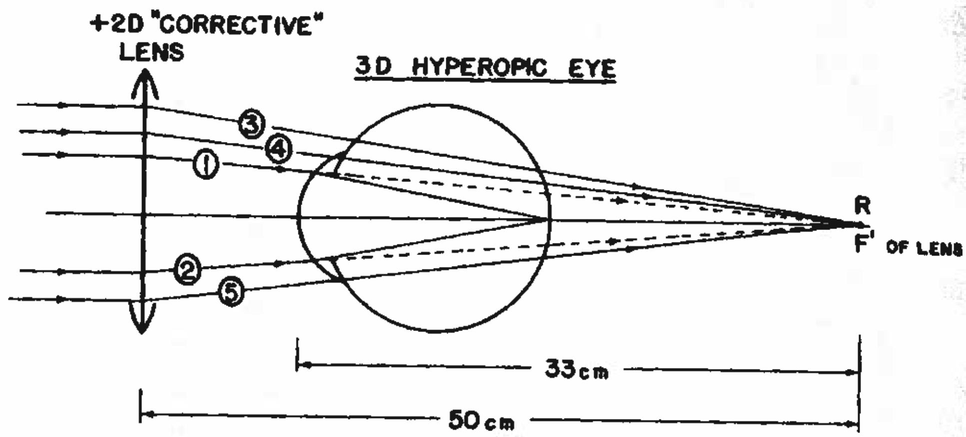
With your present background, the correction of refractive error becomes a real cinch. In a nutshell, *any* lens that images infinity at the far point of *any* given eye is a "corrective" lens. Since all lenses will, by definition, image infinity at their secondary focal points (F'), all you have to do is place that lens in such a position that its F' coincides with the far point of the eye requiring correction. This will make that particular lens a "corrective" lens for that particular eye. The corollary is just as important; *more* than one lens can "correct" a given eye.

Hypermetropia Correction

Let's take an example using a 3 D hyperopic eye. As before, our reference plane for the refractive error is at the anterior refracting surface; so, the far point R must be located 33 cm behind that surface. Light rays will have to converge toward R to be imaged on the retina, but light rays from an object at infinity are parallel and will *not* be convergent toward R, that is, without help. So, for *sharp* retinal images, a plus lens will have to be introduced into the light path to add convergence to the light. Let's use a + 2 D lens.

A + 2 lens will "correct" this eye for objects at infinity if (by definition) it is placed so that its F' coincides with the far point R. Since F' of a + 2 lens is located 50 cm behind it, the lens itself must be placed 50 cm from R for it to qualify as a "corrective" lens.

Then, object light rays from infinity will be focused by the + 2 lens at F'; these image rays by the lens become object rays for the eye, and any object rays heading for R will be sharply imaged on the retina.



In the figure above, rays 3, 4 and 5 are blocked by the sclera and do not get through the pupil; therefore, they cannot help form the retinal image point. In this figure, only those rays *between* 1 and 2, imaged by the lens at R, actually enter the eye and are imaged by *it* sharply on the retina. 1 and 2 are "limiting" rays — limited by the edge of "the pupil".

If we wanted to place the "corrective" lens smack up against the cornea (like a contact lens), it would also have to be of such power as to have its F' at R of the eye. We know the distance from this surface to R — it is 33 cm since this is a 3 D hyperopic eye. Thus, the corrective "contact" lens must be of+ 3 D.

It should now be clear that you *could* use a + 0.5 D lens and have it "correct" this eye's refractive error *if* that lens were held 200 cm from R. The 3 D of hyperopia will still be corrected by it.

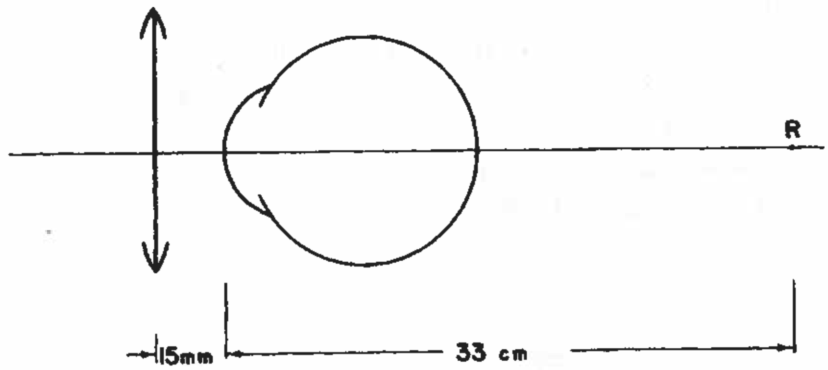
So, now you have seen that the lens power which "corrects" a given amount of ametropia is not fixed, and the far point *which belongs to the eye and not to the corrective lens* does stay rigidly in place.

I can hear the cries of anguish now: "Be realistic". "Who would wear a corrective lens at 200 cm for a 3 D hyperopic error?" The question is moot since my point is not that you *would* correct hyperopia with this lens, but that you *could;* you might use *any* plus lens, just as long as its F' is made to coincide with R. (You will soon learn that there *is* a use for such a peculiar "corrective" lens.)

O.K. Let's be more practical. Corrective lenses are typically worn in spectacle frames which place them in front of the eyes. Although I can here specify a definite location for the spectacles, this should only be considered an approximate guide since the true position depends on many factors — the type of lens frame and the position of its nose rest, the shape of the patient's brow, position of his ears, how deep set the eyes are in their sockets, etc. Wherever the corrective lens is worn, *that* is the "spectacle lens plane". *It* should be the reference plane for prescribing corrective lenses even though it varies somewhat in position from patient to patient. Arbitrarily here we will place it at 15 mm from the corneal surface. (The distance between the cornea and the corrective lens is called the *VERTEX DISTANCE.)* However clinically, especially for a patient with a large refractive error, this distance cannot be assumed; it must be measured. You will soon see why.

(This 15 mm separation between a "practical" corrective lens and the cornea places the lens just about at the anterior focal plane of the eye. Later, we will take up what this means optically, but, I will "spill the beans" now and tell you this is *not* of momentous clinical importance.)

In any case, back to our + 3 D hyperopic eye, the "practical" corrective lens must have a focal length which is 15 mm longer than the distance (33 cm) between the cornea and R. Its corrective power must be $\frac{1}{(.33 + .015)\text{ m}} = \frac{1}{.345\text{ m}} = +2.9\text{ D}$.



With low powered corrective lenses, it will not make too much difference whether one reckons with the "vertex distance" or not. In this case, there is only 0.1 D difference from the existing 3 D of hyperopic error. (This small amount will just barely be grindable by an optician's lens grinding machine.) However, for an aphakic eye (following lens extraction for cataract), the vertex distance *is* a critical consideration. Aphakic eyes are usually 10 - 12 D hyperopic; a few mm of change in the vertex distance can change the effectiveness of such a spectacle lens greatly.

To demonstrate this point, work the following problem.

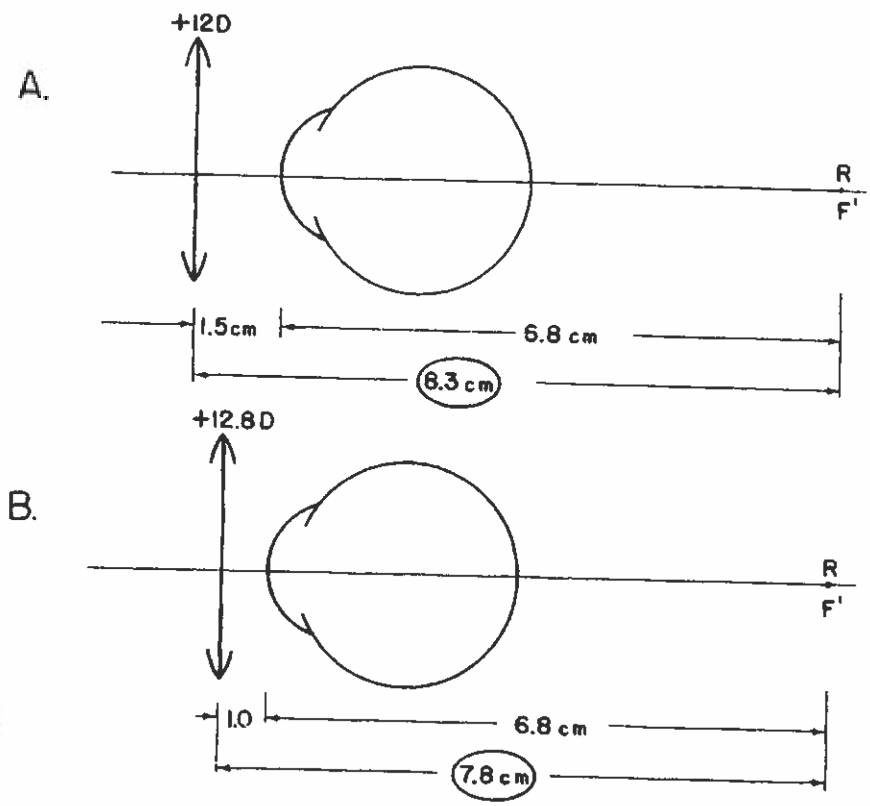
PROBLEM:

A + 12 D corrective lens (which was measured at a vertex distance of 15 mm) is prescribed for an aphakic eye. When the patient's optician fits the corrective lenses into a stylish frame of the patient's choice, the lens is placed only 10 mm from his cornea. What is the dioptric error caused by fitting the lens at this closer distance?

ANSWER:

First you must locate R — *that* is the key point no matter what the refractive error is. Since you are given that a 12 D lens "corrects" this aphakic eye, its F' must fall on R. F' is $\frac{1}{12\ D}$ or 8.3 cm behind the lens, but the lens itself is 15 mm in front of the cornea. So, R must be (8.3 — 1.5) or 6.8 cm behind the cornea. (See A below.) Now that the position of R is located, we can use any corrective lens we wish depending on its desired position from the eye.

Since this patient's actual vertex distance is only 10 mm, he *should* require a corrective lens with a focal length of (6.8 + 1.0) or 7.8 cm — a + 12.8 D lens neatly fills the bill. (See B below.)



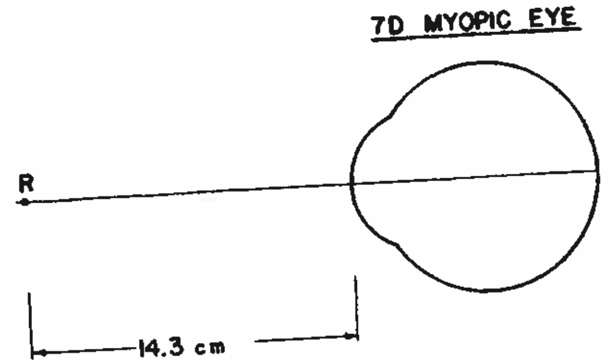
But he is wearing a + 12.0 D lens inadvertently fitted at this 10 mm vertex distance, so he is *under*corrected in plus power by (12.8 — 12.0) or 0.8 D — certainly not an *in*significant amount.

You must pay attention to the vertex distance; it becomes particularly significant with ametropias over 4 Diopters, whether in hyperopia, myopia or astigmatism.

Myopia Correction

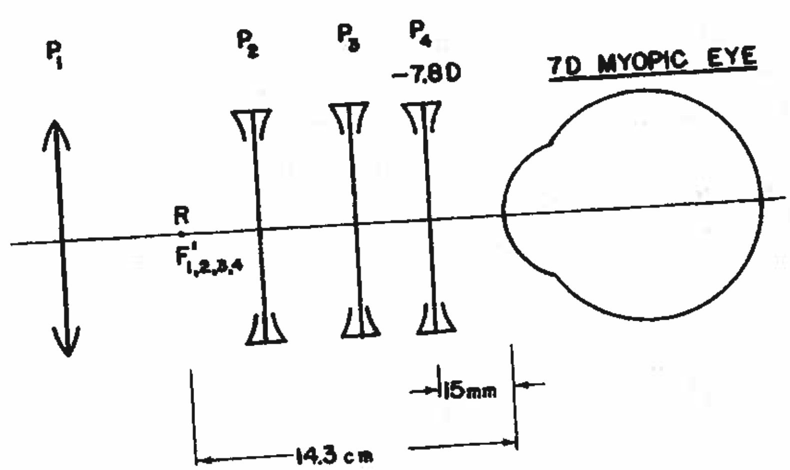
Everything we said about far point correction in hypermetropia also holds true for myopia. For any corrective lens to work, it must image infinity at the far point of the eye. "Optics" takes over from there to assure that a sharp image will fall on the retina.

When an eye is 7 D myopic (with the "error" considered to reside at the corneal surface), it has its far point located 14.3 cm from the cornea.

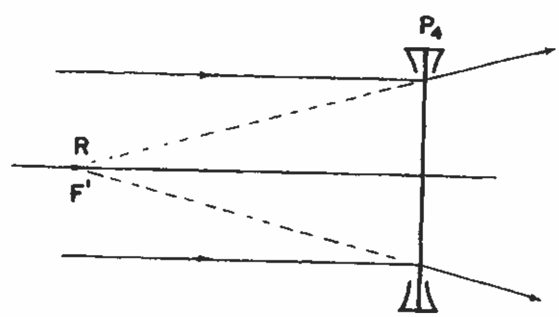


A "corrective" lens is placed so as to take parallel light bundles from infinity and, after refraction by the lens, make them *seem* to the eye as if they arose at R. Such a lens will do so only if its secondary focal point F′ coincides with R.

A number of individual lenses, each of which fulfills this criterion, are shown below:



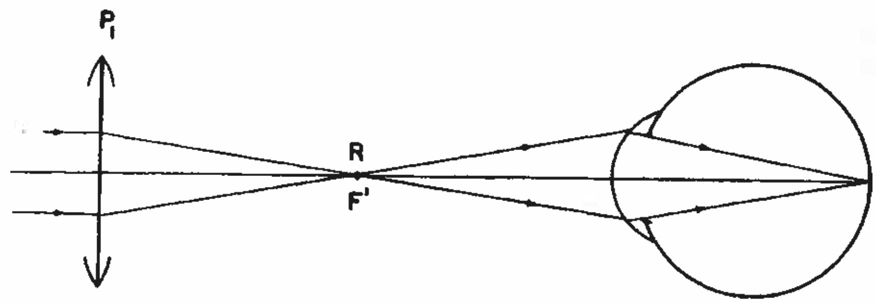
Lens position 4 places the corrective lens in the "spectacle plane" 15 mm from the cornea; its power must be as follows: In this 7 D myopic eye (again with the "error" at the corneal surface), R is 14.3 cm from the cornea. The F' of the lens must be at that same position, that is, (14.3 — 1.5) cm or 12.8 cm from lens position 4. P_4 must then be $\frac{1}{-.12\,8\text{ m}} = -7.8$ D. P_4 must be *minus* since it has to diverge the parallel light from infinity to make it seem to the eye behind it as if the rays came from R.



If the corrected lens were located at position 3 above, it would of necessity have a shorter secondary focal length and, therefore, P_3 would be greater in minus power than P_4. Of all the possible corrective lenses, the one with the *least* minus power would be situated furthest away from R, that is, in contact with the corneal surface — a contact lens of — 7 D power.

Say that the position of corrective lens 2 was only 1.0 cm from R. Its power would have to be a whopping —100 D to "correct" this eye, but correct it optically it surely would, since a sharp image of infinity would then fall on the retina.

Look now at lens position 1 on the *left* of R. Could a lens here also correct this myopic eye? Why, of course it could. However, it would have to be a *plus* lens. If located 20 cm to the left of R, this peculiar "corrective" lens would have to be of + 5 D power (with its F′ at R) — it, like the other corrective lenses, images infinity at the far point, and thereby allows objects to be seen clearly and distinctly by this 7 D myopic eye. (One small point in this case; the image of an object at infinity "corrected" in this manner would be seen *upside down,* but sharp, nonetheless!)



Let's neglect this latter, unusual "correction" except to know it as a possibility.

To summarize for the usual clinical situations:

Plus lenses are used to correct hyperopia; the closer the corrective lens is to the eye, the shorter its focal length must be (greater plus power) since each of these lenses must have their F′ precisely at the eye's far point which is fixed in location *behind* the hyperopic eye.

Minus lenses will correct myopia; and, the closer to the eye the lens is, the longer its focal length must be since R is in *front* of the eye.

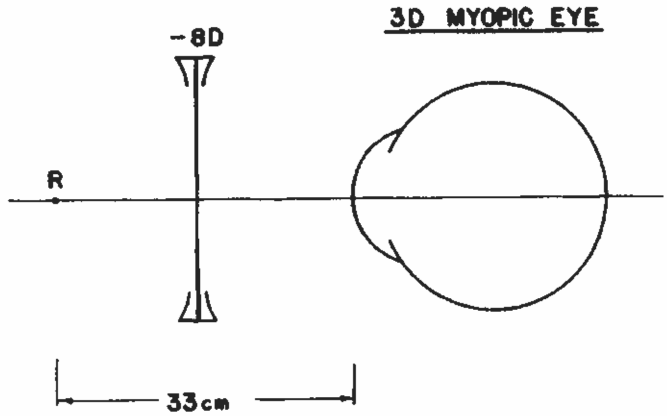
As long as you know where the far point is, in myopia and in hyperopia, you can figure out the proper corrective lens very easily.

PROBLEM:

Where would you place a −8 D lens to "correct" a 3 D myopic eye?

ANSWER:

A 3 D myopic eye has its far point 33 cm in front of the cornea.



A -8 D lens has its F′ at $\frac{1}{8\ \text{D}}$ or 12.5 cm from it. Therefore, to superimpose F′ on R, the -8 D lens must be 12.5 cm from R. This places the lens (33 − 12.5) cm or 20.5 cm in front of the eye.

You should now be able to grasp all future permutations and combinations in corrective lens power necessitated by shifts in the vertex distance. Don't bother with the formulas you'll find in other texts. Suffice it to say is that there *are* mathematical descriptions of how much effective power change is induced by each mm of lens shift; however, all you *have* to know is the actual power of any single "corrective" lens. Since this one lens pinpoints the location of R, the far point of the eye, you should be able to determine *any* other one for any vertex distance you want. The beauty of the "far point" and its clinical application to the correction of refractive error should be quite apparent to all.

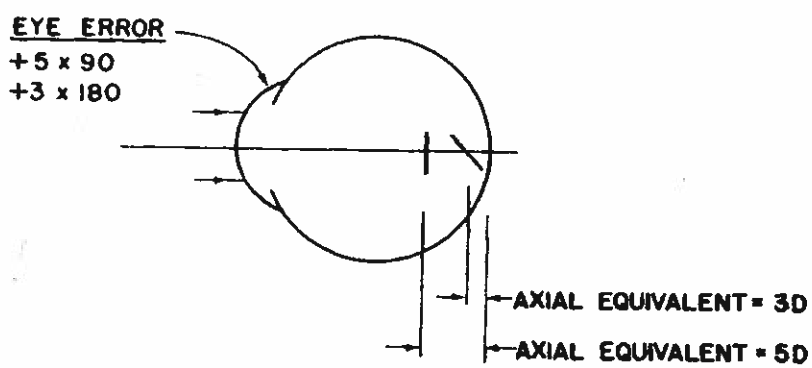
Astigmatism Correction

I have purposely steered away from discussing astigmatic refractive error until we had thoroughly digested myopia, hyperopia *and* their corrections. With these in mind, astigmatism "correction" is not tough.

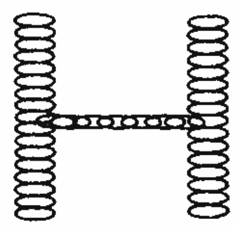
Recall from our session with basic cylindrical lenses and astigmatic imagery that the refractive surfaces in these instances are toroidal; they can be described by noting the meridians of maximum and minimum powers which, in *regular* astigmatism (the type we are concerned with), are always perpendicular to one another. (Re-read that section if you have forgotten since you must understand it to get anything out of what follows.)

Just as a lens may possess astigmatic power, so also may an eye; and just about every eye is afflicted with *some* astigmatism, which usually resides more in the cornea than in the lens. As with the spherical refractive errors, we do not care about the *total* power of the refracting surfaces; it is only the *error* which is important. For astigmatism, the error can be expressed in either spherocylindrical form (plus or minus cylinder) or the "combined" cylinder form, with each power and its associated axis stated. These three expressions, when properly stated, are all equivalent and describe the same basic eye error.

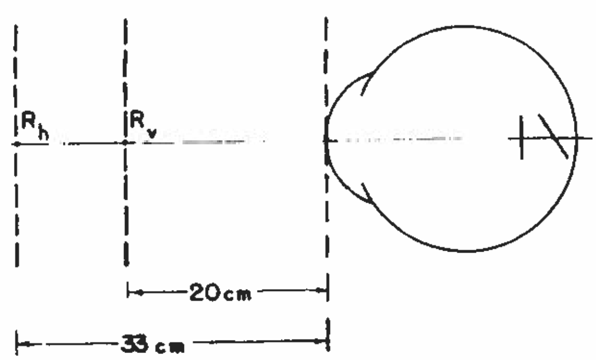
Take an eye with an *error* of $\left[\begin{smallmatrix} +5 \times 90 \\ +3 \times 180 \end{smallmatrix}\right]$ measured from the corneal surface. (Remember, this is *not* the corrective lens but the basic refractive error. It is comparable to saying a myopic eye of 5 D has an error of + 5 D — "too strong" by 5 D.) This error means the power associated with × *90* (focusing the *vertical* astigmatic focal line) is too strong by 5 D; and that power focusing the horizontal line is too strong by 3 D. Thus, the eye has less *error* in focusing the horizontal line. This means that when the eye is looking at an object point at infinity, the horizontal focal line must be closer to the retina (only 3 D in front) compared to the vertical (which is 5 D in front).



Since the horizontal line-images of each object point are positioned closer to the retina, the *horizontal* lines making up any target or test letter located at infinity will appear clearer than will the vertical strokes. For this eye, a target letter H would look something like that shown below — each object point being represented on the retina as a horizontal ellipse.



This eye would have two far points — one conjugate to the retina for the horizontal line image and one for the vertical line image. Just as with any *spherical* refractive error, the corresponding far point positions are found by knowing the refractive error of this eye in each of the primary meridians. In this case, the far point for the horizontal line image is 33 cm in front of the cornea and that for the vertical line is 20 cm in front of the cornea.

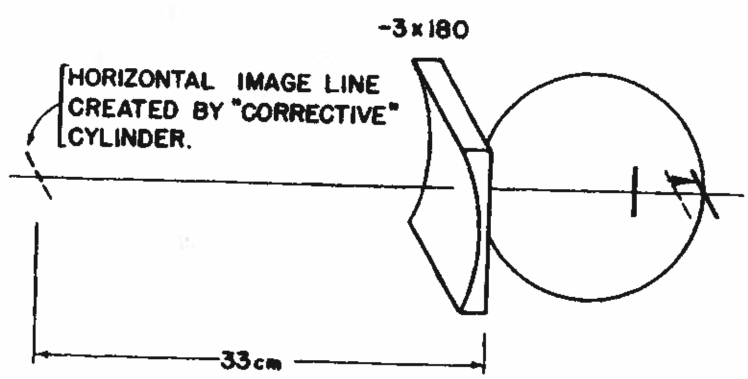


To "correct" this eye, we have to go through the same procedures as for the spherical refractive error — we have to place the corrective lens so as to image infinity at the far point; (the lens can be located at whatever position you choose if its power is appropriately adjusted). However, for the astigmatic eye there are two far points, so this procedure must be done for both primary meridians using a cylindrical lens for each.

For simplicity, let us correct this eye with lenses situated very close to the corneal surface; that is, consider the vertex distance to be zero.

First the horizontal line:

The far point associated with the horizontal line is 33 cm from the cornea, so we will need a —3 D lens at the cornea to correct it. However, we only want to move the *horizontal* line 3 D backwards to place it on the retina, so we must use a *cylindrical* lens axis *180*, which moves only the horizontal line. Thus, to "correct" the horizontal line, we require a — 3 × 180 lens at the cornea. This lens will take an object point at infinity and create a horizontal line image of it at far point R_h. The eye then takes over and will image these rays sharply on the retina as a horizontal line image. Remember, that line image on the retina represents the *original* object *point* at infinity as focused by the *vertical* meridian (which has its axis at 180°).



In the figure above, the — 3 × 180 corrective lens moves the horizontal line which was 3 D in the vitreous back onto the retina.

For the vertical line:

Similarly, we need a -5×90 lens at the cornea to image the same object point from infinity at the far point (R.) to create a vertical line there. This line will then be imaged by the astigmatic eye back onto the retina, thus "correcting" the power error *associated with* axis 90°.

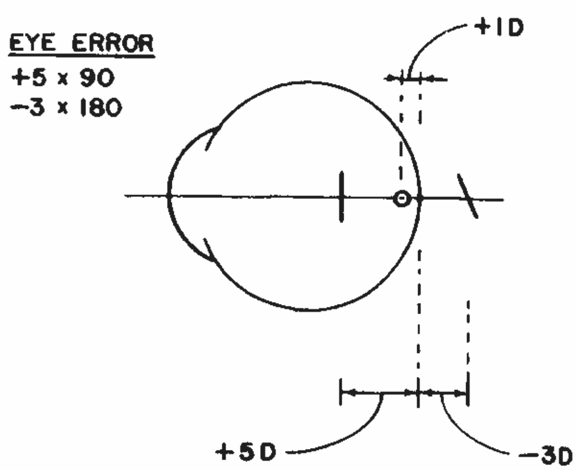
When both lines are imaged on the retina, there will be no more astigmatism present since Sturm's "interval" will have been eliminated. The eye becomes fully "corrected" (with no line foci present) by the following *corrective* lens: $-3 \times 180°$ combined with $-5 \times 90°$.

So, if you know what the eye *error* is, you not only know where the far points are, but more importantly in astigmatism, you can always *visualize* the line images *within* the eye as it images an object point at infinity.

Get in the practice of visualizing. If I tell you that the eye *error* is

$$\left[\begin{matrix} +5 \times 90 \\ -3 \times 180 \end{matrix}\right],$$

a vivid picture should pop into your head and should look something like this:



The $+5 \times 90$ means the vertical line is 5 D in front of the retina; the -3×180 signifies the horizontal line image is 3 D "behind" the retina. These lines are separated by *8 D*, that is, the astigmatic error