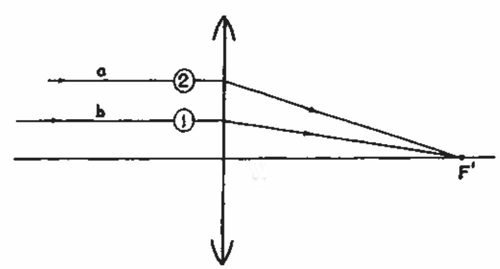
Melvin L Rubin, MD, MS. (1993). Optics for Clinicians. Florida: Triad Publishing Company

THE PRISMATIC EFFECT OF LENSES

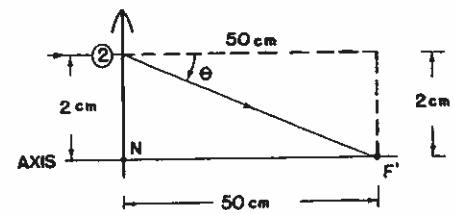
It's been some time since we studied something about prisms and their ability to change the direction of light beams. It should come as no surprise to learn that lenses also exhibit *prism* power because they also change the direction of light rays, but their ability to do is not constant. Any light ray that falls on the surface of a lens is subject to a constant *vergence* effect by that lens; however, the *prismatic* effect by that lens on any incoming ray varies, depending on specifically where on that surface the ray strikes.

Let's take a concrete example: The light coming from an axial point at infinity falls onto a lens of + 2 D power. The rays will be brought to a focus 50 cm behind the lens at its secondary focal point F'.



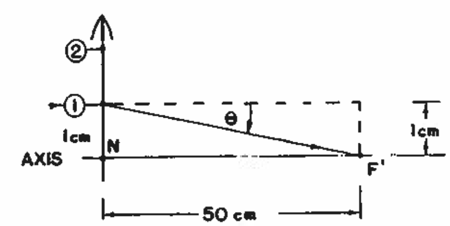
Since all parallel incident rays will focus at F', each ray must have been bent a different amount by the lens; those rays striking the lens close to its axis will be deviated only slightly while those hitting the lens nearer to its periphery will, of necessity, be bent a greater amount if they are to cross the axis at F'. The degree of bending (or deviation) exerted by the lens *at* the point that an incident ray touches the lens is its "prism power". So, the prism power of the lens at point 2 affecting ray (a) must be greater than that affecting ray (b) which strikes the lens at point 1.

To calculate how much prism power is exerted by the lens on these 2 rays, assume that point 2 is 2 cm from the lens axis and point 1 is 1 cm from the axis. Since F' is 50 cm from the lens, ray 2 is deviated from the straight-ahead direction by such an angle that it is displaced 2 cm at 50 cm as shown below:

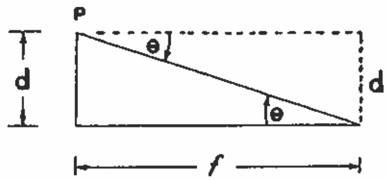


The tangent of the angle of deviation θ must be $\frac{2}{50}$ or .04. Back when we described how to measure angles, we noted that 100 times the tangent of an angle is equivalent to that angle expressed in prism diopters. So, angle θ must be 4 prism diopters.

The next diagram analyzes what happens at point 1. Here, θ is equal to $\frac{1}{50}$ or .02, and this is equivalent to 2 prism diopters:



So, the prism power exerted by the lens at position 2 is 4^{Δ} while that at position 1 is 2^{Δ}. This was a specific example; let's generalize:



Let d = the distance from the lens axis of the point we wish to examine, and f = the focal length of the lens in question. Both these distances were expressed in centimeters in our example, so let's continue with the same units. We have seen that the prism power (in prism diopters) of the point in question was 100 tan θ. Tan θ = $\frac{d}{f}$ so, 100 tan $\theta = 100\,\frac{d}{f}$. If the lens power is expressed in diopters of vergence, $\frac{1}{P} = f$, when f is given in meters; if instead, f is in *cm*, then $f = \frac{100}{P}$;

$$100 \tan \theta = 100\frac{d}{f} = 100\frac{d}{\frac{100}{P}} = d \cdot P$$

Thus, the angle θ in prism diopters = d (cm) × P (Diopters). This is known as Prentice's rule and is a most useful one for the clinician. This rule is very valuable in arriving at the prism power induced by *any* point in *any* corrective lens. Just remember that d is measured in *cm* to the *optical center* (at the lens axis).

PROBLEM:

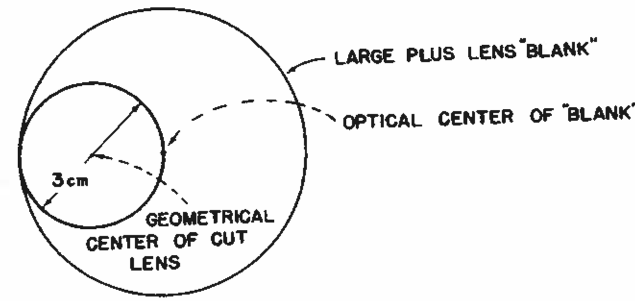
What is the amount of prism induced 7 mm from the axial point of a minus spherical lens with a focal length of 8.5 cm?

ANSWER:

$$P = \frac{1}{f}; \qquad P = -\frac{1}{.085} = -12\text{ D}$$

The prismatic power = $d \times P$ = (.7 cm) (− 12 D) = 8.4 prism diopters.

To determine the optical *effect* of this prism induction, not only must we know the *amount* of prism, we must also know which way the prism base or apex is oriented, as this tells us the *direction* of deviation of the rays caused by that particular lens point. The base of the prism is always at that lens position that is "thickest," so the base tends to be central in a plus lens and peripheral in a minus lens; but not always, such as in the following extreme example:

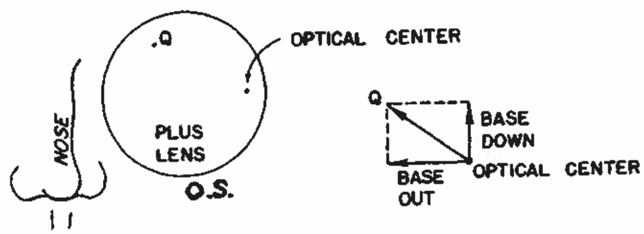


A 3 cm diameter circular lens is cut out from a much larger + 3 D "lens blank". The diagram shows how the smaller 3 cm *plus* lens can be fashioned with its optical center at an *edge* and not at its geometric center; thus the base here is *not* central as it usually is in a plus lens.

For the measurement of the induced prism, you have to know the location of the optical center (which is concomitantly the prism *base* with *plus* lenses). To determine the prism power at the *geometrical center* (1.5 cm from any edge of the small lens above), we refer to $d \times P$. The distance d in cm must be from the *optical* center which is 1.5 cm away at its right edge (as shown).

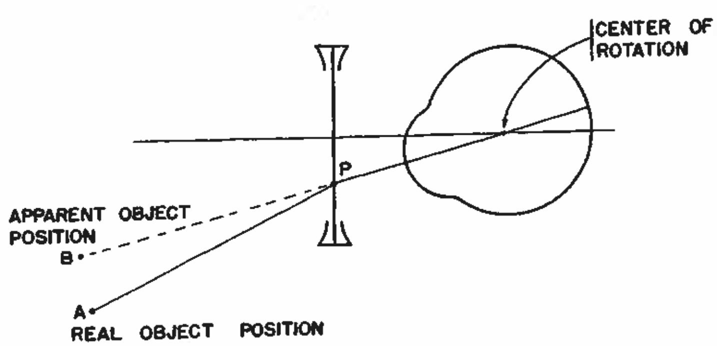
The lens power P is + 3 Diopters. So, the *prism* power is 1.5 × (+ 3) = 4.5$^{\Delta}$ *Base* to the right (as you face it). If this is a "corrective" spectacle lens and is worn so the nose is on the left of our drawing, this 4.5$^{\Delta}$ is directed *Base Out;* if the nose is on the *right*, this same prism is directed *Base In.* If this lens is rotated appropriately in front of the patient's pupil, the prism base *can* also be straight up or straight down. However, if there *is* vertical prism induced, you must also name the eye to designate the direction; Base *Up* OD is exactly equivalent (as far as the eye muscles are concerned) to an equal amount of Base *Down* OS.

Moreover, a point on the lens can exhibit both vertical *and* horizontal base effect *simultaneously,* if its direction from the lens axis is off at some angle which is not a straight vertical or horizontal one.



If the above lens is a plus lens and if the nose is on the left, Point Q introduces vectors of Base Out *and* Base Down prism effect.

If the visual axis of an eye looks through the *optical center* of any spectacle lens, there will be *no* prismatic effect induced. But if the eye rotates to look up, down, or through any positions other than the optical center, prism *is* induced, and any object viewed through that portion of the lens will appear to be displaced (*toward* the apex of the induced prism). For example, study the figure below which shows an eye peering through the lower periphery of a minus lens:



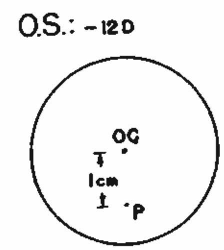
In this figure Point P in this minus lens introduces Base Down prism and makes the object at A appear to be at B. So, the object will appear to be displaced *upward*. Therefore, to align the macula with the displaced image, the eye has to rotate down a lesser amount than it would if the lens were not there.

Let's now look at a clinical example:

PROBLEM:

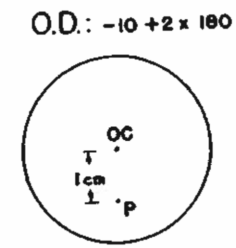
What is the prism induced when the two visual axes intersect a pair of spectacle lenses at points 1 cm directly below their optical centers? (OS: -12 D; OD: $-10 + 2 \times 180°$).

ANSWER:



Prism induced is $d \times P$.
(1 cm) $\times$ (12 D) = 12^{Δ}

Since this is a minus lens, the base of the prism (thickest part of the lens) is down.



Prism induced is $d \times P$.
d is 1 cm but what is P?

The power of this lens in the vertical meridian is gained from the sphere *and* the cylinder the spherical components: the spherical component is -10 D: the cylindrical is $+2$ D. (A $+2 \times 180°$ has no power along its axis at 180° but $+2$ D along the vertical meridian.) So the total P in the vertical meridian is -8 D and the prism induced is 8^{Δ} Base Down.

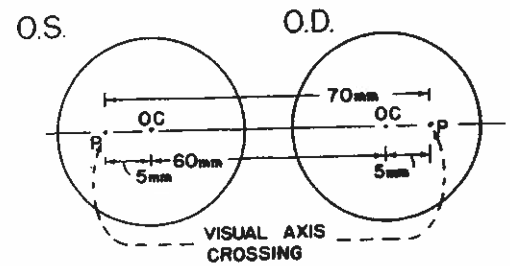
If there were 8^Δ of B.D. prism induced by *both* lenses, there would be no real problem for the patient since the prismatic effect would be symmetrical for the two eyes. The object *would* be displaced upward (toward the apex) from its normal position, but this causes no great tragedy. Though such a symmetrical "prism displacement" of the object *is* usually noticeable by patients with high powered plus or minus spectacle lenses, they tend to adjust rapidly to its presence and do not tend to be bothered by it.

Trouble can arise, however, in patients who have a *difference* of induced prism between the two eyes, as in our clinical example above; there is 4^Δ *more* Base Down OS than OD. If a patient tries to read through the point 1 cm below the optical center of each lens, he encounters a vertical misalignment of the two retinal images of 4^Δ, which may be too great for him to compensate for by using his vertical motor fusion. The *non*-presbyope will usually have no problem. He avoids this area of the corrective lens like the plague by rotating his head to read so that he looks directly through the optical centers of both lenses where there is no prismatic effect; this neatly solves the problem for him. The *presbyope,* however, is the one who has difficulty. He will *not* be able to read through the optical centers of the distance correction since there is not enough plus power there to replace his lost accommodation. He requires a reading add which is usually built in as a bifocal segment positioned below the optical centers of the distance glass. This forces him to read there, through an area of the lens that has prism power induced. We will be looking at this "differential prism" problem and how to solve it when we look more closely at bifocals in a few moments.

Clinically, the alignment between the optical centers of the two corrective lenses and the corresponding visual axes is very important. Each of these variables must be measured, and *is* routinely by the optician as part of his job. The true separation of the *visual* axes is not easy to determine, so he uses its approximate equivalent, the interpupillary distance, which *is* simple to measure. If the spectacle corrective lenses are aligned so that each optical center is directly in front of the corresponding pupil, no prismatic deviation is induced. If both lenses are of equal corrective power, and the eyes rotate behind

them so that the visual axes pierce them in comparable positions, the induced prism will affect the rotations of each eye similarly, and again there will be no *differential* prism induced. However, if the separation between the optical centers of the lenses is greater or less than the interpupillary distance (P.D.), or if these corrective lenses are of unequal powers, there *will* be a different amount of prism induced at comparable geometric positions of the lenses (upper right, lower left, etc.).

A typical problem is as follows (the figure is drawn from the *patient's* side):



The distance between *optical* centers is 60 mm. The patient's P.D. is 70 mm. If the spectacle lenses are both − 6 D, at *each* point P (where the visual axis penetrates the lens) there will be (0.5 cm) × (− 6 D) or 3^Δ Base Out prism induced — a total of 6^Δ Base Out action for the two eyes combined. Base-out prism will deviate the images *inward* for each eye and, therefore, for sensory fusion of the two images to occur, the eyes must *over-converge* by 6^Δ for objects at infinity. This convergence demand may or may not be desirable, that is, it may be either helpful or troublesome for this patient. In any case, you should be able to determine quickly the amount of prism induced at various points in any lens and to understand the effect it produces as far as the patient is concerned.

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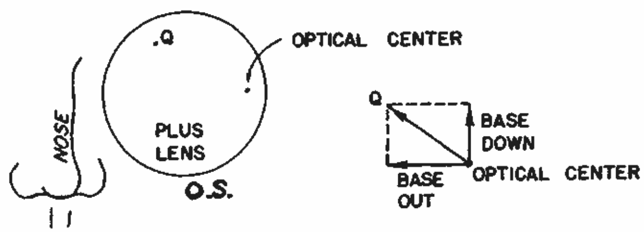

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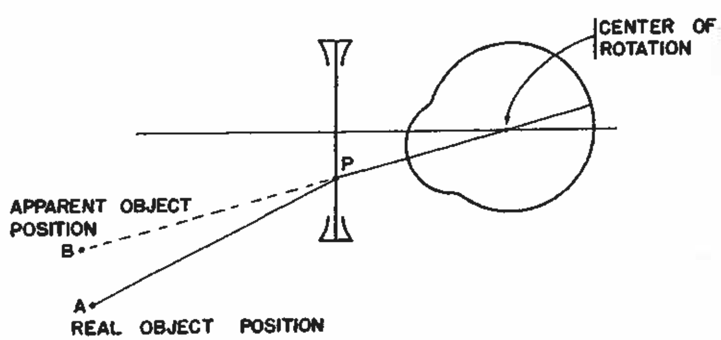

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ANSWER:

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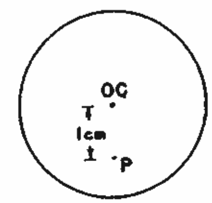

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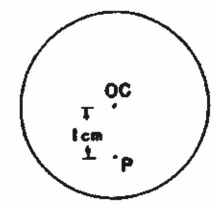
O.D.: $-10 + 2 \times 180$



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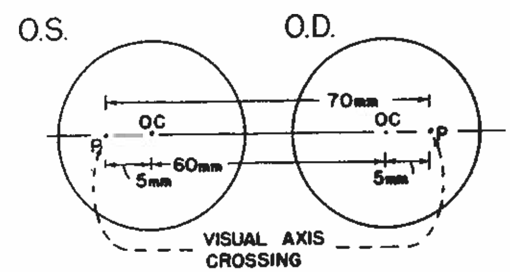

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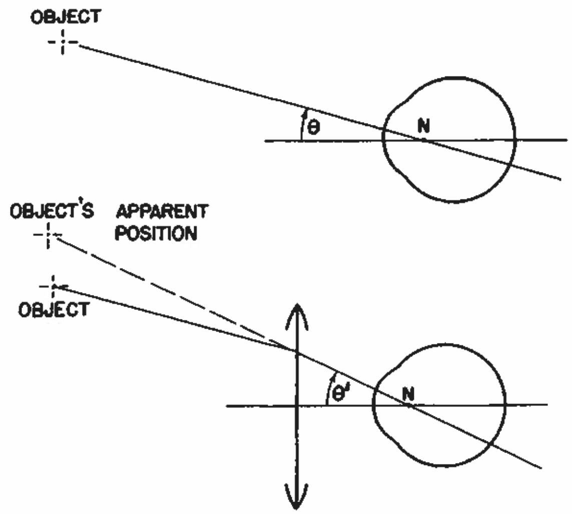
So much for prism displacement in the minus lens. What about that induced by a plus lens? As you might expect, looking through the comparable position of a plus corrective lens demands a *greater* rotation by the eye to see an off-axis object.

In the diagrams below, θ is the angular position of the object as subtended at the nodal point of the eye without any lens being present; θ' is its angular position (again subtended at the eye's nodal point) as the same object is viewed *through* the lens.

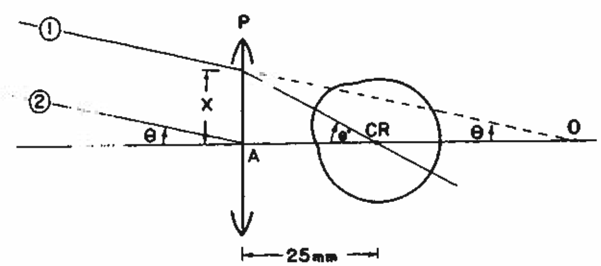


As you can see, the high plus corrective lens for aphakia is particularly adept at causing "object displacement". (The object shown above is displaced *away* from the lens axis.) This can discombobulate the hand-eye coordination for any aphakic patient; for example, when he eats (looking through the lower part of his specs) he will notice that objects not only appear magnified and closer (as you should by now recall), they will also be displaced *downward*. The combination of these three effects (plus other optical image distortions) make it particularly difficult to "get used to" aphakic spectacles. So be tolerant of your aphakic patients; they're not confabulating their symptoms.

Rotational Magnification

Let us see how *much* ocular rotation is required to look up at an off-axis object through a spectacle lens and compare this rotation to that necessary without the lens while looking at the same object. This comparison, since it is in percentage terms, can also be looked at as a magnification — so, in addition to linear, angular, and axial, we have a *rotational* magnification. This type is unrelated to the others, and it is not an unimportant consideration; in fact it may be *as* or *more* significant for a patient (symptomogenically speaking) than is the *angular* magnification of a spectacle lens.

Look at the diagram given below:



The eye is typically situated behind a corrective lens so that the cornea is about 15 mm away. The center of rotation CR of the eye is approximately at the eye's "center", perhaps 12 mm behind the cornea. The center of rotation then is *approximately* 25 mm behind the lens. (Don't quibble about 2 mm difference; the arithmetic becomes easier neglecting it!)

Ray 1 from an object at infinity strikes the lens (here, a plus lens). This ray was selected so that after refraction it would cross the axis at the center of rotation of the eye. The angle it makes with the axis is θ'. This is the angle the eye would have to rotate through to see the off-axis object at infinity while looking through the lens. Without the lens, this eye would only have to rotate through an angle θ to see that same object. (Here θ is shown by ray 2 through the lens nodal point.)

Ray 1 is parallel to ray 2; so, if we continue ray 1 (past the lens but *without* refraction by it), it would also intersect the axis at an angle θ. This straight continuation of ray 1 will cross the axis at point O.

For the moment, let's neglect the fact that both rays 1 and 2 stem from a single object point at infinity, and look at ray 1; it and the *axis* can represent two rays of light, both aiming toward O. Together then, they fix the location of point O as a virtual *object* point for the lens; you should then see that C.R. becomes the corresponding image point. Thus, axial points O and C.R. are *conjugate*, and the distance from the lens to O becomes distance u; that from the lens to C.R. (25 mm here) is v.

$$U + P = V; \text{ and } V = \frac{1}{.025} = +40 \text{ D}$$

Therefore, $U = 40 - P$

$$u = \frac{1}{40 - P}; \text{ and } v = \frac{1}{40}$$

For small angles, and with dimension x in the lens plane as shown,

$$\theta' = \frac{x}{v} = \frac{x}{\frac{1}{40}} = 40\,x$$

$$\theta = \frac{x}{u} = \frac{x}{\frac{1}{40 - P}} = (40 - P)\,x$$

The rotational magnification $= \frac{\theta'}{\theta}$

$$M_{rotational} = \frac{\theta'}{\theta} = \frac{40\,x}{(40 - P)\,x} = \frac{40}{40 - P}$$

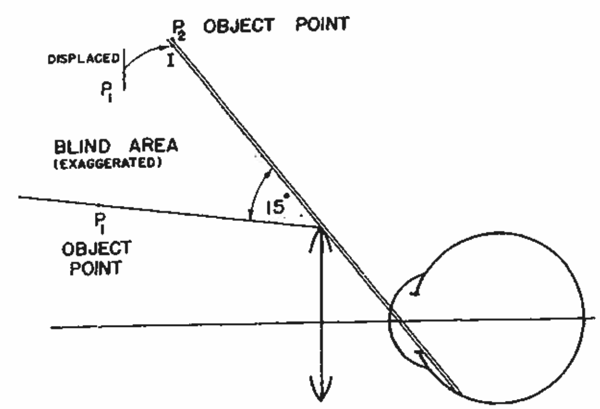
This relationship holds true for any corrective lens (plus or minus) located in the spectacle lens plane. For an aphakic lens of + 12 D, the rotational magnification is

$$\frac{40}{40 - 12} = \frac{40}{28} = 1.43 \text{ or } 143\%$$

Thus an aphakic eye through its corrective lens must exert a rotation 43% greater than a non-aphakic eye viewing that same object. As stated, this stress on a patient's extraocular muscles may present more of a problem to him than the 25% angular *size* magnification of his retinal image!

The Ring Scotoma

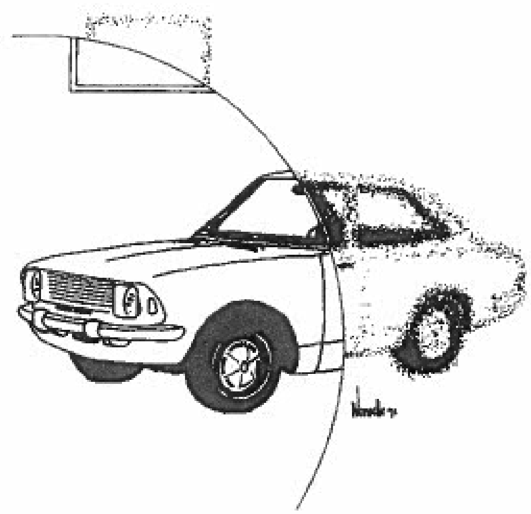
Another problem presented by aphakic (or high plus) lenses and caused by their prismatic effect is the "ring scotoma". The peripheral edge of the lens usually possesses the maximal prismatic power for that lens and will create the greatest deviation of rays.



When the eye is directed straight ahead, some object rays from P_1 will hit the lens periphery and will be refracted so that they enter the eye through the pupil and will appear to arise from a more peripheral direction (at I). Another ray, drawn from P_2 — a point located just beyond I — does *not* go through the lens; (if it did, it would not be able to enter the eye — it would be refracted by the lens in too great a downward direction). This ray from P_2 is the most peripheral one that just misses the lens and is thus not affected by it, but that ray *does* get through the pupil. Rays from object point P_2 can be seen by the eye from "around" the lens. They will not be in sharp focus but still *can* be seen by the eye. Since P_1 is the most peripheral object that *can* be seen by this eye *through* the lens and P_2 denotes the next direction that is visible to this eye *around* the lens, the entire angular space between P_1 and P_2 is *invisible*. If some object is located within this blind area, the farther away that object is from this eye, the larger it can be and still remain completely hidden. The eye is as completely blind for this region as it is for the area subtended by the optic nerve head. It is a blind ring of space roughly 15° in angular extent, depending on the actual power and size of the corrective lens and its vertex distance.

You can demonstrate this field defect easily with a perimeter. The scotoma's overall shape will depend on the exact shape of the circumference of the lens; a square lens would give a square blind area.

The patient will not see a blank area; he will see space as continuous — filled in — *but* as if a strip of visual information has been snipped out.



For example, a square window and a car might look like the sketch above, where "something" seems missing; the clearer parts of the image are those that are seen through the lens — these will be magnified.

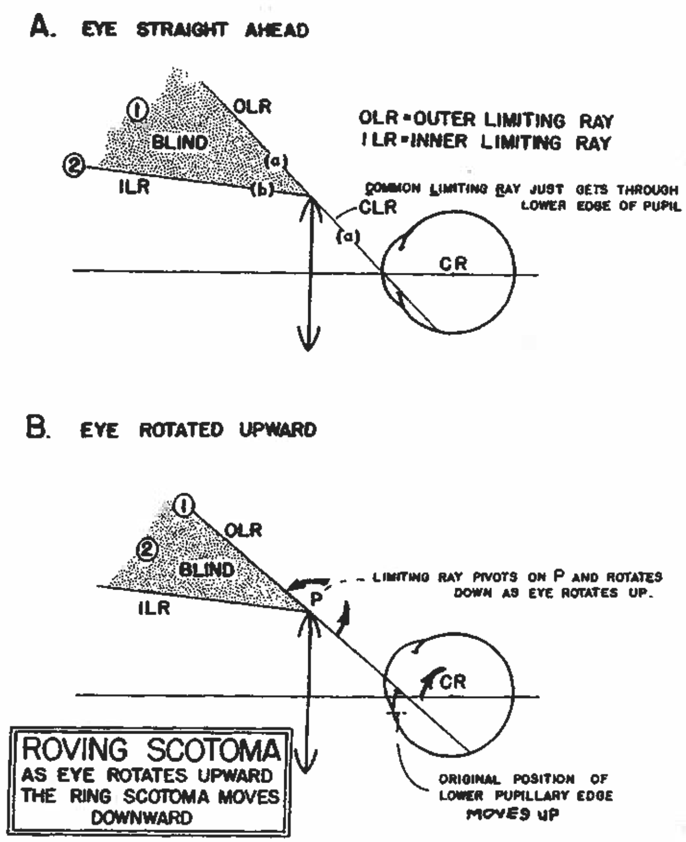
A word now about "limiting rays" — I have drawn the limiting ray as that one just managing to spill through the lower pupillary edge; this is not quite conventional. In standard optics texts it is usually shown as the particular ray that passes through the *center* of the pupil. Actually it makes no practical difference which one is used, but the ray I chose makes for an "easier-to-visualize" explanation of the next phenomenon.

The exact extent of the ring scotoma depends on those particular limiting rays that can just skim by the corrective lens and still get through the pupil to fall onto the retina. The position of the pupil then, is key. The foregoing description of the "ring scotoma" was made with the eye directed straight ahead and motionless; so the pupil's position (and, in turn, the position of the ring scotoma) was stationary. However, we know that the eye does not normally stay rigidly in position behind the corrective lens but continually moves about, so the pupil will move. This will cause *new* rays to become the "limiting ones" and the scotoma will in turn be shifted.

This shifting scotoma accompanying eye movement creates a peculiar problem called the "roving ring" scotoma. This scotoma movement is always *towards* the lens axis as the eye rotates *away* from the axis to take up fixation of a peripheral off-axis object.

I would like to explain this in more detail so look at the accompanying figure A:

(See next figure.)



When the eye is in the straight ahead position, ray (a) is the limiting one since it just barely gets through the lower edge of the pupil. Ray (b) is refracted by the lens but also just barely gets through the pupil.

Any object in Area 1 (the ring scotoma) is invisible, but an object located at position 2 near the border of ray (b) *can* be seen (but not clearly, since its image is not on the macula). To obtain a clearer image of 2, the eye will rotate around its center of rotation CR to look towards it, and this rotation moves the pupil upward.

Look now to the accompanying figure B:

As the lower edge of the pupil moves upward, a new limiting ray is created. This new ray makes *less* of an angle with the axis than did the limiting ray with the eye in the straight-ahead position. (Imagine a piece of string connected between the upper edge of the corrective lens and the lower edge of the pupil. When the globe rotates upward, the angle that string makes with the axis *decreases.* That angle is maximal when the eye points straight ahead.) The fact that the limiting ray position has lessened its angle with the axis as the eye rotates upward (shown in the figure) indicates that the entire ring scotoma has shifted *downward* in this diagram, *towards* the lens axis!

Let's take it once more for clarity: (In figure A) the final limiting ray (a) between the lens and the eye is the final common path of the *outer* limiting ray (OLR, the one which just passes beyond the edge of the lens) and the *inner* limiting ray ILR (that one that is just barely refracted by the lens). (In Figure B) when ray (a) rotates upward ("pivoting" on the top edge of the lens), the entire ring scotoma must rotate toward the axis (downward here). Thus, with the lens fixed in position and the eye rotating upward, the ring scotoma rotates oppositely and swings into position downward.

Now look specifically at positions 1 and 2 in the figure: As this downward rotation of the "ring scotoma" occurs, the "blind area" will encompass the previously visible position 2 and gobble it up — it will disappear as the eye tries to see it! Also, objects previously in position 1 (invisible with the eye straight ahead) "pop" suddenly into view. This is the "Jack-in-the-box" phenomenon often spoken of in the literature.

These phenomena can occur with the lens perfectly still, with only the eye doing the moving; this yields the "roving ring" scotoma. However, this same effect is even more pronounced when the lens is moving too; with motion of the patient's head the ring scotoma will shift about in space, making objects disappear and then suddenly appear out of nowhere! This is extremely disconcerting to many patients but thankfully it can be gotten "used to" readily by most.

This effect is *most* noticeable in the mid-distances, say, between 3 and 12 feet. Up close, for reading, one's attention is on the reading material itself and most surrounding objects are visually large enough not to be completely hidden within the ring scotoma. At distances over 20 feet, as in driving, the central field of view is large enough to encompass most of the objects which might interfere with driving. So neither the near or far distances are usually too troublesome for the aphake. It is within the confines of a single room, however, that most of the difficulty is evident and the patient becomes most symptomatic.

Since the "Jack-in-the-box" has an optical basis, the only way to remove it completely is by not wearing spectacle corrective lenses which necessarily produce this prismatic effect. Contact lenses are free from this taint.

Hand Neutralization of Lenses

This spot seems appropriate to introduce a practical application for the prismatic effect induced by spherical lenses. Since I have already written a short article on this subject,* I will reproduce it here.

The Broken Lens Puzzle (or, Hand Neutralization Without Tears)

It is 4:50 p.m. E.D.T. You have just completed a day filled with the usual tribulations — demanding patients and complicated examinations, topped off with a disastrous glaucoma problem — a typical afternoon at the office. You eagerly anticipate some sun and fun with your foursome, which is scheduled to tee off at 5:15 at the Club. At this moment, into your suburban office dashes the bejeweled wife of the local bank president. It is obvious that you are not bursting forth with enthusiasm to see Mrs. W.O.B.P. (Wife of Bank President).

* Rubin, M. L.: "The Broken Lens Puzzle" Survey of Ophthalmology, 15:105-108, 1970.

In her matronly hand she clutches some cracked lenses which were once a pair of vogue-ish spectacles. Naturally, she insists these be replaced (as with all other such demands) "yesterday." Well, no matter. Although the optician is over 40 miles away, a simple phone call of the prescription should do nicely to yield a newly-ground pair of spectacles in short order.

First to the files and the patient's previous record. Ugh; the W's are out being microfilmed this week. Aha, the lensometer in the corner. Horrors, a burnt-out bulb! Luckily, your next lane has another instrument. Double horrors and gnats!! You bulb-snatched that light last month!

Now what? The Geneva lens gauge at the back of your bottom desk drawer? No good. Mrs. W.O.B.P. has a high minus correction which has previously been ground in Thin-lite lenses (American Optical Company, Buffalo, New York) (index 1.70); the Geneva clock is calibrated for an index of refraction closer to 1.52. (Using this instrument would cause a great error in readings; so, it is certainly not appropriate for Mrs. W.O.B.P.!) Curses.

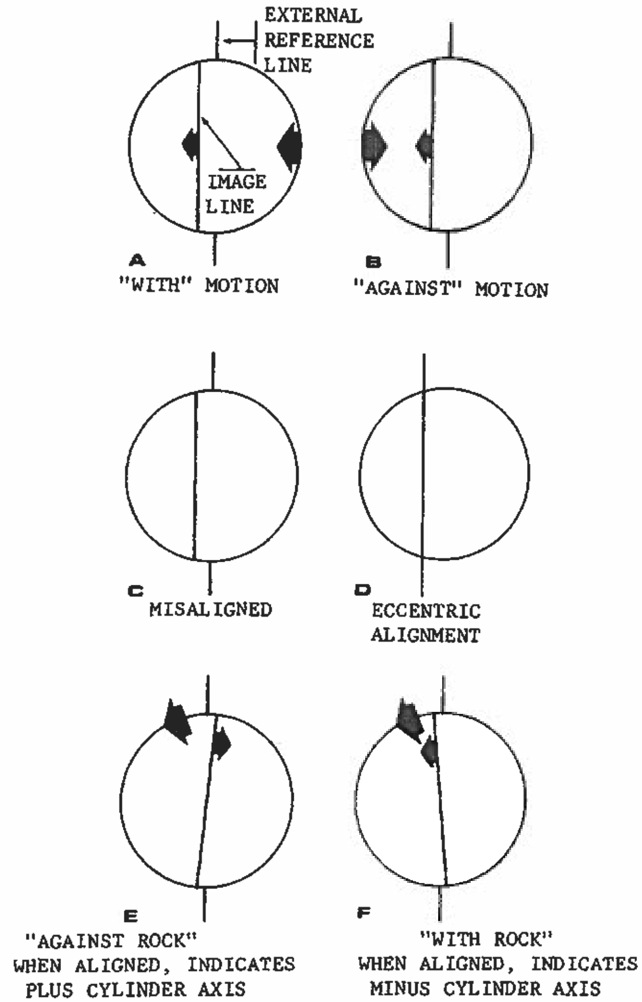
Wait . . . Could you possibly consider hand neutralization of the lens and do it effectively? It's been at least 10 years since you even held a loose lens in your hand!

Out comes a dusty box of trial lenses. In less than 1 minute you have the proper prescription. You race to the phone, call the optician and catch him at 5:00 p.m. just as he is closing. Joy. The lenses will be delivered tomorrow to a grateful patient, and punctually you meet your foursome, soundly trouncing each member in your state of euphoria.

In order to enable each reader to emulate our skillful ophthalmologist and to refresh his own memory as to the details of the useful maneuver of hand neutralization, let us now review the simple optics and rules involved.

DETECTION OF MOTION

If you hold any minus lens in front of your eye (say, about 1 foot away) and view a distant object through the lens while moving it upward, the object will appear to move upward also. This apparent motion of the object in the same direction as the movement of the lens is called *with* motion (Fig. *A*).



A plus lens similarly moved will provide an *against* motion (Fig. *B*). The detection of even minimal amounts of motion, either "with" or "against", is actually extremely simple — certainly one-quarter of a diopter should be patently obvious, and as little as one-eighth of a diopter is detectable with a bit of practice.

"Against" motion always serves as an indication that an unknown lens has plus power, and "with" motion usually labels a lens as minus. However, "with" motion can also be simulated by a *plus* lens, if it is held so that the eye-to-lens distance is greater than the focal length of the lens; in the latter instance, the image seen is inverted and real. In any case, there is rarely any difficulty in telling plus from minus.

NEUTRALIZATION

Using the "with" or "against" motion as a cue, both the spherical and the cylindrical powers of any unknown lens can be determined with ease. The technique called *hand neutralization* involves the placing of lenses of known power by trial-and-error in juxtaposition to the unknown lens, in an attempt to eliminate (neutralize) any image motion.

As a practical point, it is easier to detect the minimal image motion produced by a weaker-powered lens (or any lens that is almost, but not quite, neutralized) if it is held further (a few feet) away from your viewing eye.

After some practice using a randomly selected spherical lens from your trial set, you should be able to detect the induced motion and neutralize it with facility, using sufficient plus-lens power to counteract "with" motion and minus for "against". Spheres present no particular problem.

PRINCIPLES

Why do we see "against" motion with a plus lens?

It is somewhat surprising to find that Duke-Elder (*Practice of Refraction* (7th ed.), C. V. Mosby Company, St. Louis, 1963, p. 36) states that "The reversed motion (seen with a plus lens) is due to the fact that the image formed by such a lens is inverted." Perhaps I misunderstand his reasoning, but this explanation for the "against" motion does not seem to be correct. When your viewing eye is closer to the lens than its focal length, the image you see is virtual and upright, and *not* inverted; yet, "against" motion is visible. No, it seems to me that the motion itself results simply from "variable prismatic displacement" by the lens; the *direction* of that motion is dependent on the position of the "prism" apex (central in minus lenses, peripheral in plus).

A standard straight prism induces *constant* prismatic displacement. If such a prism is inserted into your line of sight, there will be an immediate displacement of the image *toward* the apex of the prism. However, moving the prism slightly back and forth, in the same manner described above for the lenses, will yield *no* movement of the image. A plus lens, on the other hand, is not a simple straight-sided prism. It can be considered to be composed of a number of different prisms of gradually increasing powers as one moves from the optical center toward the lens periphery. Therefore, viewing an image through progressively more distal portions of the lens forces you to utilize a variable, increasing prism power; this increases the apparent displacement of that object (toward the "prism" apex) through each "prismatic" segment. Motion is thus imparted to the image. As a plus lens is moved to the right, the image seen through it will move toward the left. (Diagram it out for yourself.)

With minus lenses, the apex of the "prism" is always at the optical center, so lens motion to the right will impart motion of the image to the right. Again here, as with the plus lens, the amount of prismatic displacement is variable and increases toward the lens periphery. The exact amount of prism displacement is given by Prentice's rule — the prism displacement induced by any point in a lens is simply the dioptric power of the lens at that point times its distance (in centimeters) from the optical center.

This variable prismatic displacement, then, is what I believe to be the explanation for the motion seen through a lens. (Is it really possible that Sir Stewart has erred?)

NEUTRALIZING CYLINDRICAL CORRECTIONS

Initially, when you pick up an unknown lens for neutralization, you are faced with an immediate question. Does that lens have any

cylindrical power? Detection of cylinder is your first obstacle, which can be surmounted more readily if you first partially neutralize some of the sphere, leaving no more than a diopter or so of spherical residual. (An unknown lens of high plus or minus spherical power tends to mask any coexistent cylinder.) To aid in this cylinder detection you will need some straight reference lines. Luckily, ubiquitous lines are usually available — a doorpost edge for the vertical, and a tabletop edge for the horizontal.

View your straight reference line through the "unknown" lens and carefully align the *image* line with the externally visible straight line. (That line will pass through the optical center of the lens.)* Rock the lens slowly about its optical axis with a wheel-like motion while holding the lens at arm's length — at this distance, it is easier to detect the minimal motion caused by low-powered *cylinders* as well as spheres; look for any rotating motion of the straight line in the image. If this rocking yields no rotating movement of straight lines, one can be fairly sure that there is no cylinder present. (To be absolutely sure, fully neutralize any sphere and recheck for cylinder.)

If you find that cylinder is indeed present, the exact positions of the two axes — the meridians of maximal and minimal power — must be determined. (The meridian of *maximal* plus power is the minus cylinder axis; that of *minimal* plus power is the plus cylinder axis). Using the lens-rocking maneuver described previously, mark the exact lens position which aligns (makes continuous) the externally viewed line and its image through the lens. This line position is one of the two cylinder axes; the other is 90° to it. If the image line seems to rock "against" the direction of the actual lens rock (Fig. *E*), the aligned meridian is the *plus* cylinder axis. It is the *minus* cylinder axis if the rock is "with" the lens rotation (Fig. *F*). Obviously, any cylindrical lens has *both* "with" and "against" rocks. (Do try it yourself to see what is meant!)

After locating these axes you will now neutralize each, using only spheres. This procedure is much easier than one which uses loose cylinders, since you can proceed to the neutralization of a meridian

* If the line seems somewhat eccentric in the lens (Figs. *C* and *D*), there may be some prescription-prism ground into the lens. At least, keep this possibility in mind.

without stopping to think whether you are dealing with a plus or minus cylinder axis. In other words, when you use loose spheres you can disregard the sign of a cylinder axis as a prerequisite for neutralization.

Align either axis with the externally visible line and, *without rocking the lens,* move it side to side, exactly perpendicular to the visible line. Note any "with" or "against" motion; neutralize whatever you find, using spheres and this side-to-side motion until no movement whatsoever is visible. This yields the spherical power of the meridian at right angles to the externally visible line.

After you complete full neutralization of this meridian, turn the lens 90° and again align the image line with the external line. Proceed to neutralize any additional motion present (in the side-to-side direction) with appropriate sphere. Then recheck the first meridian. (Using this technique with spheres, you obviously cannot neutralize all lens meridians simultaneously; however, that is not necessary.)

The maneuvers described isolate the spherical powers of the two principal meridians, and all that is left for you to do is to write the prescription from this information. (The determination of the axis will, of necessity, be through an educated guess via study of the lens fragment. Keep in mind that, for any lens prescription placed on the patient's face, the reference point — 0° axis — starts at the left ear lobe and proceeds counterclockwise — when viewed by the refractionist — for both the right and left eyes.)

For those individuals who might have difficulty in writing the final spherocylindrical prescription from the spherical data obtained above, one can learn to neutralize with spheres and loose cylinders. However, you *should* be able to transcribe the appropriate prescription.

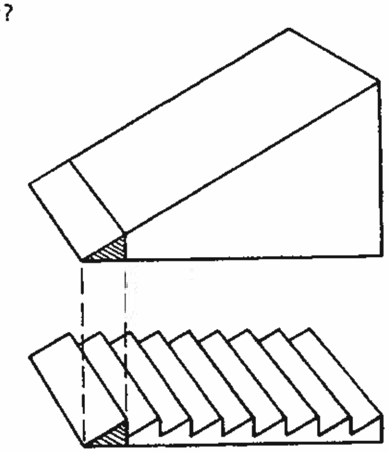
Moral: Wise men are prepared for every exigency. Plan on enlisting in this elite corps by practicing hand neutralization for the day when your lensometer goes "on the blink". (By the way, have you checked yours lately?) *(Article finis)*

Back when we were discussing prisms, I promised to mention the Fresnel surface. So now, while we are elaborating on the many prismatic effects of lenses, I think it's time to pay up.

Fresnel Surface Principle

Any prism introduces virtually the same amount of prismatic deviation over its entire surface — no matter what portion of the prism you may look through — the apex, mid-section, or base. So, any segment or strip of the prism, including the tiny wedge of prism at the apex, is *just* as effective as any other (e.g., the thicker base) in deviating the light.

What if you were to trim off the apex (say, a strip ½ mm wide) from each of a large number of prisms of identical powers and assemble the strips contiguously, laying them side by side as shown in the diagram below?



THE FRESNEL PRINCIPLE

You would then produce a ridged surface which would be able to introduce a fixed amount of prism power into any light path — just as did each large *single* prism from which each apical wedge was cut. What is gained by such a peculiar construction is a tremendous reduction in weight and bulk; what is lost is *some* optical clarity because of the number of ridges introduced by the strips — the amount of clarity reduction, though, depends on how carefully the strips are constructed.

Fresnel discovered this "stripping" principle back in the 19th century. It enabled him to duplicate the optical power of a large diameter and, therefore, heavy lighthouse lens with a much thinner and more manageable one.

For his *lens* construction, the strips were circular and of a gradually *increasing* prism power in each concentric "ring" as one moved away from the center. This gradual change of prism power across the surface, of course, optically mimics a plus lens whenever the prism apices of all the ring strips point away from the center — vice versa for a minus lens.

Now, Fresnel's principle joins hands with modern scientific technology to allow improvements in the method of production of the surfaces. So much so, that feasible and practical *ophthalmic* Fresnel prisms (and lenses too) of almost any desirable power can be manufactured. Various thin, flexible sheets of plastic incorporating a Fresnel surface of lightweight and of very good optical properties are presently commercially available.* These sheets can be cut to spectacle size and can be "pressed on" to the surface of any ordinary spectacle lens. They can create appropriate optical effects with very little of the distortion introduced by standard ophthalmic prisms and thick lenses, since much of that distortion is due to the *thickness* of the glass. Though not *yet* completely replacing these latter appliances, the "press-ons" are readily accepted by patients, especially aphakes and those requiring ophthalmic prisms. We are quite likely to hear more about other exciting applications of the Fresnel "press-ons" in the near future.

CORRECTION OF PRESBYOPIA

We have already touched on accommodation and its progressive loss with age leading to presbyopia. The correction of presbyopia is done simply by the supplementation of the patient's waning accommodative power with plus lenses. We shall assume that any co-existing ametropia has been fully corrected.

* Optical Sciences Group, San Francisco, California

In order to prescribe the correct amount of reading add, you must determine the patient's near point of accommodation. This should be done with a good accommodative stimulus, one which will tax the patient's *full* power of accommodation, such as the smallest letters on a near acuity chart (that is, those corresponding in angular size to the maximally corrected distance acuity). These small letters will demand a continuous, conscious accommodative effort to be kept clear. A card with a graded series of print sizes (by Lebensohn, Sloan, etc.) is used to test each eye separately. Such a card should be supplemented with constant verbal exhortation by the examiner to "keep it clear" in order to help the patient reach his closest "Nearpoint". This tells us how much accommodation a given patient can muster up if he *had* to and will expose his *full* accommodative reserve.

The eye is a biological system with all the associated vagaries, so it has always been surprising to me that the accommodation reserve is so remarkably equal in the two eyes. Since we have always considered that the loss of accommodative power with age is a *local* one for each eye and probably not centrally controlled, why *shouldn't* one eye lose accommodation more rapidly than the other? (Cataracts and other bilateral eye problems are rarely so symmetrical.) In any case, the accommodative loss *is* typically symmetrical, and only rarely is it not. So in your refraction lane with a patient, if you happen to find a closer "Nearpoint" for one eye than the other, suspect the adequacy of your *distance* correction and recheck *that* before proceeding. You may have "under-plused" one of the eyes.

Once the near point is determined, you have an inkling of how your patient compares with others of the same age (Duane's accommodation table was given previously), but that is not of crucial import. What is definitely of major significance is how your patient's accommodative ability fits in with his *own* needs — what level of ability he requires for his own vocation and avocations. This varies tremendously and gives weight to my plea that you don't just read from a table the "proper" prescription for a reading add for a given age. The visual requirements of a machinist, a concert pianist, a stockbroker, and a shoe salesman are all so different that the management of their visual needs must be individualized.

It is said that the patient should be using about one-half his available accommodation to perform the task for which he requires glasses. As is true with rules, there are exceptions, but generally, this seems to work out in practice. Have the patient sit with his eyes closed and use his kinesthetic sense to place his reading matter or close work at a comfortable working distance for himself. Or, you can have him show you where he has to hold his head in relation to his work demand, as a dentist looking at a molar. You can then measure this distance, convert it to the dioptric equivalent and prescribe a glass which leaves one-half his available accommodation in reserve for that distance (after trying it first in a trial frame, of course!).

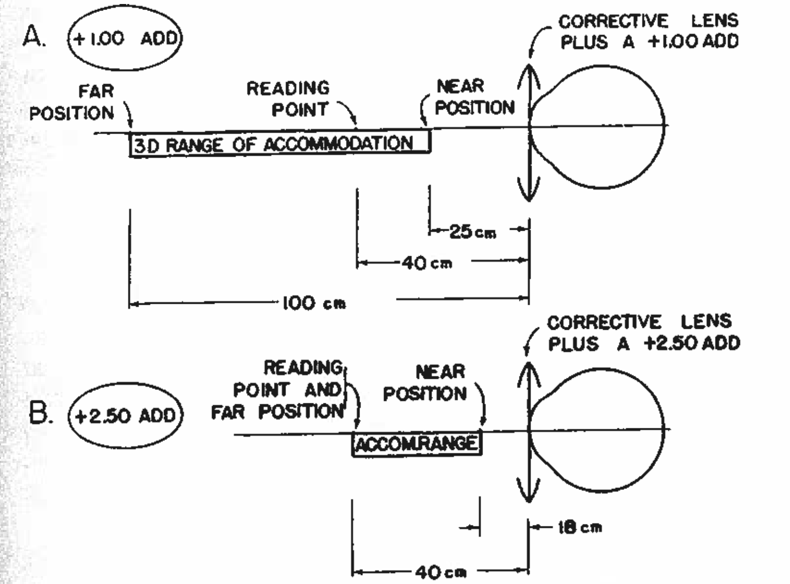
PROBLEM:

A nearpoint of accommodation (NPA) is found to be 33 cm, so the accommodative ability is 3 D. The patient would like to read at 40 cm. What add should I prescribe?

ANSWER:

Since we wish the patient to use ½ of his 3 D amplitude for a task which stimulates an accommodative demand (at 40 cm) of 2.5 D, we arrive at the following: The demand is 2.5 D; the patient is to use 1.5 D of his own accommodation and this leaves 1.0 D to be supplemented. Thus, the appropriate lens to try is a + 1.00 D add over his distance correction. With this in place, he will have a good range of clear vision surrounding his reading "position" at 40 cm.

For this patient, the full extent of his near "range of accommodation" is 3 D; this is his *amplitude* of accommodation. With his reading glasses on, the maximal near position of clear vision is 4 D (as determined by his amplitude of 3 D plus the + 1.00 add). His clear vision range will extend to his furthest position of clarity, where no accommodation will be required; this is to a distance equivalent to 1 D, the amount of his add alone. (See figure A below).



WITH AN INCREASE IN THE ADD, THE ACCOMMODATION RANGE SHRINKS

Always check the *range* of accommodation with the add you plan on prescribing so you can determine if it will be useful to *your* patient.

It is usually an advantage to give as *little* plus add as possible. Sure, you can bring the maximal near point closer by giving more add, but, if you do so, you will lose accommodation range on the far side of the reading position. If this same patient were given a + 2.50 add for his reading (see figure B above), he would not have to exert *any* of his own accommodation to read at 40 cm. However, he will be mighty unhappy since everything beyond 40 cm would appear blurry to him; he will not like this add even though his "new" near point is brought in to a (3 D + 2.5 D), that is, 5.5 D or 18 cm. So, while a 2.50 add *might* be of value to an embroidery seamstress, it will probably not be to a journalist.

Notice that with the 2.50 add, the range of accommodation (though still 3 D) has shrunk from 75 cm (100 — 25) to 22 cm (40 — 18). This shrinkage of zone is one of the main reasons not to prescribe the higher power adds to young presbyopes, that is, unless it is absolutely necessary. Personally, I rarely find it necessary to prescribe a patient's *first* bifocal add until he needs at least + 1.00 D or so. The *frequent* prescription of low power adds makes those who dispense glasses wealthy. (Take that as a hint or a warning, depending on your point of view!)

CLINICAL POINT:

It is amazing how often a 40 year old who has never worn glasses comes into your office with presbyopic symptoms. Do not be tempted to start right in with the near vision tests. You may find that he has some hyperopia which hitherto has been uncorrected.* It is very likely that if you simply correct the *distance* ametropia alone, he will require no near add whatsoever. You'd be surprised at how often this simple point is missed by refractionists.

Say you find that + 1.00 D distance spectacles are necessary for a patient; you prescribe them while telling him that he does not *have* to use them for distance viewing unless he wants to, but should use them whenever he reads and wants to see what he is reading. This is *not* a reading glass even if he uses it only for reading; it is a distance correction. However, it probably will not be too long before he uses it all the time. As he gradually loses more of his accommodative reserve, he'll find it more comfortable not to exert any accommodative effort at all for distance vision — a luxury bestowed by your prescription.

* * *

Of course, as patients get older and lose more of their accommodation, you will have to prescribe more add. However, in doing so, only very rarely will you have to exceed 2.5 D**, and when the patient has lost enough accommodation to require that much add, you will probably also have to add some sort of "in-between power" to take care of the patient's visual needs in the intermediate range (about 50 — 100 cm). In the standard *trifocal* lens, where the distance, intermediate power, and near lens are all put together in one spectacle lens, this "in-between" lens power is automatically about one-half the near add.

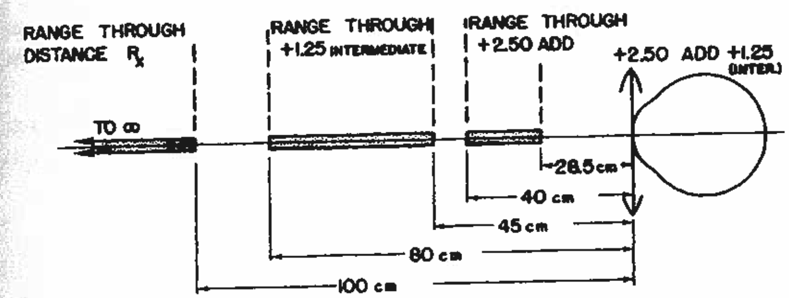
* Even in an adult (including the prepresbyope!), a cycloplegic refraction may well be required to *fully* expose the hyperopia — a fact not often appreciated.

** For an exception to this, read *"The Case of the Myopic Capitalist"*, which is reprinted in Appendix D.

PROBLEM:

A 62 year old patient has an accommodative amplitude of 1 D and wears a + 2.50 D near add with a + 1.25 D intermediate add. Draw a sketch of his zones of clear vision.

ANSWER:



The small "gaps" between zones of clear vision are easily compensated for by shifts in head position. (Don't cheat yourself. Go back and make sure you check the ranges to find out if you understand how they were obtained. I didn't draw this out to demonstrate my prowess.)

CLINICAL POINT:

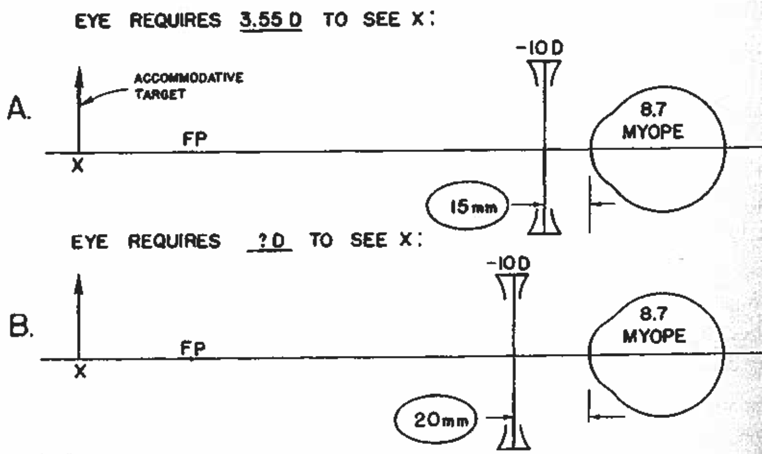
The last few diagrams have shown a corrective lens and the add placed *at* the cornea for schematic simplicity. However, in real life, the lenses are worn in the spectacle lens plane so the vertex distance becomes a factor. Remember, with high minus ametropic spectacle corrections, the accommodation demanded at a given distance is *less* than for an emmetrope; but moreover, the existence of a vertex separation between the lens and the cornea gives the moderate to high myope a bonus. By slipping his spectacles slightly (a few mm) down his nose while he is reading, he further lessens the demand on his own accommodation. This is a little trick all of us pre-presbyopic myopes have learned!

To explain this, let us use the same clinical data we did with the example given previously. This patient was an 8.7 D myope who required 3.55 D accommodation to see reading material held 20 cm from the spectacle lens, which was – 10 D (see figure A below).

If the lens now is allowed to slip down the patient's nose by 5 mm, the optical situation is as diagrammed in figure B below:

PROBLEM:

Calculate the accommodation required.



ANSWER:

$$U + P = V$$

$$-\frac{1}{.195} - 10 = V$$

$$-5.13 - 10 = V$$

$$-15.13 = V$$

$$v = -6.60 \text{ cm}$$

The image is located 6.6 cm in front of the *lens.* Since the lens is now 20 mm from the cornea (originally 15 mm + 5 mm "slip"), the image (which is the "object" seen by the eye), is 8.6 cm away from the *eye.* (That is, 11.62 D away). But the eye is 8.7 D myopic and so

must exert 11.62 – 8.7 or only 2.92 D of accommodation to see it clearly.

We have thus shown that if the – 10 D spectacle lens slips 5 mm further down the patient's nose, his accommodation requirement to see material located 20 cm away has decreased from 3.55 D to 2.92 D, saving him 0.63 D of accommodation — a substantial quantity for a prepresbyope. But, please do not assume that this benefit is limited to *pre*presbyopic myopes. This same principle aids even the presbyopic myope who is wearing some bifocal add in his spectacles, as long as his *overall* lens power (minus correction plus bifocal add) is still minus. So, the presbyopic myope also gains "additional plus" help by letting his glasses slip down his nose; the higher the myopia, the more the "help".

The exact reverse is true for the high hyperope who has to keep pushing his glasses back up on his nose to keep the accommodative demand at a minimum*. (See also Appendix E.)

Bifocals

The types, styles, shapes and forms of bifocal lenses commercially available are manifold. Each manufacturer is constantly plugging his own. I want only to introduce a few principles and not present a full treatise on this subject.

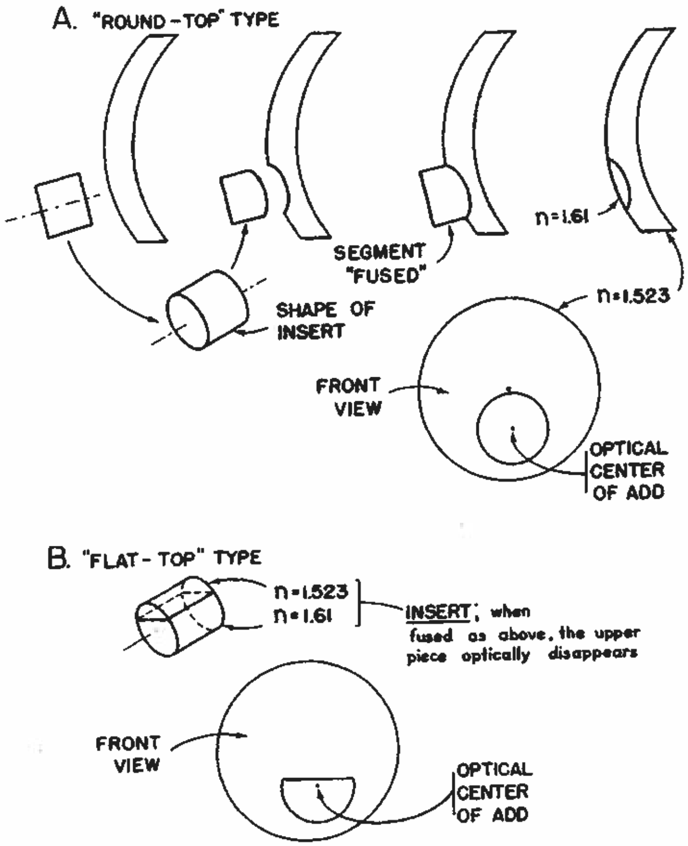
The precise methods of producing a bifocal are not germain here though you should have *some* idea about some of them.

FUSED TYPE:

Usually a plug of glass of high index of refraction is placed into a depression on the front surface of a standard glass lens and fused there at 700°C. The front surface of the add is then polished smooth, to the same curvature as that of the main lens. The bifocal segment area will have a greater dioptric power than the main lens since it is built of material with a greater n', which makes *its* surface power $(\frac{n' - n}{r})$ the greater one.

* This last statement is true *only* when the object distance is less than two times the focal length of the plus corrective spectacle lens. The specific circumstances which govern the inconsistent effect on accommodation of a shift in the position of such a *plus* lens is the subject of another paper: Rubin, M. L., *The Sliding Lens Paradox*, Survey of Ophthalmology 17:180-195, 1972.

THE "FUSED" BIFOCAL

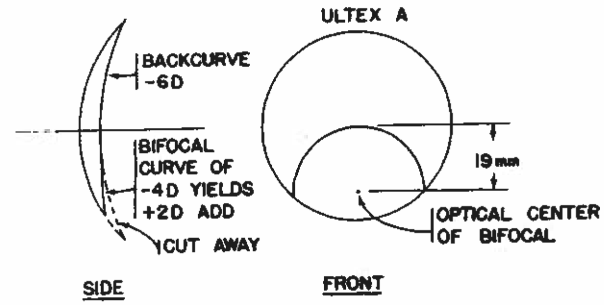


ONE PIECE TYPE:

Another type of bifocal (the "Ultex" type) is ground out of one piece of glass, but the reading area is cut with a different curvature. This area is usually on the back and provides the increase in power necessary to produce the "add".

The radius of the "add" circle (see figure below) may be varied, and each has a different name: the radius of an Ultex *A* is 19 mm, that of an Ultex *E* is 16 mm, that of Ultex *B* is 11 mm.

ULTEX TYPE BIFOCAL



From here on, we will assume that whatever the manufacturing process, all bifocal segments will be equivalent, diopter for diopter, in providing a given amount of add.

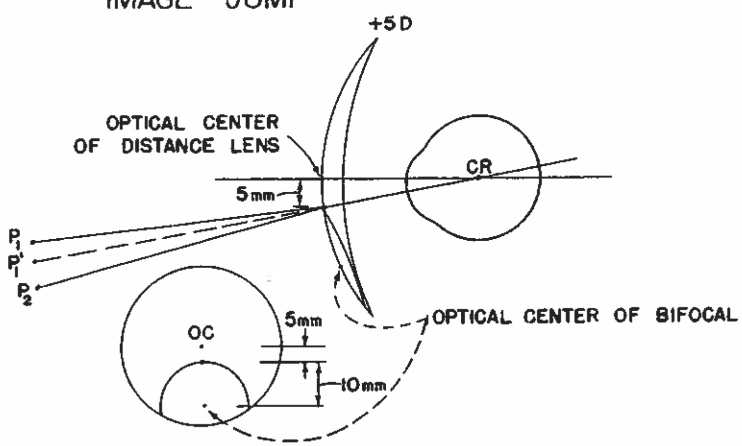
Aside from cosmetic or vocational* reasons for choosing one type of bifocal over another, there are various optical considerations which would encourage you to use a specific type — we will consider only three: the first challenge is to decrease the "image jump" which occurs as the visual axis sweeps across the junction of the top edge of the bifocal segment and the distance lens correction; the second is to reduce the overall quantity of "object displacement" by reducing the total prismatic effect through the reading area of the lens; and the third is to reduce any induced prismatic *difference* in comparable reading areas of the two spectacle lenses, since this difference puts an unequal strain on the vertical eye movements of the two eyes.

Image "Jump"

Prism "image jump" is the commonest and probably the most annoying aspect of wearing bifocals.

* Some types of occupational bifocals have the segments placed at the *top* of the primary lens, such as for inventory clerks, shoe salesmen, and librarians; that is, any presbyope who frequently does close work above normal eyelevel.

IMAGE "JUMP"



Say that to see object P_1 through a distance lens of + 5 D, the eye must rotate to look through a point 5 mm below the optical center of that lens. The prism induced at that point is (0.5 cm) × (+ 5 D) = 2.5$^\Delta$ Base-Up — Prentice's rule. So, object P_1 will appear to be *down* at P_1'.

As the visual axis moves down further, it crosses the top of the bifocal segment. If we consider that the bifocal segment is + 2.5 D add and has *its* optical center 10 mm below the segment top (see front view of lens in above diagram), then, as the visual axis crosses the top of the segment, it *suddenly* encounters (1 cm) × (2.5 D) or 2.5$^\Delta$ Base-*Down* prism. (The prism base of the plus lens segment is at the optical center of the *segment.)*

If there were *no* bifocal segment incorporated into a given plus distance lens, as one's visual axis swept downward, objects would appear to become more and more displaced downward — nothing dramatic, but a gradual shift. (A comparable movement with a *minus* lens would cause an *upward* object displacement.) However, when a bifocal segment *is* present, as the visual axis sweeps across its upper edge, there will be a *sudden* upward shift of any object being scrutinized. This shift is "image jump".

Now look again at the last diagram. As the visual axis crosses the top of the segment, the sudden introduction of base-down prism makes object P_2 appear in the same straight-on direction as that occupied by P_1'. Thus, all the *real* space between P_1 and P_2 is optically collapsed — no object point located therein will be visible. This blind area around the bifocal is identical to the "ring scotoma" around any plus lens; it is less noticeable here than in aphakia since the amount of plus is less.

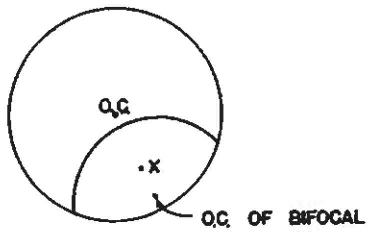
Image jump occurs with any bifocal that does *not* have its optical center at the top of the segment; if this "center" *is* at the top, there will be no image jump. So, it is the location of the optical center of the bifocal *segment* that causes the jump — *not* the influence of the distance correction at all. A corollary is that the further away from the segment top the bifocal's optical center is located, the greater the jump induced for a given bifocal power. Thus, to reduce "image jump" for any patient, the clinician must choose a bifocal type that has its center at or near the top of the segment.

Object Displacement

We studied this phenomenon when we examined how all lenses produce prismatic effects which result in a greater apparent displacement with lenses of high power. (I mentioned that the patient's sensory adaptation to the "new" position of objects caused by new spectacles is quite rapid, thank goodness.)

Bifocal segments can either exacerbate or reduce the apparent object displacement caused by the distance lens in the reading area of that lens. A plus corrective distance lens induces base-*up* prism in the lower fields. This can be counterbalanced somewhat by a base-down prism effect given by an appropriate bifocal segment with its optical center down low. Remember, base-down effect would be produced by the segment between its upper edge and its optical center, so the closer to the bottom of the segment the center is located (the center can even be beyond the segment entirely!), the greater the base-down effect created by this reading add.

For a plus distance lens, such an arrangement as just described can equalize the combined prismatic displacements, but *only* for one specific area.



In the above diagram with the plus distance lens, let us arbitrarily say that point X (through which a patient may read) will have 3^{Δ} of Base-Up prism induced by the distance lens and 3^{Δ} of Base-Down prism induced by the segment. Above point X though, the B.U. effect of the distance lens is reduced, but the B.D. effect by the segment is increased, so overall there is a net *B.D.* displacement. Below X the reverse is true and there will be a net *B.U.* displacement. The exact position of this "null" point, of course, will vary as different lenses and different types of bifocals are considered.

CLINICAL POINT:

Neutralizing the prismatic effect near the chosen reading point of a bifocal lens may be of great value to someone who occupationally must spend much of his time at a desk (a lawyer, bookkeeper, or draftsman, etc.). To such an individual, reduction of image displacement may be a very important need, and he might gladly tolerate the increased "image jump" at the bifocal top which is obligatorily present in the above example. You should be able to see that attempting to correct "object displacement" for this patient (as for anyone who wears a high plus lens) will only make matters worse as regards "image jump". In contrast, to someone whose vocation requires a constant need to change from distance vision to near (with the visual axis continually criss-crossing the upper bifocal edge), "image jump" elimination would be the more important consideration. A steeplejack

would be more likely to require help for "image jump" rather than for "object displacement", and so would a waitress.

For any hyperopic presbyope, then, you cannot have the best of both worlds. You'll have to choose which defect you want to reduce since correcting one will worsen the other. The myope, however, is golden in this regard. Since base-*down* prism is induced in the bifocal area by the distance lens, a bifocal segment with the center near the top would induce base-up prism to counter the base-down; in addition, it would obtain the fringe benefit of reduced "image jump" too!

Both "image jump" and "object displacement" are made manageable by manipulating the same bifocal variable — the distance from the top of the segment to its optical center, and so, depending on what you wish to influence, you can choose segments with the center near the top or near the bottom.

Induced Prism Difference

The third defect caused by the prismatic effect of corrective lenses is the induced vertical prism *difference* at comparable reading points on two spectacle lenses which are anisometropic (of unequal refractive power). We saw such an example previously on p. 243. Since this optical problem may cause even more symptoms than the others discussed above, we should be concerned with ways of eliminating it, and fortunately there *are* a few ways to help reduce the induced prism difference.

1) Use two *different* types of bifocal segments — one for each eye: segments with different positions of their optical centers would vary their prism induction at the reading point desired; so, if you choose the two properly, you can sometimes eliminate the anisometropically-induced prism difference.

2) Actual compensating prisms *could* be ground into the segments, but this is not cosmetically acceptable to most patients. However, there *is* a feasible method available and it is occasionally used; it is not really a "compensating prism bifocal" but fits more nearly into this category. That method is called "slab-off" or "bi-centric

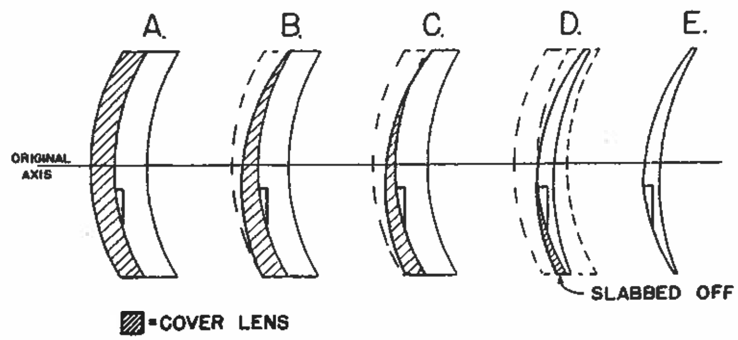
grinding" in which a lens is ground so as to remove extra base-down prism, usually from that spectacle lens of the pair which has more minus power in its vertical meridian. In effect, then, "slab-off" grinding "adds" base-up prism to help balance out any induced prism difference in the reading position.

"Slab-Off"

I am asked so often how this "slab-off" grinding is accomplished that, for those of you that are interested, this exposition is given below. This is *not* a very important detail, however.

First, a definition: A lens "blank" is a partly-finished lens having either the front or the back surface curvature completely ground and polished. (A lens "blank" which has a "fused" bifocal segment embedded on the front surface usually has *that* face already finished.) When an order comes to the optical shop to make a lens to a specific prescription, a lens "blank" is chosen which has the appropriate front surface power and the proper add already incorporated; the additional power may then be ground on the rear surface to provide the desired overall power. It is just such a lens "blank" with a fixed "base curve" on the front surface that we use in the "slab-off" method.

"SLAB-OFF" GRINDING



On top of this lens "blank" another "cover" lens (of immaterial refractive index) is cemented (A) and the entire combination is placed on a lens grinding machine; but, it is positioned *off* the original axis of the lens blank, so that the grinding wheel will cut the upper part of the lens first (B). The front surface of this combination is ground and polished with the same curvature as that of the *original* blank so the front surface power remains the same. This peculiar method of grinding creates a new, second optical center which, in the diagrams, is located *below* the old one.

After the lens is ground further (C and D) so as to reach the upper edge of the bifocal, the remaining piece of cemented glass below (covering the segment) is then knocked away, or "slabbed-off", leaving the original lens with two identical curves on the front providing the same surface power above and below. The line of intersection between these two curves (or between *any* two identical spherical curvatures) must necessarily be a straight line. Because of this, it is more cosmetically acceptable to use a flat-top bifocal segment in the "slab-off" method of grinding; the flat top is aligned with the straight intersection line on the front surface.

Now the lens is completed as any regular lens "blank" by grinding away the back surface to yield the proper total corrective lens prescription. The back surface is ground on the same "new" axis as that on which the front surface was just ground. This removes the back area of the lens as shown in diagram (D) and leaves the finished lens (E).

You should be able to see that the segment of glass "slabbed-off" has a base-down prism appearance and, therefore, this method removes base-down prism from the reading area, typically between $1\frac{1}{2}^{\Delta}$ to 6^{Δ}.

* * *

The need for the slab-off method of grinding (or, for that matter, any of these methods of compensating for the differential prism in the reading area) is only necessary for the presbyope, since the non-presbyope can always look through the optical centers of his distance lenses where there is no interference by any prismatic displacement whatsoever. This last comment leads us to the third method for avoiding a troublesome prismatic displacement.

3) You could forget completely about using a *bifocal* at all and revert to full, single-vision *reading* glasses (with the necessary plus add power incorporated into the distance prescription). Here you entirely bypass the problem of any anisometropic prism difference which may exist in the reading area of the lens.

ABERRATIONS

When the term "first order optics" was introduced to describe the level of mathematics we would need in order to show the action of lenses on light rays, I elaborated on the necessary approximation, $\sin\theta = \theta$; I mentioned that for our purposes that was all the refinement necessary to present the material in this book. I lied. There *is* a bit more detail you should have, some of which would not exist were it not for "third order optics". (Have you forgotten this term already?) This material need only be touched on, but must be included to round out your basic understanding of some clinically useful information. It deals with the aberrations of optical systems — the term *abberration* signifying that an optical system fails to produce an image which is an accurate representation of an object.

Just as you might suspect, there is more than one type of aberration. Here we will discuss one which occurs because of the *multi-*wavelength nature of light and others which exist even when dealing with *monochromatic* light. Aberrations can either deform the overall image (such as distortion and curvature of the image plane), or destroy the sharpness of each image point (such as, spherical aberration, radial astigmatism and coma).

Though many special purpose optical systems are specifically designed to eliminate certain of these aberrations, *all* optical systems* possess these defects to a greater or lesser extent. For practical purposes, I will consider the aberrations in two groups — those mainly affecting the optics of the *eye*, and those most applicable to corrective *lenses*.

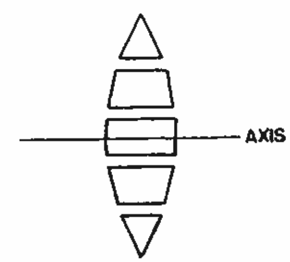
* Mirrors, however, do *not* introduce chromatic aberration since the angle of reflection is equal to the angle of incidence for *all* wavelengths.

Aberrations — With the EYE as an Optical Instrument

Chromatic Aberration

When the term "refractive index" was discussed, I stressed that the decrease in the velocity of light which occurred when light entered some medium was dependent not only on the medium itself but also on the *wavelength* of the light. The fact that *each* wavelength has its own, private refractive index number for each medium accounts for chromatic dispersion by a prism. In passing through a prism then, the blue (or short) wavelengths of light are always bent the most, the redder (longer) ones, the least. (This was diagrammed in the section on refractive index.)

As you should now know, lenses are "modified" prisms. In reality we *should* think of a "lens" as a *stack* of prisms of gradually changing prism power as we leave the axis. (In the figure below, such a "stack" comprises a plus lens.)



However, for schematic purposes, let's neglect the "changing prism" power aspect and depict a lens cross-section as consisting of only two straight prisms; a plus lens is represented by two prisms with their bases in contact — a minus lens, with the two apices touching.