Myopia - the ametropia and its compensation

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The ultimate aim of the quest must be neither release nor ecstacy for oneself, but the wisdom and power to serve others.

- Joseph Campbell

"Optical pharmacists" -- as ophthalmic dispensers, that is really what we are. Oh sure, we all spend much of our time cleaning glasses, making them "just a little bit tighter" and doing paper work. The most important thing we do, however, is guide the customer through the confusing selection of lenses and frames to best compensate for their particular optical deficiency. Like the pharmacist, we often must describe the pros and cons of the different medicines we dispense -- in our case, lenses. And often the customer will ask for our recommendation. To make the best recommendation, we need to understand their visual deficiency and the characteristics of the lenses needed to perform the compensation. In this treatise, I will explore the optical deficiency of simple myopia starting with the definition of the condition. Once we understand the disorder, we can then delve into how simple myopia is compensated for in a spectacle prescription. A professional dispenser should also be aware of the characteristics of the lenses used as well as any special considerations in lens selection and fitting. Without a good understanding of the nature of both the ametropia and the mechanism of its correction, we, as opticians, are less likely to succeed in correctly filling the prescription. Remember, the prescription is only as good as the optical pharmacist who fills it.

Emmetropia is the condition of the eye we would all like to have. An emmetropic eye is defined by Troy Fannin and Theodore Grosvenor as "one in which, with accommodation at rest, infinity and the retina are conjugate points."[1] This simply means that when the crystalline lens has the least amount of refractive power, (accommodation is most relaxed) light coming from optical infinity comes to a point focus on the retina. In the myopic eye, infinity and the retina are not conjugate points and the point focus lies in front of the retina.

There are three possible reasons the refracted light may focus before reaching the retina. Axial myopia is when the eye is too long for the assumed ideal refractive power of the eye. The eye has the correct amount of focusing power but the retina is positioned behind the focal point. For illustrative purposes, I will use the Gullstrand exact schematic

[1] Troy Fannin and Theodore Grosvenor. *Clinical Optics* Butterworth-Heinemann. 1984. p 127.

eye as defined in H. H. Emsley's *Visual Optics* [2] where the ideal total refractive power of the eye is 58.64 diopters and the ideal axial length is 24.00 millimeters (Figure 1).[3]

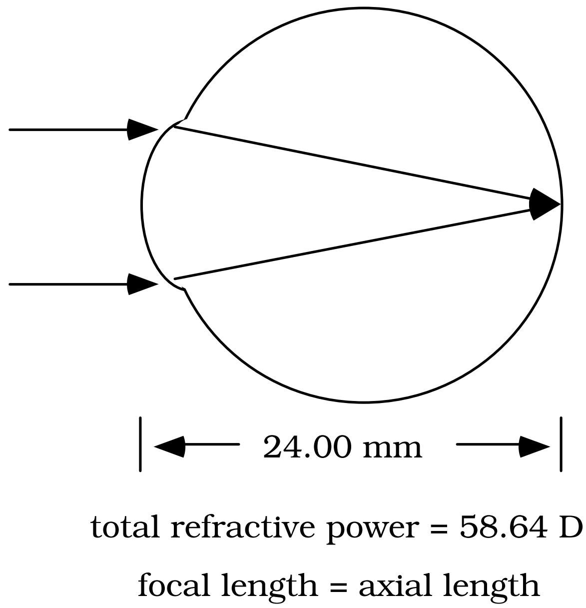
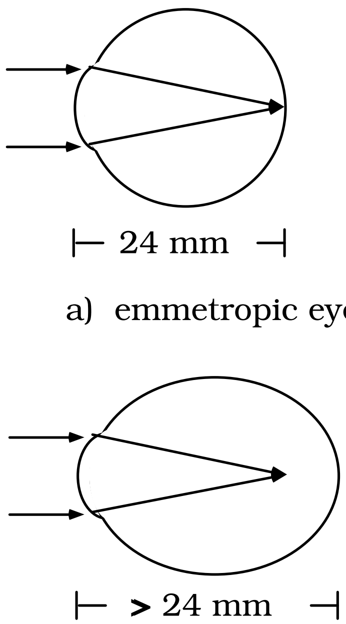


Figure 1. Gullstrand's exact schematic eye.

In our example, the eye with axial myopia would have an axial length of greater than 24.00 mm (Figure 2). Refractive myopia is the condition when the eye has too much convergent refractive ability for its ideal length. The extra convergence of the light is usually caused by increased curvatures or refractive indices of the cornea or the crystalline lens. Our schematic eye, for example, has more than 58.64 diopters of convergence (Figure 3).

[2] H. H. Emsley. *Visual Optics* Vol. 1. Hatton Press. 1963. pp 343 - 348.

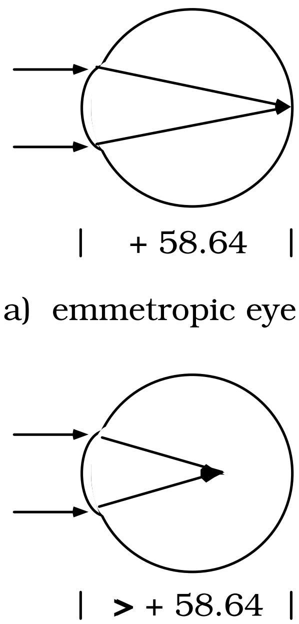
[3] For those who take the reciprocal of the total power of the Gullstand exact eye and realize that it does not equal the focal length of 24.00 mm, don't panic. Gullstrand's exact eye accounts for much more than these two measurements. Gullstrand broke the eye down into different refractive indexes for not only the cornea and lens, but also for the aqueous, lens cortex, lens nucleus and the vitreous. Factoring all these variables as well as thickness into wave vergence formulas results in an amazingly accurate answer. An interesting sidelight is that while the "exact" eye is 1.00 D hyperopic, it is considered that the focal length does match the axial length!



a) emmetropic eye

b) Axial myopia

Figure 2. Axial myopia



a) emmetropic eye

b) Refractive myopia

Figure 3. Refractive myopia

Remember, that by definition, the accommodative system is at rest in normal myopia. If the extra convergence is in the lens but is caused by excessive accommodative tone[4] or a ciliary spasm,[5] the condition is a pseudo-myopic one and treating it as a real myopia would only make the condition worse.[6] Fortunately, recognizing pseudo-myopia is in the realm of the doctor. The final reason for the myopic eye is simply a combination of the eye being both "too strong and too long." Sorsby et al.[7] found that ametropic eyes within 4.00 diopters of emmetropia have a mixture of refractive and axial ametropia whereas

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[4] Accommodative tone is a reflection of how tense the ciliary muscle is when at rest. If the tone is excessive, the ciliary body forms a smaller annulus reducing tension on the zonules. The relaxed zonules then allow the lens to reach a more curved form, adding more convergence to the system, artificially creating a myopic condition.

[5] The ciliary spasm, while similar in effect to excessive accommodative tone, is a result of the eye accommodating and then not being able to easily relax. The net result is also a pseudo-myopic condition.

[6] Benjamin Milder and Melvin L. Rubin. *The Fine Art of Prescribing Glasses Without Making a Spectacle of Yourself.* Second edition. Triad Publishing Company. 1991. p 80.

[7] A. Sorsby, B. Benjamin, J. B. Davey, M. Sheridan and J. M. Tanner. *Emmetropia and Its Aberrations: A Study of the Correlation of the Optical Components of the Eye* Medical Council Special Reports Series, No. 203. H. M. Stationery Office, London. 1957.

those eyes with greater than 4.00 diopters of ametropia are almost purely axial in nature. While these classifications are largely abstractions due to the wide range of normal lengths and powers, the optician should be aware of the predisposition of the axial myope to vitreoretinal abnormalities such as posterior vitreous detachment and retinal tearing.[8] In the event that a customer may call the optician with complaints such as "streaks of lightning" or a sudden vision loss, the optician should be aware of such common symptoms that would warrant immediate referral to the doctor.

Having explored the etiology of the myopic condition, the optician needs to be aware of the various options available for the correction of the nearsighted ametropia. While opticians are not expected to perform these corrective procedures, we should at least be aware of them. Perhaps the most well know surgical correction of myopia is RK or radial keratotomy. This is the procedure where an ophthalmologist makes a series of radial incisions on the cornea to allow it to flatten the curvature and thereby reduce the convergence of the cornea and move the focal point back to the retina. A related technique is that of photorefractive keratotomy (PRK). A laser is used in this refractive surgery to excise a thin portion of the anterior cornea (the second and third corneal layers -- Descemet's membrane and the stroma, respectively) flattening the surface and, as in RK, reduce its convergence. A lesser known technique is called epikeratophakia. In this modality, a corneal button is custom-shaped on a surgical lathe and then sutured to the recipient's cornea. As with the other types of refractive surgery, the intent is to flatten the curvature of the cornea to correct the myopia. [9] [10] [11] Orthokeratology is a nonsurgical technique used to flatten the corneal surface by wearing a series of progressively flatter fitting contact lenses to reshape the cornea even after the contact is removed. This treatment, however, is not a permanent correction as the patient will have to periodically wear the contacts to maintain the corneal shape. This technique has slipped somewhat out of vogue with the advent of the 30 minute refractive surgery.[12]

Now, the doctor has finished the examination, told a nearsighted Mr. Jones that he is not a good candidate for RK and has written a spectacle prescription. How does that

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[8] William M. Hart, Jr., editor. *Adler's Physiology of the Eye* Ninth edition. Mosby Year Book. 1992. pp 321 - 329.

[9] Marchon and Marcolin Training Center. Lesson 1 The Optics of light and vision: Understanding the visual process. 1990. pp 6, 7.

[10] Stephen J. Rhode and Stephen P. Ginsberg, editors. *Ophthalmic Technology: A guide for the eyecare assistant.* Book 3. Raven Press. 1987. pp 255 - 260.

[11] Deborah Pavan-Langston, editor. *Manual of Ocular Diagnosis and Therapy*. 4th edition. Little, Brown and Co. 1996. pp 123 - 129.

[12] Benjamin Milder and Melvin L. Rubin. *The Fine Art of Prescribing Glasses Without Making a Spectacle of Yourself.* Second edition. Triad Publishing Company. 1991. p 75.

series of numbers on the R_X pad translate into Mr. Jones being able to see your credentials on the wall across the room?

As we have seen, the myopic eye focuses the light in front of the retina. With the surgical forms of correction, the curvature of the cornea is flattened to reduce the amount of convergence. A method of compensation available to the myope is to increase the amount of divergence the light incident upon the cornea has. Recall our original definition of myopia that had the object at infinity. It is important that our definition of myopia includes the object being at optical infinity because this tells us the vergence of the light incident on the cornea.[13] When the object is at infinity, its vergence is considered to be zero. Any vergence caused by the object's position must be included in the total refractive power of the eye. (Note that at 20 feet, approximately 6 meters, the vergence of the wave front is actually -0.16 diopters.) So, we add the vergence of the incident light to the convergence of the eye 0 + 58.64 = +58.64 diopters of convergence. If we have a divergent wave incident upon the cornea, the total power will be reduced. For example, if the object is positioned so that the wave has a vergence of -2.5 diopters, the total power becomes -2.5 + 58.64 = +56.14. Our convergence is lessened and we have moved the focal point back to the retina.

The ametrope has two methods of increasing the divergence of incoming light. First, bring the object closer. Bringing the object closer increases the amount of divergence the light wave entering the eye has. This decreases the amount of total convergence and moves the focal point back toward the retina. The stronger the degree of the ametropia, however, the closer the object must be held. This is why many simple myopes can read better when they take off their glasses. The second method is to wear the glasses to see better at a distance. The glasses the myopic ametrope wears cause the light to diverge which moves the focal point back to the retina allowing Mr. Jones to see those credentials on your wall. So, how does the spectacle lens do this?

A prism is a wedge shaped piece of ophthalmic material that causes light to change direction. For any prism, the light passing through it will be deviated toward the base of the prism (Figure 4). When the newly directed pencil of light stimulates the

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[13] For those not familiar with wave vergence, most basic physics and optics texts should have more than ample discussions. Perhaps the most important formula is one relating the distance from the point focus (the focal point for a convergent wave and the point source for a divergent wave) and the dioptric power of the wave.

FOOTNOTE CONTINUED ON NEXT PAGE

wave vergence = 1/distance from point focus or source in meters

For example, if the vergence of a wave front is measured two meters from the source, the power of the wave is 1/2 or 0.5 diopters. The sign convention would quantify the 0.5 diopters as -0.5 diopters for a diverging wave front.

photoreceptors in the retina, the signal processed by the brain cannot discern that the light did not always come from that direction. The brain traces the path of the light ray back to what appears to be its original source. The source of the light appears to be an object closer to the apex of the prism[14] (Figure 5). Now imagine a second prism placed apex to apex on top of the first prism (Figure 6). Draw the ray for the upper prism (Figure 7). Note how in figure 7 the two prisms project an image that is smaller and closer to the adjoining apexes and the deviated rays are diverging. A minus, diverging lens acts much like a pair of prisms joined apex to apex. A diverging lens may even be thought of as an infinite number of prisms all oriented with their bases toward the outside of the lens.[15]

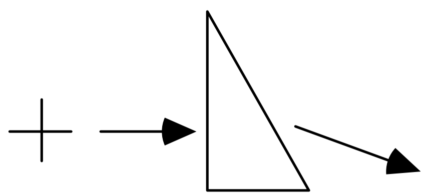

Figure 4. Deviation toward base

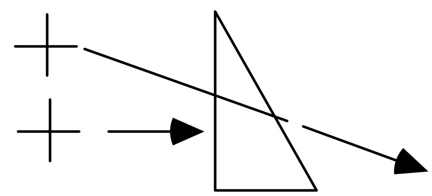

Figure 5. Projection of image toward apex

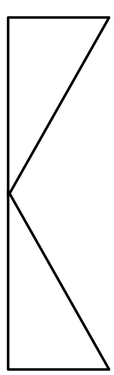

Figure 6. Apex to apex prisms

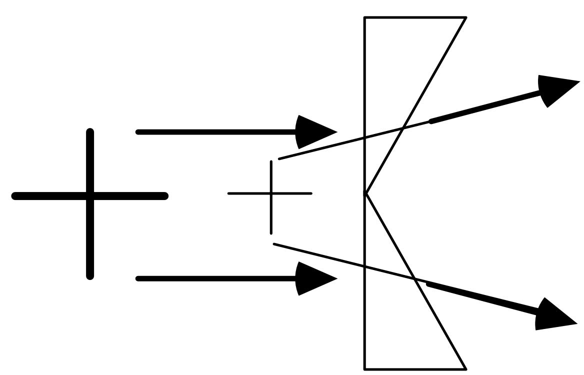

Figure 7. Projected image

[14] Michael P. Keating. *Geometrical, Physical and Visual Optics* Butterworths. 1988. p 355.
[15] Russell Stimson. *Ophthalmic Dispensing* Charles C Thomas Publishers. 1979. p 118.

For a more precise mathematical explanation, we shall use Snell's Law. Snell's Law states that "the index of the medium in which the ray travels before the interface times the sine of the incident angle is equal to the index of the medium in which the ray travels after passing through the interface times the sine of the refracted angle."[16] [n sin i = n' sin i'] (Figure 8) For our mathematical model, we will use an idealized diverging lens with a flat front surface and a refractive index of 1.50 and it will be surrounded by air (n = 1.00). The light will also be from a source at infinity and so has zero vergence at the lens surface (Figure 9).

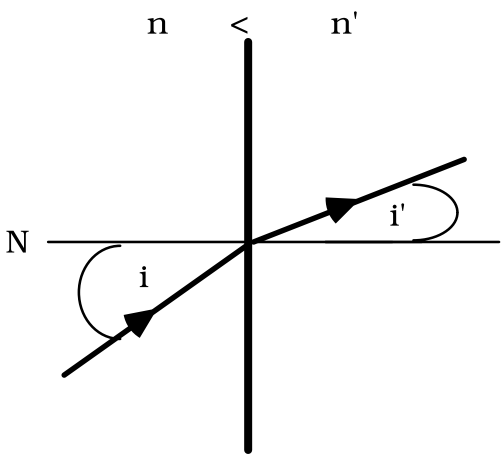

Figure 8. Snell's Law

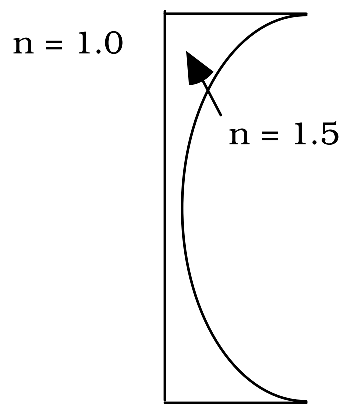

Figure 9. Idealized Diverging Lens

Now, for the first interface, the initial medium is air and the angle of incidence is zero degrees from the normal. Our formula variables then become: n = 1.00, i = 0, n' = 1.5. So (1.00)(sin 0) = (1.5)(sin i'). To find the refracted angle, rearrange the formula to become (1.00 x sin 0) / 1.5 = sin i'. Taking the sine of the left side gives the refracted angle of zero. That is, the ray has not been deviated and is perpendicular to the first surface (Figure 10). The light, which is now inside the lens, comes to the rear surface that does have a curve. Now draw a tangent to the curve of the lens. For our example, we will specify that the light ray will be incident on the surface at an angle of thirty degrees (Figure 11). Redefining our variables: n = 1.5, i = 30, n' = 1.00. Substituting the variables into the formula it becomes: (1.50 x sin 30) / 1.00 = sin i'. Solving the left side we have (1.50 x 0.5) / 1.00 = 0.75. Taking the inverse sine, the refracted angle becomes 48.59

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[16] David S. Loshin. *The Geometrical Optics Workbook* Butterworth-Heinemann. 1991. p 27.

degrees. This refracted ray has been deviated by 18.59 (48.59 - 30.0) degrees further away from the normal, making the ray divergent in nature (Figure 12). So, using either prism theory or Snell's Law shows that light exiting a lens that has a steeper curve on the back surface (and is therefore thinner in the middle) will cause light to become more divergent than the light incident on the front surface. It is this extra divergence that moves the focal point back to the retina giving a clearer image.

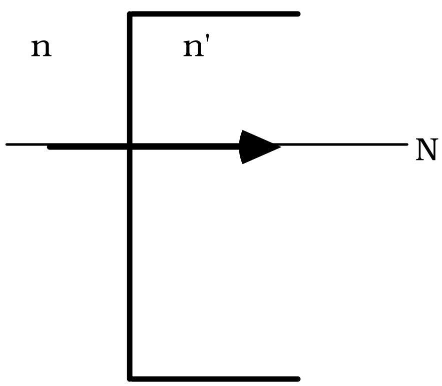


Figure 10. Refraction at First Surface

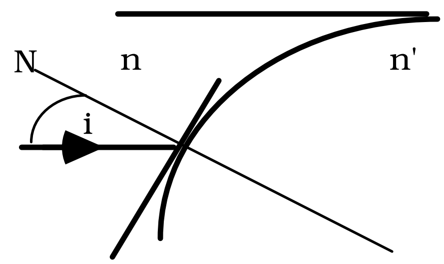
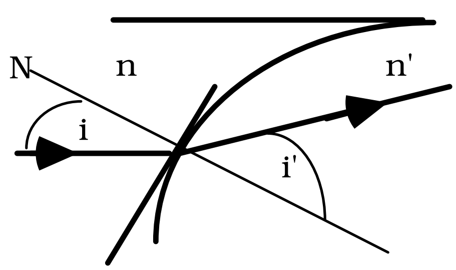


Figure 11. Light Incident on Second Surface



i = 30 i' = 48.59

Figure 12. Refraction at the Second Surface

Now we know what the spectacle lens does for the myope, but what characteristics do Mr. Jones' -5.00 lenses have of which we should be aware? The first characteristic is the one the customer will most often comment on. "Everything looks smaller" is frequently the questioning comment made by the wearer of the more myopic prescription and is caused by the characteristic of minification.[17] As we saw earlier (Figure 7), the diverging nature of the light leaving the lens makes objects look closer but smaller. This effect is seldom troublesome to the spectacle wearer as the changes are usually very small[18] and easy to adapt to. In many cases, it is not the minification of objects being seen by the person, but rather that the eye behind the lens looks smaller to the observer that causes frustration to the myopic customer.

A positive effect the wearer of the diverging lens might be aware of is an increased field of view. How can we explain this expanded field of view? There are two ways to look at this phenomena: intuitive and with geometrical optics. Intuitively, think of the lens as being a window frame that the wearer cannot see around. Now think of a large photograph of a giant cross placed behind the window frame so that the picture fills the entire window frame (Figure 13). Now the photograph is shrunk in size but placed the same distance away from the window. Now that the picture is smaller, you can see more of what is around the cross (Figure 14). Your field of view has been expanded by making the picture smaller. Now lets try to justify the increased field of view using geometrical optics. Remember that the diverging lens behaves much as prisms placed base out. This prism orientation projects the image inward toward the prism apex. By moving the image inward, the wearer can see further toward the outside giving a wider field of view. Draw a lens and project the line of sight in a straight line (just as the brain thinks the light is behaving) through the most distant portion of the lens (Figure 15). The brain thinks that it is looking through the

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[17] An interesting aside is that many customers will actually say that things look larger regardless of the amount of minification. What they really are noticing is a larger degree of clarity and not size.
[18] No pun intended.

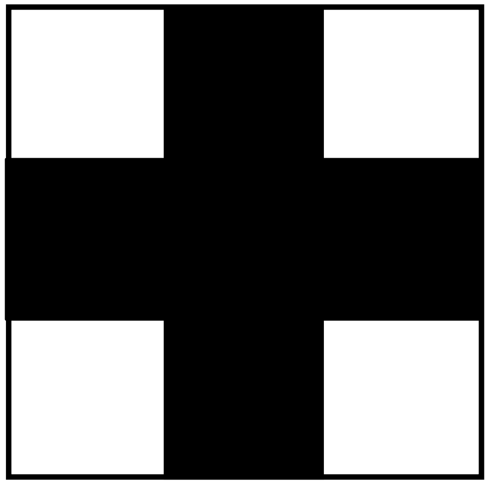

Figure 13. Window full of cross.

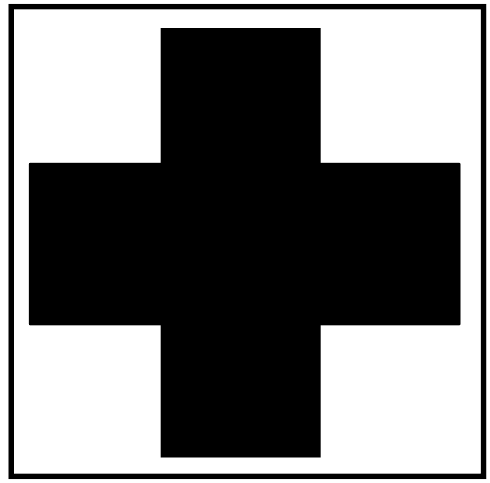

Figure 14. Smaller picture - larger field of view

most distant portion of the lens at some object, but we know that it is looking through a prism that has deviated the direction of the light. The effect of the prism was to bend the light toward the base of the prism. We already have the light entering the eye from the furthest edge of the lens, so imagine the light incident upon the lens at a steeper angle so that it will be deviated along the line of sight that we have already established (Figure 16). This line is the actual line of sight that the wearer has through the lens. The actual light entering the eye has a wider area than what the eye thinks it has.[19]

An effect related to the increased peripheral vision is an area near the edge of the lens where the person sees two of everything. This is called a ring of diplopia. This ring of diplopia is caused by the increased peripheral vision. With smaller lenses becoming more popular, spectacle wearers can more easily see objects outside the field of view of the lens. Even though these objects seen without benefit of a correcting lens are blurred, the wearer might be aware of them. The ring of diplopia is caused by the small overlap of the objects seen outside the lens with that seen because of the increased field of view through the lens[20] (Figure 17). The image to the observer would be that of two images: one smaller and in focus as viewed through the lens and one larger, but blurred, to the outside of the clearer image (Figure 18).

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[19] Troy Fannin and Theodore Grosvenor. *Clinical Optics* Butterworth-Heinemann. 1984. p 382.
[20] Troy Fannin and Theodore Grosvenor. *Clinical Optics* Butterworth-Heinemann. 1984. p 382.

While the previous three characteristics keep the proportions of the object being seen the same, the next characteristic actually distorts the shape of the viewed object. Barrel distortion is the term used to describe the typical shape alteration caused by the minifying lens of the myope. We have already established that the diverging lens creates a smaller image. What we did not discuss is that the

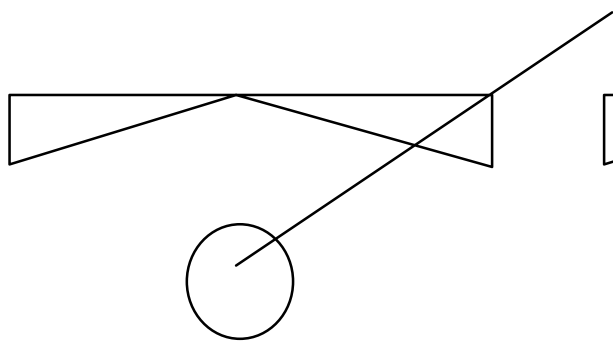

Figure 15. Apparent line of sight

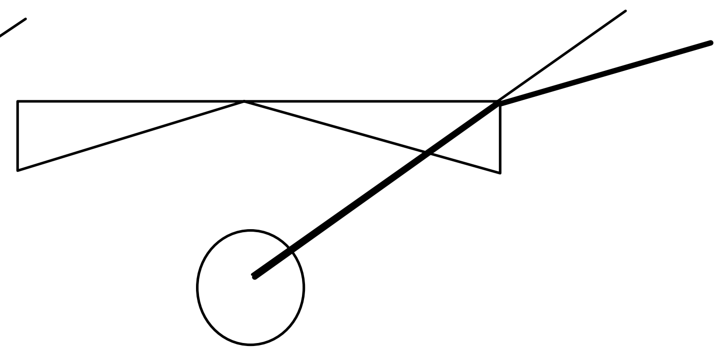

Figure 16. Actual line of sight

minification is also dependent on the distance from the optical axis of the lens. Magnification/minification is defined as the ratio of the absolute value of the image distance to object distance.[21] If we measure the distance from the object to the lens (the object distance), the distance will be very similar for all points on the object (Figure 19). Now consider the image distances. For any given image distance along the optical axis (Figure 20, distance c), the light ray must travel further for a peripheral ray (Figure 20, distance d) more distant from the optic axis. (Note that in figure 20, the light is shown to form a real image behind the lens. I have taken some liberty here by switching the virtual image that would have formed in front of the lens to a real image behind the lens. I have only done this to make the diagram less cluttered on the left of the lens but realize that the light leaving the lens to the right is diverging and will form

[21] Michael P. Keating. *Geometric, Physical and Visual Optics* Butterworths. 1988. p 119.

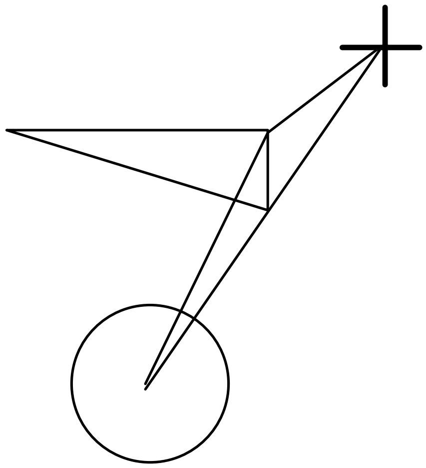

Figure 17. Object viewed with and without lens.

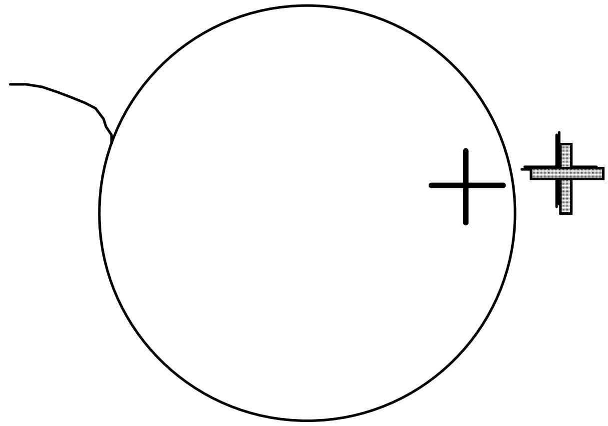

Figure 18. Ring of diplopia as viewed through lens for one object.

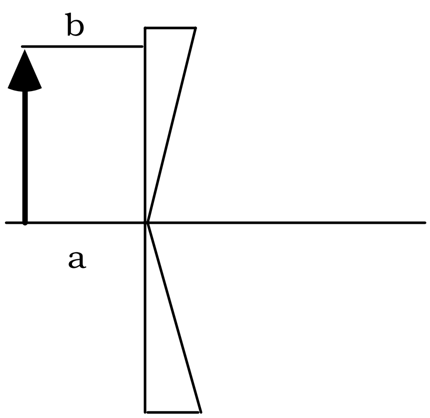

Figure 19. Equal object distance points

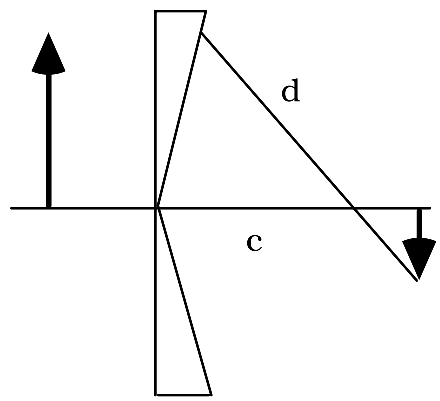

Figure 20. Axial ray c is shorter than peripheral ray d

a virtual image to the left of the lens.) Now, when we substitute our ray diagram lengths into the minification formula, the minification for the axial ray is given by $|c/a|$. The formula for the peripheral ray then becomes $|d/b|$. Since $|c|$ is less than $|d|$, the minification ratio for the periphery is greater than the axial minification. This means that those portions of an object seen further from the optic axis will look smaller than those objects viewed along the optical axis. To the wearer, this phenomenon may be expressed in two different ways. In all cases, any line viewed through a portion of the lens other than the optical center will appear to be curved. In most cases, the effect demonstrated by a square will be observed where the edges appear to be bowed outward from the center (Figure 21). In the case where all the points of the object are equal distances from the optic axis (a circle) the shape will not be altered. If, however, the wearer is looking at a set of concentric circles, the distances between the circles will not maintain the same proportions but will appear to be getting closer together as the circles further out appear to be smaller than they really are (Figure 22).[22] [23] As with all lens characteristics, the stronger the power of the lens, the more exaggerated the barrel distortion appears. In lower powers, these characteristics are minimal, if observable at all.

The most common complaint about spectacle lenses for myopia is probably made by the person who observes the wearer of the lenses -- those annoying concentric rings of light seen near the lens edge. Those rings of light are reflections of the edge of the lens. As light enters the thicker lens edge, the edge becomes a source of light. As the lens edge "emits" the ray of light, the light strikes the rear surface of the lens but strikes at such an oblique angle that it reflects off the rear surface and travels toward the front surface. At the interface between the front surface of the

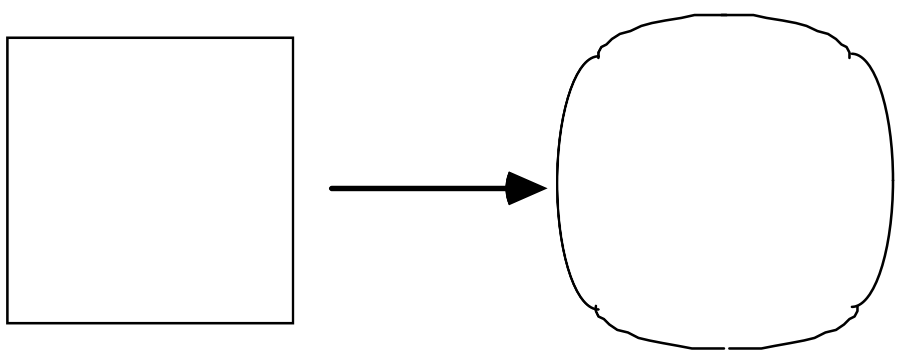

Figure 21. The barrel distortions of a square object

[22] Michael P. Keating. *Geometric, Physical and Visual Optics* Butterworths. 1988. p 446.
[23] Troy Fannin and Theodore Grosvenor. *Clinical Optics* Butterworth-Heinemann. 1984. p 161.

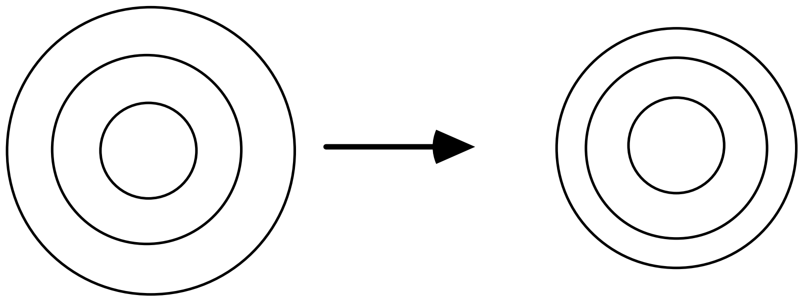

Figure 22. Barrel distortions of concentric circles

lens and air, the light may either exit the lens toward the observer or be reflected back toward the rear surface of the lens. If the light does exit the lens, an observer will notice a ring of light near the edge of the lens. If the light continues toward the back surface, the same thing happens at the rear surface: if the angle of incidence is too shallow, the light is reflected back toward the front surface but more toward the center of the lens; if the angle was steep enough to pass through the surface, the wearer might see a ring of light (Figure 23).[24]

So, how shallow is too shallow? If the light is to be totally internally reflected, the sine of the angle of incidence must be greater than the ratio of the refractive index of the media trying to be entered to the refractive index of the media the light is in: sin • > n' / n.[25] Presuming a lens refractive index of 1.5 in air (n' = 1.00), if the light is incident on the surface more than 41.8 degrees from perpendicular, the light will not pass through the surface but will be reflected to the next surface.[26] Unfortunately, as the refractive index gets higher, the light must be incident even more perpendicular to the surface to not be totally internally reflected.

[24] Troy Fannin and Theodore Grosvenor. *Clinical Optics* Butterworth-Heinemann. 1984. p 230.
[25] Michael P. Keating. *Geometric, Physical and Visual Optics* Butterworths. 1988. p 356 - 358.
[26] This angle, which must not be exceeded for light to pass through, is called the critical angle.

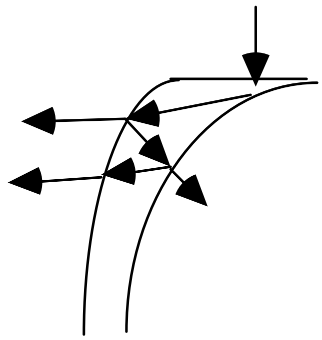

Figure 23. Internal reflections causing rings

Another factor to be aware of related to internal reflections is that of other reflections. Again, in a refractive index dependent situation, the higher the refractive index, the greater the amount of light that will be reflected from the surface -- even if the light is incident perpendicular to the surface.[27] This is not to say not to use high-index materials -- simply be aware of these characteristics and be prepared to make recommendations based on your knowledge of the best way to use these lenses. Not only will you feel good about making the best recommendation, your customer will feel good as well!

Returning to Mr. Jones, who has just given you his prescription and you have quickly run through the characteristics of the diverging lenses that will be needed -- he would like to get these glasses. So now your attention turns to the frame to hold the lenses. "I got these glasses from that guy across the street. And I hate 'em. I don't like the frame and these lenses are so thick and ugly. What can you do?" asks Mr. Jones. "I didn't know they would look like this." Here is a chance to shine in your customer's eyes. You begin by suggesting a smaller frame, one in which Mr. Jones' eyes are well centered. And then it happens, Mr. Jones asks the question: "How thick will my lenses be?" You smile as you recognize that same question that so many former customers of "that guy across the street" ask. Having already measured Mr. Jones' interpupillary distance (pd) at 66 millimeters (33/33) and the frame distance between centers (dbc) at 68 millimeters, you quickly calculate the amount of decentration. Subtracting the pd from the dbc, you

[27] The amount of surface reflection is given by the equation as follows:

$$\text{reflected intensity} = [(n' - n)(n'-n) / (n' + n)(n' + n)] \times 100\%$$

know the lens will have to be decentered inward a total of 2 millimeters for the pair, or 1 millimeter per eye. Having measured the effective diameter of the frame at 58 millimeters and then dividing by 2 to get the radius of 29 millimeters and then adding the 1 millimeter of decentration to get a distance from the optical center to the most distant edge of 30 millimeters or 0.030 meters you are ready to do the calculation to determine the edge thickness. Pulling out your handy calculator, you use the following formula:[28]

$$\text{edge thickness} = \frac{(\text{lens power})(1/2\ \text{ED} + \text{decentration in meters})^2}{2(\text{refractive index} - 1)} + \text{center thickness}$$

Mr. Jones's prescription is -5.00 sph OU and you are already thinking about a high-index lens (n=1.60) with a 1.5 millimeter center thickness. Substituting the numbers in the formula we get:

$$\text{edge thickness} = \frac{(5.00)(0.03)^2}{2(1.60 - 1.00)} + 1.5$$

This works out to 0.00375 meters (or 3.75 millimeters) + 1.5 millimeters for an edge thickness of 5.25 millimeters. (Remember to convert to millimeters before adding the center thickness.)[29]

"You're right," says Mr. Jones, "this smaller frame is much better and I can see exactly how this is going to look. I'll be back for many more glasses from you." "Wait just a minute," you yell as he starts toward the door, "I have a few more measurements to take." As Mr. Jones seats himself at the fitting counter, you ready a few tools to measure the optical center placement: a penlight, marker and any method of measuring the amount of pantoscopic tilt on the frame. After adjusting your chair so that you are at eye level with Mr. Jones, you hold your penlight at eye level to illuminate the corneal apex and then place a small spot on the demo lenses over the corneal reflection. Now measure the amount of pantoscopic tilt as Mr. Jones will wear it. Now divide the amount of tilt by

[28] (adapted from) Troy Fannin and Theodore Grosvenor. *Clinical Optics* Butterworth-Heinemann. 1984. p 87.
[29] This formula has proven very accurate in the instances I have used it, but do remember that it does not account for aspherical lenses or prescribed prism. A quick and dirty approximation for non-aspherical lenses and those without prism is that for a 50 mm blank (25 mm from the OC) a lens will have a change of thickness of 0.6 mm per diopter of power.

two and lower the height of the mark on the demo lens by this amount. For example, the frame Mr. Jones is wearing has 12 degrees of pantoscopic tilt and the mark on the lens is 30 millimeters above the lowest point of the eyewire. So, divide 12 by 2 to lower the optical center placement to 24 millimeters.[30] The reason we adjust the height based on the optical center comes from the purpose of the optical center placement. "According to lens designers, modern lenses (corrected curve, aspheric etc.) should be placed before the eye so that the optical axis of the lens passes through the center of rotation of the eye (an imaginary point around which the eye rotates)."[31] Where the confusion lies is in the understanding of where the optical center really is. The optical center is more than the spot on the lens found by the lensometer, but marks a point (usually not even on the lens) that lies on the optical axis. The optical axis is found by connecting the centers of curvature for the front and back surfaces (Figure 24). If there is no tilt on the frame, we would place the lensometer spot on the lens in front of the eye (Figure 25). However, if there is any pantoscopic tilt, the axis will be projected upward (Figure 26) and must therefore be lowered to project the axis through the center of rotation of the eye (Figure 27). Generally we lower the optical center by 0.5 millimeters per degree of pantoscopic tilt to get the correct alignment. If we neglect to compensate for the amount of pantoscopic tilt: first, we are probably inducing too much prism and thickness at the bottom of the lens by having the optical center too high and, second, we are causing an alteration of the powers of the spectacle lens.

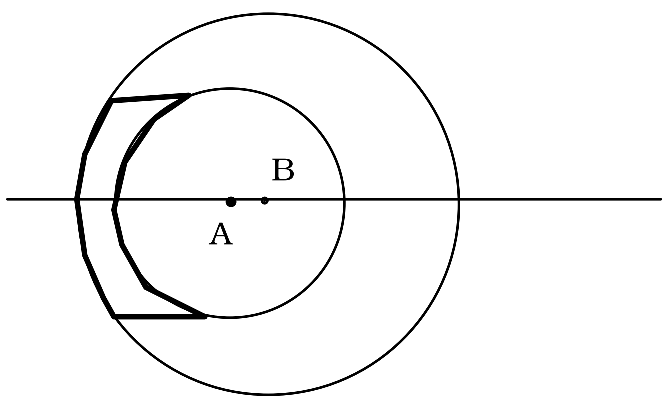

Figure 24.   Optic axis AB

[30] Marchon and Marcolin Training Center. *Op-Topics* Vol 8. No. 1. 1991. p 8.
[31] David Zaccaria. Distance optical center placement on single vision lenses. *Eyecare Business*. November, 1995. p 45.

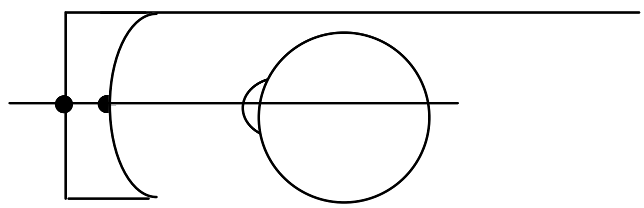

Figure 25. Correct optical center placement with no pantoscopic tilt

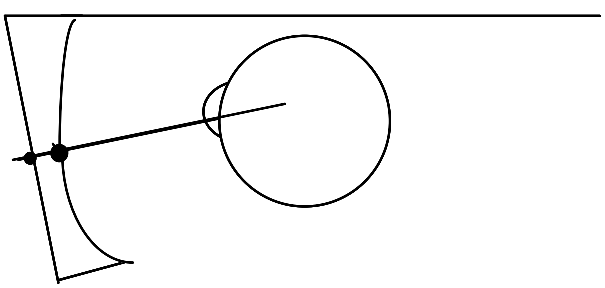

Figure 26. Correct optical center placement with pantoscopic tilt

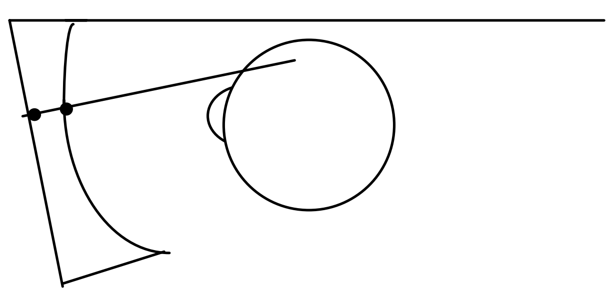

Figure 27. Incorrect optical center placement with pantoscopic tilt

This alteration of the lens powers stems from the misalignment of the optic axis and the center of rotation of the eye. When the optic axis projects over the center of rotation, the eye cannot turn to align the light path. By viewing the pencil of light at an oblique angle the spherical component of the prescription is changed and an astigmatic component is introduced according to two formulas derived by L.C. Martin:[32]

$$\text{new sphere} = D\left(1 + \frac{\sin^2\emptyset}{3}\right) \qquad \text{cylinder} = D\tan^2\emptyset$$

D = dioptric power of lens

$\emptyset$ = excess pantoscopic tilt

For example, on Mr. Jones' glasses that he was so unhappy with, part of the edge problem was that the guy across the street placed the optical center measurement directly in front of the pupil. Unfortunately, the frame has 15 degrees pantoscopic tilt. The optical center should have been placed 7.5 millimeters lower than it was. This extra decentration of the lens caused extra thickness to be created at the bottom of the eyewire and also changed the effective power of the prescription. Using Martin's first equation for the new sphere power (new sphere = (-5.00)(1 +($\sin^2$ 15)/3) and his second equation to find the amount of induced astigmatic correction (cylinder = -5.00 ($\tan^2$ 15)) we see that Mr. Jones was not looking through a -5.00 spherical lens but rather a prescription of -5.11 -0.36 x 180. (By definition, Martin's law specifies that the axis of the induced cylinder is always that of the meridian around which the lens is tilted (e.g., pantoscopic tilt induces cylinder with axis 180) and is of the same sign as the sphere power.) So, by placing the optical center at the correct location, not only will Mr. Jones have a more cosmetically pleasing pair of glasses but the prescription will be more accurate. In both cases, a win for Mr. Jones and yourself.

As Mr. Jones starts to get up he suddenly remembers that he also wants to get a pair of those new sports sunglasses that really wrap around your face. "I've heard from some friends that there is a thing in back to put lenses in. Is that right?" "Sure is. Let me take one last measurement for the order" you respond while getting the glasses out of the display. "I want to see just how far away from the front of your eye the lenses will be. If they are too close, I will need to make the lenses a little weaker" you explain. "Remember how a wave's power is dependent on its curvature -- more curvature means

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[32] Russell Stimson. *Ophthalmic Dispensing* Charles C Thomas Publishers. 1979. pp 109 - 111.

more power?" you ask Mr. Jones knowing that he teaches Physics and has some understanding of wave functions. "And with your diverging type of lens, the further from the lens the wave travels, the less curvature it has and, therefore, less power. Well, the opposite is also true, the closer to the lens the more curvature and power the lens has. So, if the lens is positioned closer to your eye, it is stronger than the prescribing doctor intended and we can make the lens a little less strong but still have the same effective power as your regular glasses."[33] "Okay Mr. Jones, that's the last measurement. I'll call you doctor and make sure that this is okay and then give you a call as soon as your glasses are ready. Thank you for your business" you call out as Mr. Jones leaves your shop and the formula you will use enters your mind.[34]

$$F_c = \frac{F_o}{1 - dF_o}$$

F_c = compensated lens power

F_o = original lens power

d = distance lens moved in meters

In Mr. Jones case, the refracted vertex distance was 15 millimeters but the sunglasses will be only 10 millimeters away. The quantity d will be a positive number because the new lens position will be closer to the eye. If the lens were being moved further away, the quantity d would be minus making the denominator become: $1 -(-dF_o)$.

Substituting the new values into the formula we now have:

$$F_c = \frac{-5.00}{1 - 0.005\,(-5.00)}$$

$$= -5.00 \;/\; 1.025$$

$$= -4.87$$

[33] Check you own local regulations about whether you, as an optician, can alter the prescription based on vertex distance changes. Even if you are allowed to alter the prescription in this way, I highly recommend that you ask approval of the prescribing doctor before doing so.

[34] Troy Fannin and Theodore Grosvenor. *Clinical Optics* Butterworth-Heinemann. 1984. p 70 - 71.

Does this make sense? The lens is moved closer and therefore acts as a stronger minus lens. But Mr. Jones does not need a stronger lens. So, the total power must be reduced to give Mr. Jones an effective power at the corneal surface equal to the power of the lens in the phoropter at a refracted vertex distance of 15 millimeters.

A few days later, Mr. Jones stops in after having picked up his new glasses the day before. "You know," says Mr. Jones, "I walked by the store front of that guy across the street after I picked these up yesterday. And then I walked by your store front. There is something that guy has that you don't." Answering the puzzled look on your face, Mr. Jones continues: "He has a blank space on the wall where your credentials are." As he heads back out the door, Mr. Jones finishes "I can clearly see your certification, and I can see clearly why you have it." And then doing a very bad Arnold Schwarzenegger, he laughs "I'll be back."

No Give and Take. No Exchange of Thought. It gets you nowhere, particularly if the other person's tail is only just in sight for the second half of the conversation.

- Eeyore

Summary of Formulas

wave vergence = 1 / distance in meters from focal point

Snell's Law

n sin i = n' sin i' where

n = refractive index of first medium
i = angle of incidence (from normal) at first surface
n' = refractive index of medium being entered
i' = angle of refraction in degrees away from the normal

minification

m = i / o where

m = minification
i   = image distance
o = object distance

internal reflections (critical angle)

sin • • • n' / n where

• • • • • • angle of incidence which cannot be exceeded
n' = refractive index of media trying to be entered
n = refractive index of medium light is in
if the angle exceeds • • , the light is internally reflected

surface reflections

$I = (n' - n)^2 / (n' + n)^2 \times 100\%$ where

I = intensity of reflected light

n' = refractive index of medium light is entering

n = refractive index of medium light is leaving

decentration

$d = dbc - pd$ where

d = total decentration

dbc = distance between centers or frame pd

pd = interpupillary distance

edge thickness

$$et = \frac{(\text{lens power})(1/2\ ED + \text{decentration in meters})^2}{2(n-1)} + ct$$

et = edge thickness
ED = effective diameter of frame (in meters)
ct = center thickness
n = refractive index of lens

pantoscopic tilt and optical center placement

oca = p / 2 where
oca = optical center adjustment
p = pantoscopic tilt

Martin's Law

$$S = D\left(1 + \frac{\sin^2 q}{3}\right) \qquad C = D \tan^2 q$$

S = new sphere power
D = back vertex power of lens
C = new cylinder power
q = amount of excess tilt
the axis will be at 180 for excess pantoscopic tilt
the cylinder form (+ or -) will be the same as the sphere

Vertex distance compensation

$$F_c = \frac{F_o}{1 - dF_o}$$ where

Fc = compensated power
Fo = original power
d = distance lens is moved in meters

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