Understanding Prism in Lenses

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Defining Prism

Prism refers to a wedge-shaped optical component. Like a triangle, the *thinnest* edge of the prism is referred to as the apex and the *thickest* edge is referred to as the base. When a ray of light passes through a prism, the *ray of light* is deviated toward the *base* of the prism. If you are looking through the prism, however, the *image* appears to be displaced toward the *apex*, because the image appears to originate from the direction of the deviated light ray (Figure 1).

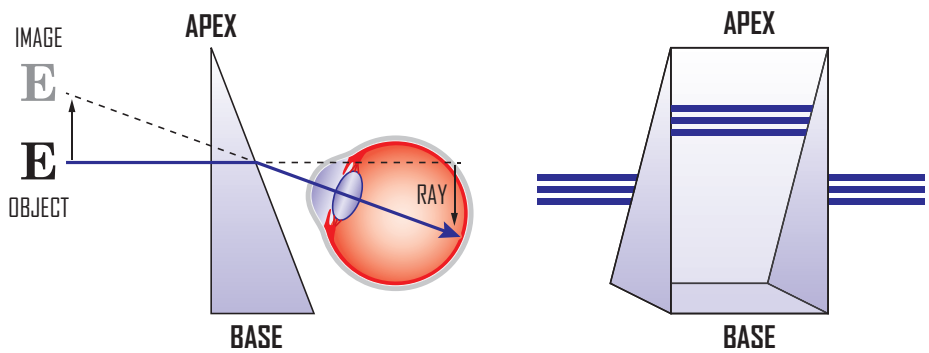


Figure 1. A prism deviates rays of light toward the base, or the thickest edge, which causes the image to appear displaced toward the apex, or the thinnest edge.

The orientation of a prism or prismatic effect relative to the line of sight of the wearer is specified by the direction of the *base* of the prism. The unit of measure of the prismatic displacement of an image is the prism diopter, abbreviated with the delta (Δ) symbol:

1 Prism Diopter = 1 centimeter of displacement over a distance of 1 meter

While unwanted prism is generally undesirable, prism is sometimes prescribed by an optometrist or ophthalmologist to treat a binocular vision disorder. When a prism deviates an image toward its apex, the eye must also turn toward the apex of the prism in order to remain aligned with the image. Consequently, if one eye has a tendency to turn away from an object due to a muscle imbalance, prism can be prescribed to shift the image in the same direction. This allows the eye to rotate to a more comfortable position, while still remaining aligned with the image.

Prism occurs in an optical lens whenever the thickness of the lens varies between two points. A prismatic effect can be obtained at the center of the lens, if the edge thickness on one side of the lens is made thicker than the other side. This is achieved during the lens surfacing process by grinding the back surface at an angle relative to the front surface. When the lens has non-zero power, grinding the back surface at angle to the front surface shifts the optical center of the lens. Consequently, for lenses of sufficient power, it is possible to produce a prismatic effect by simply moving—or decentering—the optical center of the lens (Figure 2).*

** Note that you cannot decenter aspheric lenses to induce a prismatic effect without compromising optical performance due to the aspheric surface.*

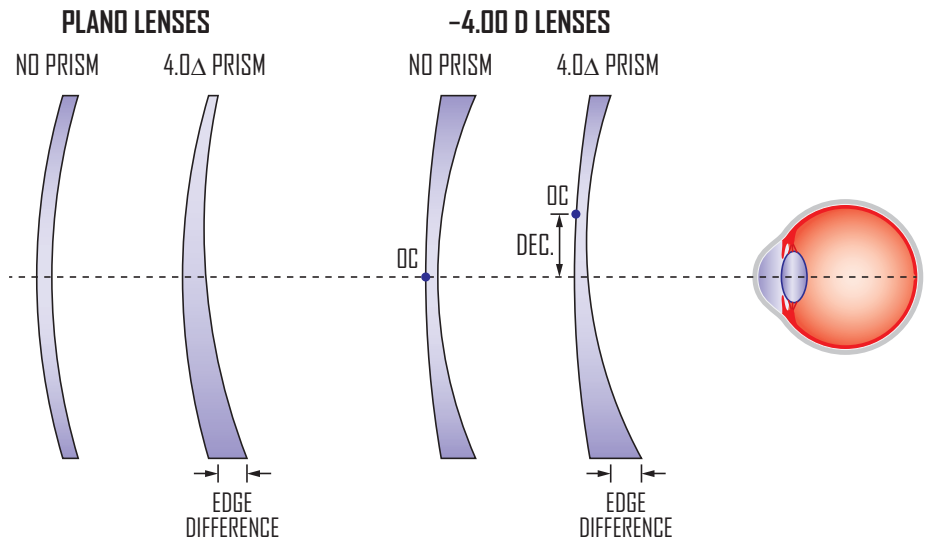


Figure 2. A prismatic effect is obtained at the center of an optical lens by producing a difference in edge thickness, either by grinding the back surface at an angle to the front surface during lens surfacing or, if the lens has sufficient power, decentering the optical center of the lens.

Prismatic Effect of Eyeglass Lenses

Prism occurs whenever there is a difference in lens thickness between two points on the lens. Because lenses with power always have a variation in lens thickness, prescription eyeglass lenses produce prismatic effects away from the optical center of the lens. At any point away from the optical center of the lens, a *minus* lens, which is thicker at the *edge* and thinner at the center, produces a prismatic effect with the prism base pointed *away from* the optical center. Conversely, a *plus* lens, which is thicker at the *center* and thinner at the edge, produces a prismatic effect with the prism base pointed *toward* the optical center (Figure 3).

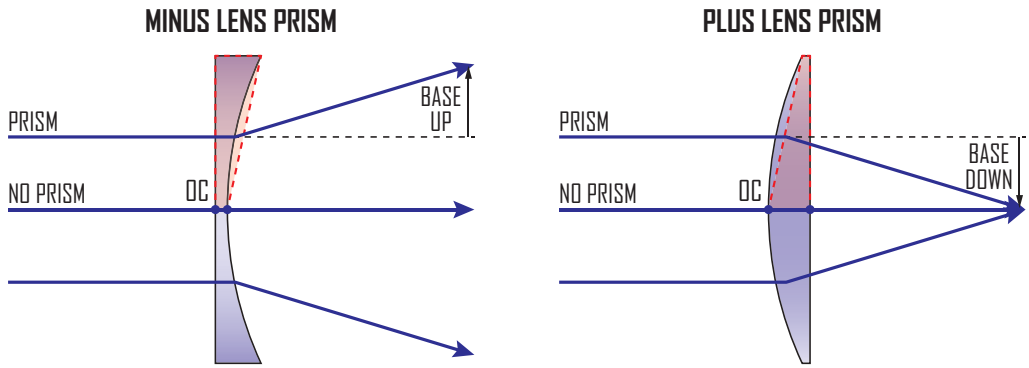


Figure 3. A minus lens, which is thicker at the edge, produces a prismatic effect with the base pointed away from the optical center, whereas a plus lens, which is thicker at the center, produces a prismatic effect with the base pointed toward the optical center of the lens.

In order to bring rays of light to a focus, an optical lens must deviate these rays toward the focus of the lens in much the same way that a prism deviates light. Through the optical center of the lens, rays of light are not deviated at all, because the focus of the lens is aligned with the optical center. As the distance from the optical center increases, however, the rays of light must be deviated more and more in order for the rays to continue to pass through the focus (Figure 4).

In fact, the prismatic effect at any point on the lens is directly proportional to the power of the lens and the distance of that point from the optical center. This extremely important relationship is described by Prentice's rule:

Prism = Decentration × Power ÷ 10

Two important conclusions can be drawn from Prentice's rule:

1. If the wearer does not look through the optical center of an eyeglass lens with power, a prismatic effect is induced, which is why eyeglass lenses are decentered from the center of the frame opening to the specified interpupillary distance.

2. If a prismatic effect is desired in the lens, it can often be achieved by decentering the optical center away from the line of sight, if the lens has sufficient power (however, this is not an option for multifocal lenses).

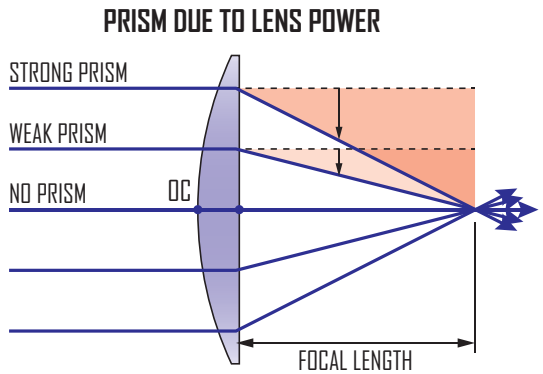


Figure 4. Because optical lenses must deviate rays of light in order to bring light to a focus, a prismatic effect occurs through the lens away from the optical center, which is proportional to the distance of that point from the optical center of the lens.

We will now consider an example using these principles. A frame with an eyesize of 52 mm and a bridge of 23 mm is selected for a patient with monocular interpupillary distances of 30.5 mm and a prescription of −5.00 D sph in each eye. Each lens must therefore be decentered in from the center of the frame by ½ (52 + 23) – 30.5 = 7.0 mm. If the lenses are incorrectly fabricated with no decentration, how much prism is induced in each eye (Figure 5)?

Prism = 7.0 × –5.00 ÷ 10 = –3.50Δ

The negative sign tells us that the prism base is pointed in the opposite direction of the optical center. Note that the optical center of each lens is located on the temporal side (outside) of the line of sight of each eye. Because the prismatic effect of a minus lens is pointed away from the optical center, the base of the prismatic effect in this example is toward the *nasal* side of the lens. This is described as *Base In* prism. The final prism value should not have a plus or minus sign; only the base direction is required:

Prism = 3.50Δ Base In per eye

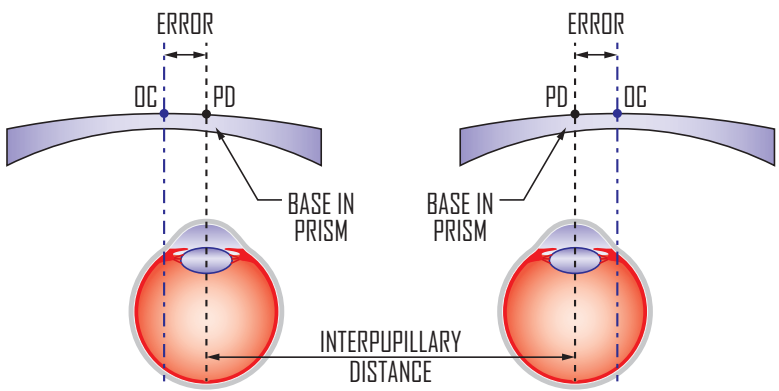


Figure 5. If the distance between the optical centers (OC) is wider than the specified interpupillary (PD) distance due to errors in fabrication, minus lenses will produce a Base In prismatic effect; conversely, if the optical center distance is narrower than the interpupillary distance, a Base Out prismatic effect is produced by each lens.

What if the same mistake had been made for a pair of +2.50 D sph lenses, instead?

Prism = 7.0 × +2.50 ÷ 10 = +1.75Δ

The positive sign tells us that the prism base is pointed in the same direction as the optical center. Because the prismatic effect of a plus lens is pointed toward the optical center, the base of the prismatic effect is toward the *temporal* side of the lens in this example. This is described as *Base Out* prism. Note that the prismatic effect of the +2.50 D lens is equal to half of the prismatic effect of the −5.00 D lens, because the lens has half as much power. The prism base is also pointed in the opposite direction (Figure 6):

Prism = 1.75Δ Base Out per eye

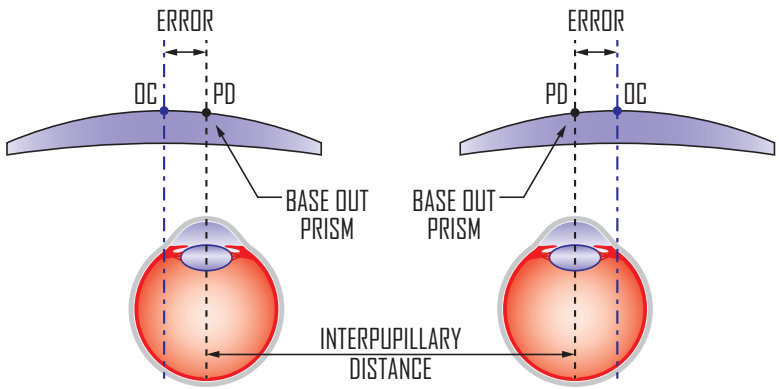


Figure 6. If the distance between the optical centers (OC) is wider than the specified interpupillary (PD) distance, plus lenses will produce a Base Out prismatic effect; conversely, if the optical center distance is narrower than the interpupillary distance, a Base In prismatic effect is produced.

For weak lens powers, within ±1.00 D, very little prismatic effect is induced by decentration. For a plano lens, virtually no prism is induced by decentering the lens. This has two important consequences for eyeglass lenses:

1. Even large errors in the location of the optical center relative to the specified location of interpupillary distance will not introduce significant prism in low prescription powers.
2. Prescribed prism must be surfaced into the lens by grinding the front and back lens surfaces at an angle to each other, in order to create a difference in edge thickness, because obtaining the necessary prism by decentration will not be possible.

Lenses with cylinder power also produce a separate prismatic effect through the meridian of the lens containing the cylinder power, 90° away from the cylinder axis. If the cylinder axis is at an oblique angle, moving the lens to the right or left will actually induce a vertical prismatic effect in addition to the horizontal prismatic effect. Furthermore, if one meridian of the lens is plano in power, the lens will not have a true optical center, because the plano-powered meridian of the lens will have zero prismatic effect. These optical characteristics can sometimes make verifying the prism in lenses with cylinder power challenging.

Binocular Prismatic Effects

The orientation of a prismatic effect is defined by the direction of its base relative to the line of sight of each eye when looking straight-ahead (Figure 7). Typically, the orientation of the prism base is specified by a vertical component, if any, and a horizontal component, if any. This is similar to the X and Y coordinates of a graph. The vertical component is specified as a prism value that is either *up* or *down*. The horizontal component is specified as either *in* (nasal, toward the nose) or *out* (temporal, toward the temple).

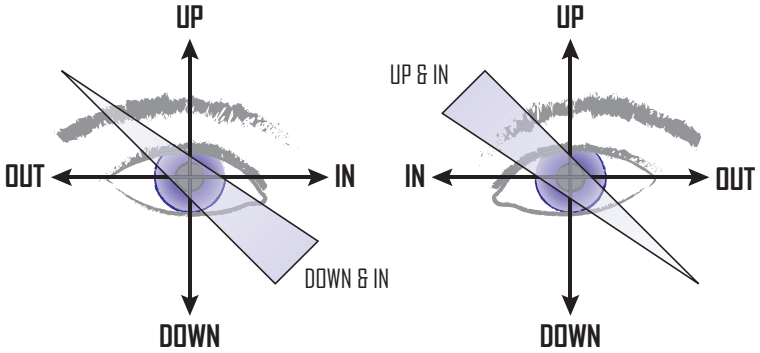


Figure 7. The orientation of the base of a prism is specified using a vertical component, if any, and a horizontal component, if any.

When considering the prismatic effects of a pair of eyeglass lenses, we are primarily concerned with the *net* prismatic effect between the right and left lenses. This is the prismatic imbalance, which affects binocular fusion. Prismatic imbalance is essentially the *difference* in prismatic effects between the right and left lenses. Prism bases in front of the eyes that point in the *same* general direction relative to the wearer—that is, up or down or to the wearer's right or left—*neutralize* or cancel each other. Prism bases that point in *opposite* directions relative to the wearer *compound* or augment each other, which results in prismatic imbalance.

When two prism bases point in opposite directions, the net prismatic effect is found by *adding* the two prism values. The prism imbalance may then be stated with respect to either eye using the original prism base direction of that eye. When two prism bases point in the same general direction, the net prismatic effect is found by *subtracting* the smaller prism value from the larger value. In this case, the prismatic imbalance is most conveniently stated with respect to the eye with the larger prism value.

Add Prism Bases to Each Other		Subtract Prism Bases from Each Other	
Right Eye	Left Eye	Right Eye	Left Eye
Base In	Base In	Base In	Base Out
Base Out	Base Out	Base Out	Base In
Base Up	Base Down	Base Up	Base Up
Base Down	Base Up	Base Down	Base Down

Prism causes the eye to rotate. When the two eyes are made to rotate in the same direction, by equal amounts, conjugate movements result. When the two eyes are made to rotate in opposite directions, disjunctive eye movements result. When the two eyes are made to rotate in the same direction, but by unequal amounts, the difference in ocular rotation represents disjunctive movement. Consequently, prism base directions that *add* to each other result in *disjunctive* eye movements, whereas prism base directions that *subtract* from each other result in *conjugate* eye movements when the prisms are equal (Figure 8).

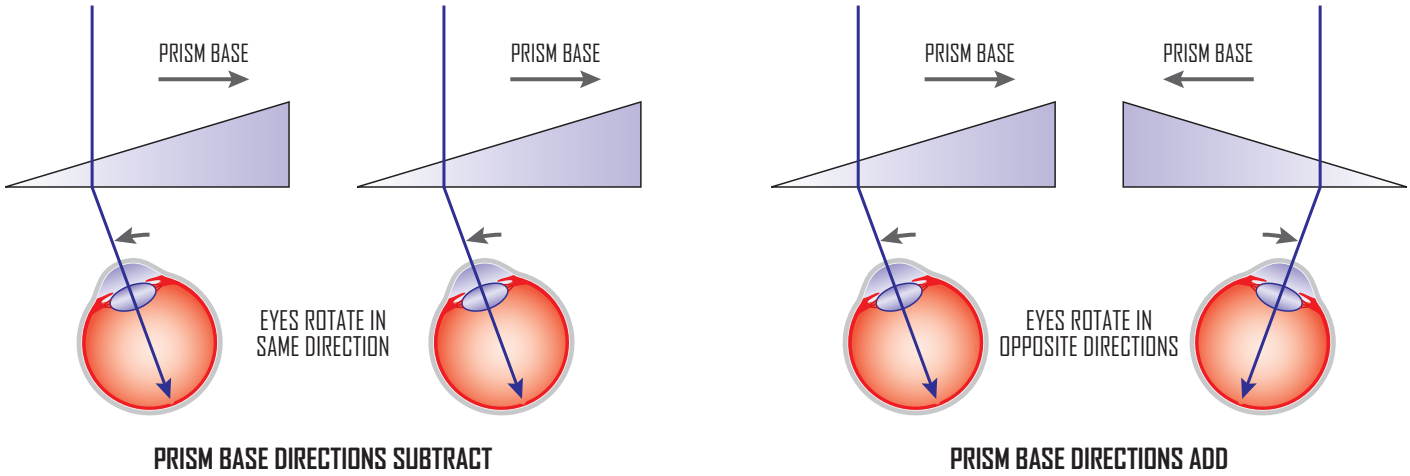


Figure 8. A Base In prismatic effect in front of the left eye combined with an equal Base Out prismatic effect in front of the right eye results in conjugate eye movements, whereas Base In prismatic effects in front of both eyes results in disjunctive eye movements that pull the eyes apart.

Prism imbalance represents a much more important clinical consideration than monocular (individual) prismatic effects. Prismatic effects that result in conjugate eye moments are well tolerated by the visual system. However, disjunctive eye movements that result from prismatic imbalance place a demand on the fusional vergence system of the eyes, which can lead to eyestrain and even double vision, if the prismatic imbalance exceeds the capacity of the eyes to maintain comfortable binocular vision.

For horizontal prismatic imbalance, the eyes must both either rotate in (*converge*) or rotate out (*diverge*) in order to maintain binocular alignment when looking at distant objects. For vertical prismatic imbalance, one eye must rotate down while the other eye must rotate up. Because prismatic imbalance is more detrimental to comfortable vision, guidelines for assessing the quality of finished (edged and mounted) eyeglass lenses typically only address the prismatic imbalance between a pair of eyeglass lenses, not the individual prismatic effects of each lens.

We will now consider an example using these principles. The right lens of a pair of eyeglass lenses has 2.0Δ Base Up & 1.0Δ Base In. The left lens has 1.0Δ Base Up & 1.5Δ Base In. What is the net prismatic effect or prismatic imbalance between these two lenses?

For vertical prism: The 2.0Δ Base Up prism in front of the right eye and the 1.0Δ Base Up prism in front of the left eye both point in the same direction. These prisms therefore *neutralize* each other, at least partially, resulting in a net effect of 2.0 – 1.0 = 1.0Δ of Base Up prism in the right lens, which as the stronger prism.

For horizontal prism: The 1.0Δ Base In prism in front of the right eye of the wearer points to the wearer's right, while the 1.5Δ Base In prism in front of the left eye points to the wearer's left, in the opposite direction. These prisms therefore *compound* each other, resulting in a net effect of 1.0 + 1.5 = 2.5Δ of Base In prismatic imbalance (in front of either the right eye or the left eye).

Verifying Prism and ANSI Tolerances

Manual-focusing focimeters, including lensometers and vertometers, typically have a *reticle* with a *prism scale*, which indicates the prismatic effect of the lens at the measurement point. The rings of the prism scale are labeled in prism diopters (Figure 9). Once the measurement point of the lens has been centered in front of the lens stop of the instrument, the prismatic effect at the measurement point, if any, appears as a displacement of the illuminated target from the center of the reticle.

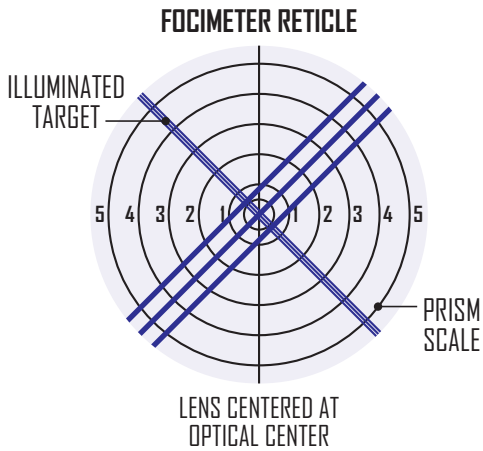


Figure 9. The reticle of manual-focusing focimeters includes a prism scale that indicates that magnitude of any prismatic effect present at the measurement point on the lens as well as the direction of the prism base.

The location of the center of the illuminated target relative to the prism rings of the reticle scale indicates the magnitude of the prismatic effect and the direction of the prism base. In the absence of prism, the illuminated target will appear centered on the prism scale of the reticle. When marking the location of the optical center on the lens with a focimeter, the lens is positioned so that the illuminated target is centered on the prism scale. If the prescription calls for prism, on the other hand, the location on lens that satisfies the specified prism requirements is marked by positioning the lens so that the illuminated target matches the vertical and horizontal prism components of the prescription on the prism scale (Figure 10).

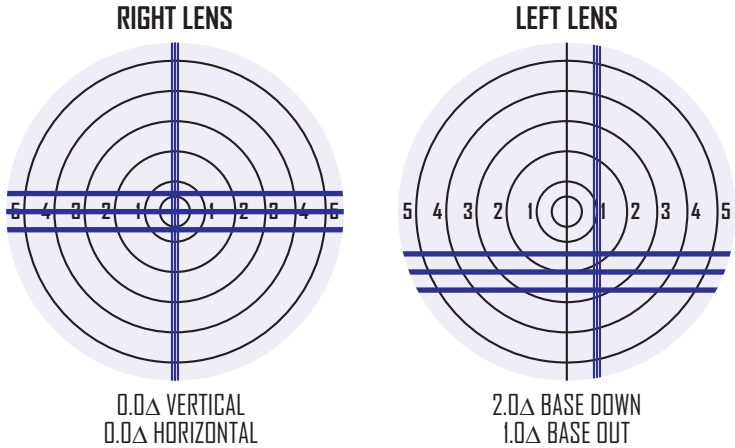


Figure 10. When marking a lens, if the prescription calls for no prism, the lens is positioned so that the illuminated target is centered on the prism scale or, if the prescription does call for prism, the lens is positioned so that the illuminated target matches the specified prism requirements.

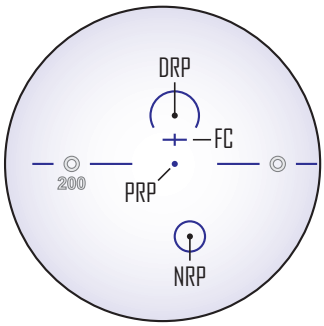
When no prism has been prescribed, the optical centers of the lenses should be at the same vertical level on each lens and separated by an amount equal to the specified far interpupillary distance of the wearer (unless the lenses are for near vision) in order to prevent vertical and horizontal prismatic imbalance. A centration error in the location of the optical center on either lens, once edged and mounted, can introduce vertical and/or horizontal prismatic imbalance that may be unacceptable. Errors in the centration of the optical centers are considered problematic to the extent that these errors introduce prismatic imbalance.

When verifying finished eyeglass lenses, the optician must confirm that the lenses provide the specified prism, if the prescription calls for any, while also ensuring that any prismatic imbalances or lens centration errors do not exceed company quality guidelines or national optical standards. National optical standards are described in the ANSI Z80.1–2010 Standard for Prescription Spectacle Lenses, which provides both prismatic imbalance and lens centration tolerances for a pair of mounted eyeglass lenses:

1. Vertical and horizontal tolerances on prismatic imbalance between are provided for lower powered lenses, which allow for higher lens centration errors in lower prescription powers, because less unwanted prismatic imbalance is induced by these lenses; the vertical prismatic imbalance tolerance for all lenses is ⅓Δ (0.33Δ) and the horizontal tolerance is ⅔Δ (0.67Δ).
2. Vertical and horizontal tolerances on lens centration as measured by the separation between the optical centers, in millimeters, are provided for higher powered lenses, which allow for at least a small amount of lens centration error, regardless of the strength of the lenses or how much prismatic imbalance is induced; the specific tolerances depend upon the lens type.

ANSI Z80.1–2010 Prism & Centration Tolerances For Mounted Lenses	Single Vision and Multifocal Lenses		Progressive Addition Lenses	
	Power Range	Tolerance	Power Range	Tolerance
Vertical Imbalance	0.00 D to ±3.37 D	0.33Δ Imbalance	0.00 D to ±3.37 D	0.33Δ Imbalance
	Higher than ±3.37 D	1.0 mm Difference	Higher than ±3.37 D	1.0 mm Difference
Horizontal Imbalance	0.00 D to ±2.75 D	0.67Δ Imbalance	0.00 D to ±3.37 D	0.67Δ Imbalance
	Higher than ±2.75 D	2.5 mm Total Error	Higher than ±3.37 D	1.0 mm Each Lens

The ANSI Z80.1 Standard also provides separate tolerances for progressive addition lenses and non-progressive lenses, including single-vision and lined-multifocal lenses, because the verification methods differ. For progressive addition lenses, the prismatic imbalance is evaluated at the prism reference point of each lens. The prism reference point (PRP) is located between the two semi-visible reference engravings or "logos" along the 180-line of the lens (Figure 11).



PAL REFERENCE MARKINGS

Figure 11. Prism is verified at the prism reference point of a progressive addition lens, which is located between the two semi-visible alignment reference engravings or "logos" along the 180-line of the lens, directly below the fitting cross.

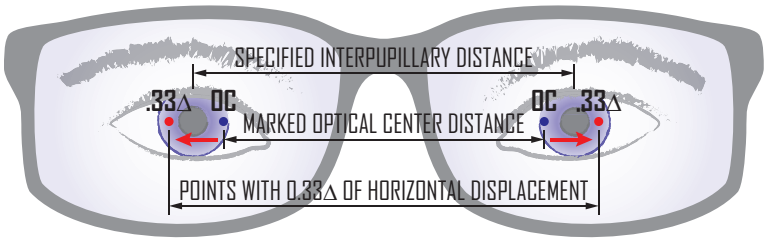
Furthermore, progressive lenses typically utilize prism-thinning, which is vertical prism ground into each lens in order to minimize thickness and weight, particularly in plus prescriptions or lenses with high add powers. Prism-thinning uses equal amounts of Base Down (or, in some cases, Base Up) prism in the lenses. The vertical prism value is roughly equal to half of the add power. Because equal amounts of vertical prism in the same direction are used, prism-thinning should not result in any prismatic imbalance. As with prescribed prism, prism-thinning is verified in a progressive lens at the prism reference points, considering only the difference.

In order to verify that the prismatic imbalance and lens centration requirements of the ANSI Z80.1 Standard have been met for *progressive addition lenses*, use the following method:

1. Position each lens in the focimeter at the prism reference point, and measure the individual vertical and horizontal prism values of each lens at the prism reference point.
2. If the net difference (prismatic imbalance) between the horizontal prism values does not exceed 0.67Δ, and the net difference (prismatic imbalance) between the vertical prism values does not exceed 0.33Δ, then the lenses are acceptable.
3. Otherwise, if the prismatic imbalance tolerances have been exceeded, position each lens in the focimeter at the location of the optical center—or point that satisfies the specified prism requirements, if any, including prism-thinning—and mark each point.
4. If the horizontal separation between the marked point and the actual prism reference point on each lens does not differ by more than 1.0 mm, and the vertical separation between the marked points on the right and left lenses does not differ by more than 1.0 mm, then the lenses are acceptable.

In order to verify that the prismatic imbalance and lens centration requirements of the ANSI Z80.1 Standard have been met for *single-vision* and *lined-multifocal lenses*, use the following method:

1. Position each lens in the focimeter at the location of the optical center—or point that satisfies the specified prism requirements, if any—and mark the point on each lens with the focimeter.
2. If the total horizontal separation between the marked points on the right and left lenses does not differ from the specified interpupillary distance by more than ±2.5 mm, and the vertical separation between the marked points on the right and left lenses does not differ by more than 1.0 mm, then the lenses are acceptable.
3. Otherwise, if the lens centration tolerances have been exceeded, position the lens with the *stronger* power through the *vertical* meridian in the focimeter at the location of the optical center or point that satisfies the specified prism requirements.
4. Slide the frame over to position the opposite lens in the focimeter, without raising or lowering the support table of the focimeter, so that any displacement of the illuminated target is in the vertical (90°) meridian of the prism scale.
5. If the measured vertical prism in the weaker lens does not exceed 0.33Δ, then the vertical prismatic imbalance of the lenses is acceptable, and the horizontal prismatic imbalance of the lenses should be verified.
6. If the measured distance between the marked points on the right and left lenses is *wider* than the specified interpupillary distance, slide the lens *out* until the illuminated target shows 0.33Δ of horizontal displacement, and mark this point; if the measured distance is *narrower*, slide the lens *in* until the target shows of 0.33Δ of displacement, and mark this point.
7. Slide the frame over to position the opposite lens in the focimeter, and mark the point on the lens with 0.33Δ of displacement, so that each lens has two sets of focimeter markings, an inside (nasal) set of markings and an outside (temporal) set.
8. If the measured distance between the *inside* focimeter markings on the right and left lenses is *narrower* than the specified interpupillary distance, and the measured distance between the *outside* focimeter markings on the right and lenses is *wider* than the specified interpupillary distance, then the lenses are acceptable (Figure 12).



VERIFYING HORIZONTAL PRISMATIC IMBALANCE

Figure 12. When verifying a pair of eyeglass lenses that exceeds the horizontal centration tolerance of 2.5 mm, the lenses are each moved in or out to induce 0.33Δ of horizontal displacement and then marked in order to compare the measured distances to the specified interpupillary distance.