Reading Material for
Dispensing Opticianry
(Paper-B)

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PREFACE

A two years post matric teaching program of Dispensing Opticianry Technician for the students of Allied Health Sciences. The purpose of this reading material is to provide basic education to the paramedics about Dispensing spectacles. This reading material attempts to cover almost all the basic theoretical knowledge required by students about Dispensing, optics, spectacles manufacturing so that they can perform their work better in Optical Laboratories.

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Section II

Unit 1:

Review of Elementary Mathematical Principles

Learning Objectives:

This chapter reviews the mathematical principles used in basic optics. If you are well versed in mathematics, you may omit this chapter and use it for reference. The Proficiency Test may help you determine your mastery of this subject. If the questions are easy for you, continue on to the next chapter.

1. Students will be able to learn/ revise mathematical principles of algebra, geometry and trigonometry.

THE METRIC SYSTEM

When using the metric system of measurement, it is best to develop such familiarity with it that it is no longer necessary to think of it in relation to the English system. For example, it is much simpler to know how long a centimeter is than to figure out what fraction of an inch it might be. This can be done without much effort since most rulers now have a metric scale on one edge. Additionally the interpupillary distance (PD) rule, which no dispenser can be without for measurement of PD, uses the metric scale exclusively.

The unit of measure upon which the metric system is based is the *meter* (m). All other units are expressed as either multiples or fractions of that unit.

Just as there are 10 *dimes* in a dollar, so also are there 10 *deci*meters (dm) in 1 m. Just as there are 100 *cents* in a dollar, so also are there 100 *centi*meters (cm) in 1 m. And just as the wormlike *milli*pede is reputed to have 1000 legs, so also does 1 m have 1000 *milli*meters (mm).

A kilometer also has reference to a thousand, but this time 1 kilometer D 1000 m. Therefore:

1 m D 10 dm D 100 cm D 1000 mm and
1 km D 1000 m

(Weight measures are in multiples of 10 as well, retaining the same prefixes as the previously discussed linear measures. The basic unit of metric weight is the *gram*.) If conversion from metric to English linear measurements becomes necessary, conversion factors are:

1 m D 39.37 in

1 cm D 0.394 in
1 in. D 2.54 cm

REVIEW OF ALGEBRA

Algebra uses positive and negative numbers and letters or other symbols to express mathematical relationships (Table 11-1). These relationships are used in formulas or equations. Letters or systematic symbols take the place of a number that is either unknown or subject to change to allow for dimensional variations.

Algebra offers versatility by allowing an equation to be altered to a new form for a specific need. For example, the formula:

a D *b* D *c*

is in the best order if *a* and *b* are known, and *c* is unknown. (If *a* is equal to 1 and *b* is equal to 2, what is *c*?) This form of the equation is not as easily used if *a* is the unknown. In this case it would be better to trans- form the equation to make for greater ease in solving for *a*.

Transformation

To transform an equation, the components are moved from one part of the equation to another. If a component is moved across the equal sign, the sign of the number moved must be changed from plus to minus or minus to plus. To follow the logic behind a required change in sign, it is noted that the same number (or symbol for a number) may be added to or subtracted from both sides of an equation. If

1 D 2 D 3

the two sides of the equation are still equal even if 2 is subtracted from each side:

1 D 2 D 2 D 3 D 2

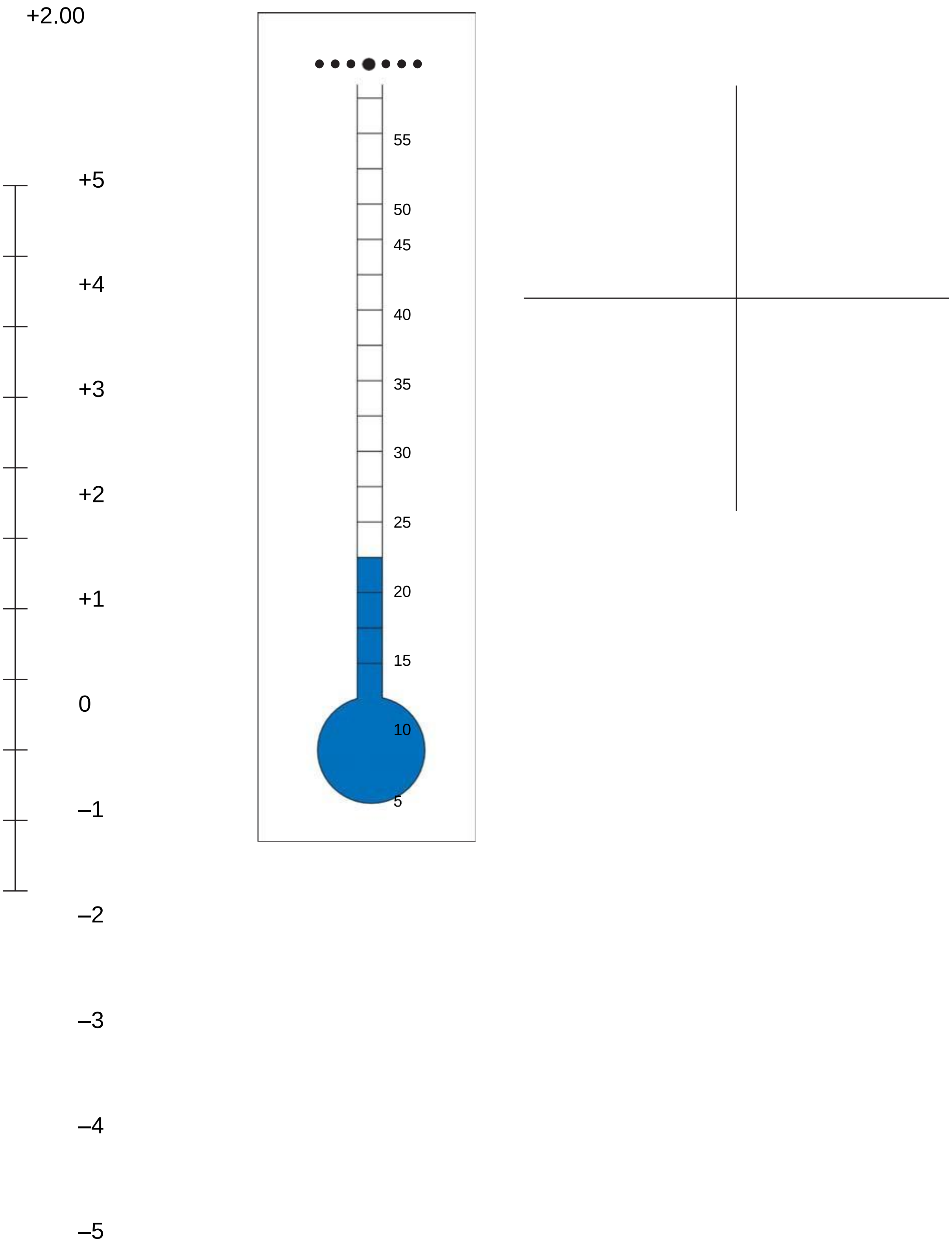


Figure 11-1. The concept of positive and negative numbers is easily illustrated by

use of a number line and is seen com- monly on instruments, such as a thermometer.

then the equation becomes

x D $\underline{2\text{D}c\ \text{D}b\text{D}}$

Da D bD

Positive and Negative Numbers

Positive and negative numbers are continuous with one another on the same line. Both start at zero but begin “counting” in opposite directions (Figure 11-1). Most everyone uses both positive and negative numbers daily.

–2.0 **Figure 11-2.** Illustrating the relationship between positive and negative numbers, the prescription shown has a value of

D2.00 −4.00 D 90. The difference between positive and negative meridian is the value of the cylinder, which is 4.00 D.

numbers. Again this can be most easily illustrated using the thermometer concept. How many degrees colder is

−10° than D10°? When the mercury drops from D10° to −10°, it travels 10 units to reach zero and another 10 units to reach −10°. The drop in temperature is a total of 20°. In optics this is most directly applicable to cylinder values. If the 90-degree meridian has a power of D2.00 D and the 180-degree meridian a power of −2.00 D, how strong is the cylinder (Figure 11-2)? (The cylinder value is the difference in power between the two major meridians of a lens.) On a number line, such as found on conventional lensmeter scales, it is readily seen that a total of 4 units must be traveled in going from the D2 mark to

the −2 mark. Therefore the value of the cylinder is 4.

Use of the Reciprocal

The reciprocal of a number is obtained by dividing that number into 1. For example, the reciprocal of 2 may be written as 1 D 2 , or ^{1}/2, or 0.5. Conversely, then the reciprocal of 0.5 is 1 D 0.5, or ^{1}/0.5 or 2.

In optics reciprocals are used to convert focal lengths into dioptric units of lens power. If the focal length of a lens is 0.20 m, the dioptric power of the lens is the reciprocal of that focal length.

$\underline{1\quad}$D

For example, when the thermometer drops below zero, negative numbers are used to describe the temperature. When something is indicated as being 300 feet below sea level, it can be said to be at −300 feet. In this case sea

0.20 m

Roots and Powers

5 D of lens power

level is the zero point.

In working with negative numbers, one must remember how they relate in their distance from positive

When a number is multiplied by itself, it is said to be *squared*. For example, 10 squared D 100, which is another way of saying 10 D 10 D 100. “Squared” is abbreviated mathematically by a superscript 2 written above and to the right of the number. The number indicates that 2 units of that same number are to be multiplied by each

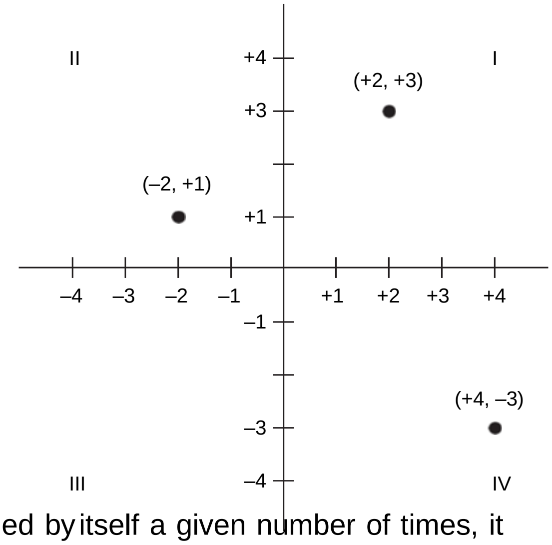
other. Ten squared (10•10) would be written as 10^2. It may also be spoken of as 10 to the second *power*. If 10^2

equals 100, the “root” from which the result of 100 has “grown” was the quantity 10 squared. Therefore the *square root* of is 100 is 10. To find the square root of a number, the operation is indicated by the symbol $\sqrt{\ }$ enclosing that number. For example,

$$\sqrt{100}\ 10$$

A number can be “raised” to any given power; in other words, a number can be multiplied by itself any number of times. This operation is again indicated by a superscript:

Y Axis



X Axis

10^3 D 10•10•10 D 1000

10^4 D 10•10•10•10 D 10,000

a^5 D *aaaaa*

and so forth.

When indicating that the quantity is multiplied by itself a given number of times, it is also possible to place the superscript outside a parenthesis. This indicates that the whole quantity within the parentheses is multiplied by itself the number of times indicated by the superscript.

For example,

$(a \bullet b)^2$ D $(a \bullet b)(a \bullet b)$

REVIEW OF GEOMETRY

Since geometry is used fairly often in optics, a basic understanding of it is essential. It might be said that the concept of geometry is built on a “triangular foundation,” which is to say that understanding the mathematics of a triangle is the basis for understanding geometry.

The Cartesian Coordinate System

The Cartesian coordinate system is a method of graphical localization of a point in space. In two-dimensional space, which is a flat plane, such as a sheet of paper, localization may be done with a paired set of numbers, *x* and *y*. These two numbers symbolize the horizontal and vertical location of a given point with reference to an original point: *x* is the number of units to the right (D) or to the left (–) of the zero point, whereas *y* refers to the localized point above (D) or below (–) this point (Figure 11-3). The reference point, or *origin,* is specified as (0,0). The horizontal location (*x*) is always given as the first number in the pair, and the vertical (*y*), as the second. The Cartesian coordinate system allows for ease and clarity of localization of any point, line, or geometric figure.

Figure 11-3. The Cartesian coordinate system allows the specific, repeatable localization of points in space. The *x*- and *y*-axes divide an area into four quarters known as *quadrants*. The upper right-hand quadrant is termed the *first quadrant,* or *quadrant I*. *Quadrant II* is the upper left quadrant, *quadrant III* the lower left, and *quadrant IV* the lower right.

Triangular Forms

There are 360 degrees in a complete circle. The wedged end of a pie-shaped piece of the circle contains a given number of these 360 degrees. The number of degrees contained between the two edges of the piece of pie that meet at the point is the degree measure of the angle formed.

A triangle contains three such points, or angles. The sum of the three angles contained within a triangle always equals 180 degrees.

If any one of these three angles is a 90-degree angle, the triangle is known as a *right triangle* (Figure 11-4). It obtains its name from the angle itself since 90-degree angles are known as *right angles*. The side of the triangle *opposite* the right angle is called the *hypotenuse*. If one of the angles of a triangle is 90 degrees, it logically follows that the sum of the two remaining angles must be 90 degrees.

In any right triangle, there is a certain relationship that exists between the lengths of each of the sides. This relationship states that *for a right triangle, the length of the hypotenuse squared is equal to the sum of the squares of the remaining two sides*. This relationship is referred to as the *Pythagorean theorem* (Figure 11-5) and may be abbreviated as a^2 D b^2 D c^2 where *c* is the length of the hypotenuse and *a* and *b* the lengths of the two remaining sides.

Triangles even more specific in shape than the right triangle also can have more specific established relationships between their sides. For example, a triangle whose angles are 45 degrees, 45 degrees, and 90 degrees has two

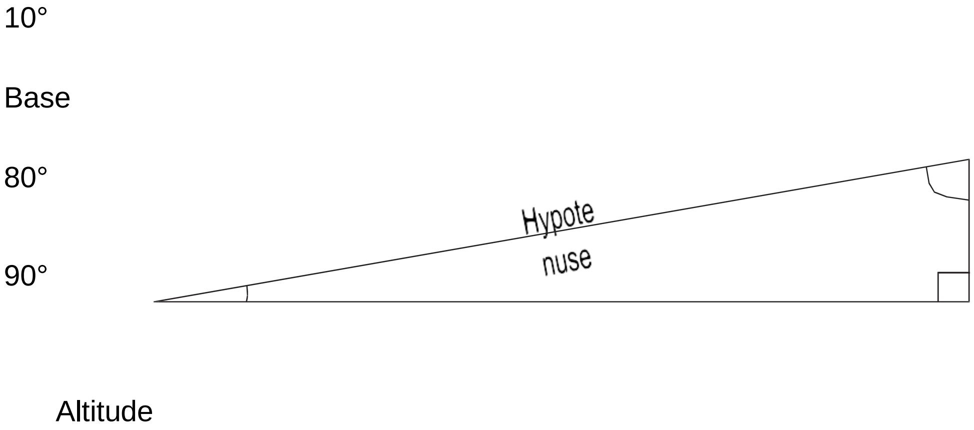


Figure 11-4. A right triangle contains one angle that is 90 degrees.

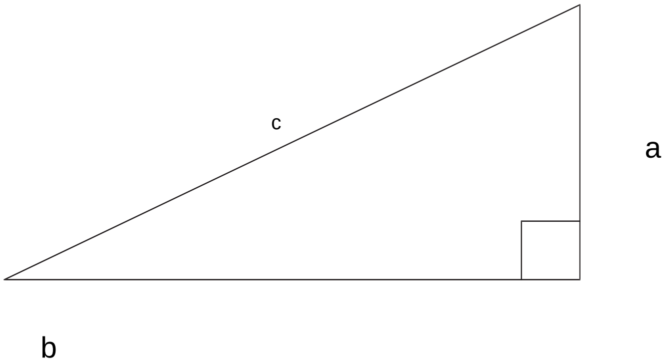
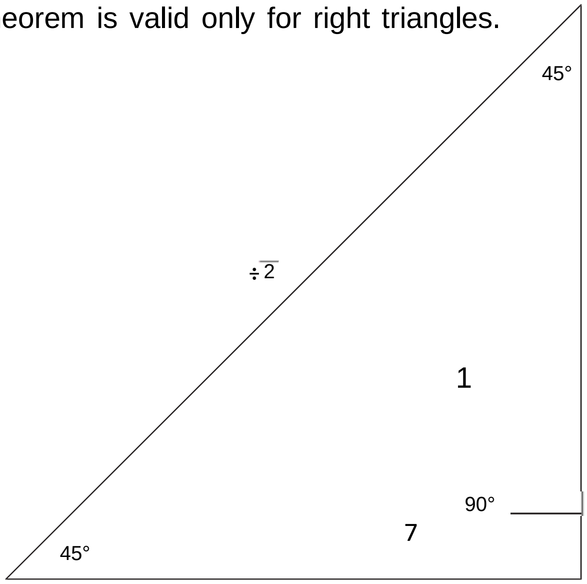


Figure 11-5. The Pythagorean theorem states that $a^2 + b^2 = c^2$. This theorem is valid only for right triangles.



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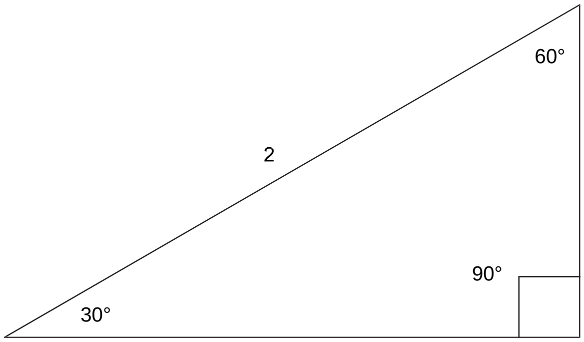

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Figure 11-7. The relationship between the lengths of the sides for a 30-degree, 60-degree, and 90-degree triangle.

Similar Triangles

When two triangles have exactly the same shape but different sizes, they are said to be *similar triangles*. Similar triangles have (1) corresponding angles that are equal and (2) corresponding sides that are proportional in size (Figure 11-8). This corresponding size relationship helps considerably in finding unknown linear measurements when other corresponding measures in a similar geo- metrical configuration are known. Simple algebraic equalities may be used to find these unknown dimensions.

Figure 11-6. The relationship between the lengths of the sides for a 45-degree, 45-degree, and 90-degree triangle.

sides of equal length. If each of these sides is taken as

*a*D *b*D *c*D

(See Figure 11-8.)

Sample Questions:

1. If a vertical stick protruding 0.80 m out of the ground casts a shadow 0.30 m long, how high is a flagpole nearby that casts a shadow 5 m long?

being 1 unit long, then the hypotenuse $\sqrt{2}$ will be units long (Figure 11-6). This follows from the Pythagorean theorem. (If this triangle occurs, algebraic equalities may be used to simplify solutions to a given problem.)

Another triangle with specific side-length relation- ships is the 30 degrees-60 degrees-90 degrees triangle. In this case if the shortest side is taken as 1 unit of length, the second side $\sqrt{3}$ will be units, and the hypotenuse 2 units (Figure 11-7).

Solution

Referring to Figure 11-8, a corresponds to the 0.80 m stick, b to the 0.30 m shadow. The 5-m flagpole shadow corresponds to bD and the unknown height of the flagpole to aD.

In other words,

a D 0.80 m b D 0.30 m bD D 5 m

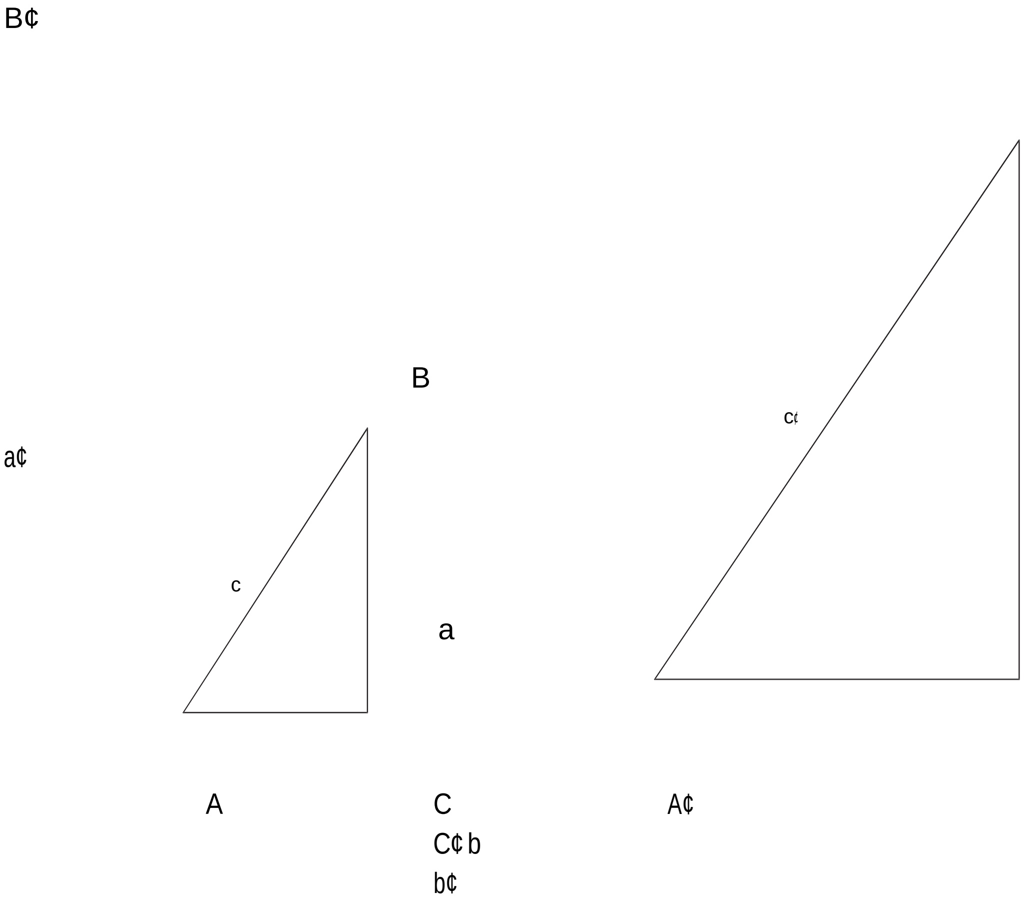
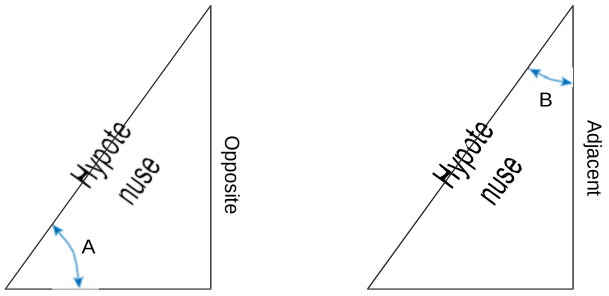


Figure 11-8. Similar triangles facilitate calculation of unknown dimensions from those which are already known. Capital letters represent angular measures; small letters stand for side lengths. In similar

triangles, angles *A* D *A*D, *B* D *B*D, and *C* D *C*D.

since



a D *b*

*a*D *b*D

0.80 D 0.30

*a*D 5

0.80 D D0.30D•*a*D

5

D0.80DD5D D *a*D

.30

Adjacent

Op*a*D D 13.33 m

This means that the flagpole is $13^1/3$ m high.

REVIEW OF TRIGONOMETRY

The section on geometry demonstrated how unknown length dimensions can be found when one dimension of a triangle is known along with the dimensions of a similarly shaped triangle.

This can also be done when only one dimension of a triangle is known using the angular measures of the triangle. This method uses *trigonometry*.

If the specific angles of a given triangle are known, it is possible to predict the ratio of any two sides of a tri- angle using a concept of similar right triangles. One can determine unknown dimensions of a triangle through the use of these predetermined ratios, which are known as *trigonometric functions*.

Figure 11-9. Although the position of the hypotenuse remains constant, the sides termed *opposite* and *adjacent* vary as to which of the angles is being referred to.

For a given angle of a triangle, there are three main ratios of importance. In Figure 11-9, if angle A is the angle being used, then the ratio of

thesideoppositeangleA D the sine of angle A hypotenuse

The ratio of

thesideadjacenttoangleA D the cosine of angle A hypotenuse

And the ratio of

thesideoppositeangleA D the tangent of angle A this side adjacent to angle A

These are abbreviated more commonly as

$$\sin A \ D \ \frac{opp}{hyp}$$

$$\cos A \ D \ \frac{adj}{hyp}$$

$$\tan A \ D \ \frac{opp}{adj}$$

Sine, cosine, and tangent ratios are found by using a calculator preprogrammed for these functions.

2. The image of an object 6 m away from a prism is displaced upwards 10 degrees by that prism. How far above the original position does the image now appear to be? (Figure 11-10 shows this situation.)

Solution

The ratio used for the 10-degree angle must include the known dimension and the dimension that needs to be calculated. In this case the needed dimension is that which is *opposite* the 10-degree angle, and the known dimension is the one *adjacent* to the angle. The proper trigonometric function must contain both of these sides. The function containing both opposite and adjacent sides is the tangent of the angle.

Therefore if

$$\tan D \ D \ \frac{opp}{adj}$$

then

$$\tan 10 \text{ degrees } D \ \frac{opp}{6}$$

A calculator tells us that the tangent of 10 degrees is 0.17632. So tan 10 degrees D 0.17632. This means that

$$0.17632 \; D \; \frac{opp}{6}$$

Using algebraic transformation,

$$opp \; D \; (0.1763)\,(6)$$
$$D \; 1.06 \text{ m}$$

This indicates that the image is displaced 1.06 m from its original position by the prism.

Unit 2:

characteristics of ophthalmic lenses

Learning Objective:

An understanding of lens optics begins with basic study of the action of a single ray of light and how it is affected when passing into or through a transparent optical surface. Principles of reflection and refraction of light form the basis for understanding the nature of prism. Vision takes place when rays of light from an object or objects are brought together in focus on the retina of the eye. Once again, the process of refraction, or bending of rays, is involved. This time, however, a curved refracting surface is required so multiple rays will all be either directed toward or away from a specific point in space.

At the end of this unit, students will be able to;

1. Understand the action of a curved surface on more than one ray of light is the basis for comprehending the optics of lenses.
2. Learn process of refraction, reflection and absorption of light through lenses.

THEORY OF LIGHT

To understand the way light behaves for lenses, we need to look at the nature of light itself. In simplistic terms, when light travels, it behaves in two ways:

1. Like a wave generated by dropping a rock into a pond (Figure 12-1).
2. Like a particle or photon. This could be compared with a controlled and continuing "explosion" of light that might be visualized in Figure 12-2.

For our purposes, we can best understand light as a wave.

Defining Light Waves

A light wave has certain characteristics as shown in Figure 12-3. The highest part of the wave is called the *crest,* and the lowest, the *trough*. The vertical distance from the trough to the crest is called the *amplitude*. The greater the amplitude is, the greater the intensity of the light. The horizontal distance from one crest to the next is called the *wavelength*. As wavelength changes, so does the perceived color of the light.

The Visible Spectrum

The wavelengths of light that are visible to the human eye vary in length from 380 to 760 nm. These are only a small part of what is called the *electromagnetic spectrum*. The electromagnetic spectrum goes from very short cosmic or gamma rays to extremely long radio waves

(Figure 12-4). Human vision is sensitive to only a very small portion of the electromagnetic spectrum.

When the sun radiates visible light, it includes the entire visible spectrum. When we see the whole spec- trum of visible wavelengths together, we perceive the light as being white; when we see only one wavelength of light or several wavelengths that are very close to one another in length, we see that light as one specific color.

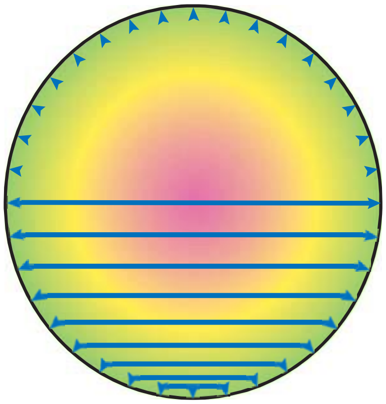
Colored Light

When white light is broken up into its component colors, it has a specific order of colors. Those colors of the rainbow were memorized by most people in elementary school by using the acronym for the imaginary name “Roy G Biv” (Figure 12-5). The letters refer to the colors red, orange, yellow, green, blue, indigo, and violet. In optics we order colored light according to wavelength, starting with the shortest and going to the longest. The shortest visible wavelength is blue, and the longest is red. Therefore we need to consider the “Roy G Biv” acronym as being spelled backwards (vib g yor).

Technically, each wavelength has its own color. However, the changes in color from one wavelength to the next are so small that we can only discriminate in wavelength areas. Figure 12-6 shows approximate wave- lengths and their associated colors. Interestingly enough, different cultures make the color break at different places. For example, at the border between blue and purple, some cultures will identify that “in-between” wavelength area as blue, whereas another will call it purple.

A luminous or primary source is one that generates light. A candle would be an example of a primary source of light. The color of such an object depends upon the wave length(s) of light that the luminous source generates.

A secondary source of light is one that is reflecting light from a primary source. The moon is a secondary source of light, or a sweater would be a secondary source. The color of a secondary source of light depends upon what wavelengths it is reflecting. A white shirt reflects all wavelengths of light. A blue shirt reflects only blue light and absorbs all other wavelengths. A black shirt absorbs all wavelengths of light. With this in mind, it is



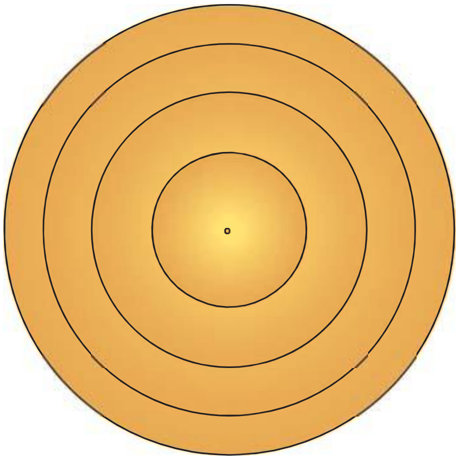


Figure 12-1. Light can be thought of as traveling away from its point of origin in waves, much like what happens when an object is thrown into a smooth pond, causing a wave to travel outward.

Figure 12-2. Light can also be thought of as particles of energy leaving the source.

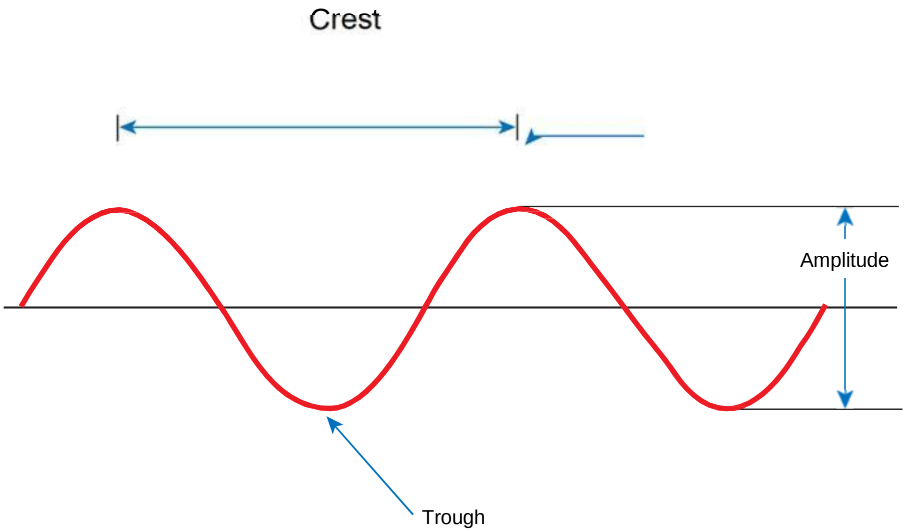


Figure 12-3. Light waves have crests and troughs, with a wavelength being measured from crest to crest

REFLECTION

Unless interrupted, a single ray of light travels in a straight line. Placing a highly reflective object in its path causes the light to bounce back at an angle. This type of reflection is called *regular or specular reflection* (Figure 12-7). The angle at which the light strikes the surface is known as the *angle of incidence* (Figure 12-8).

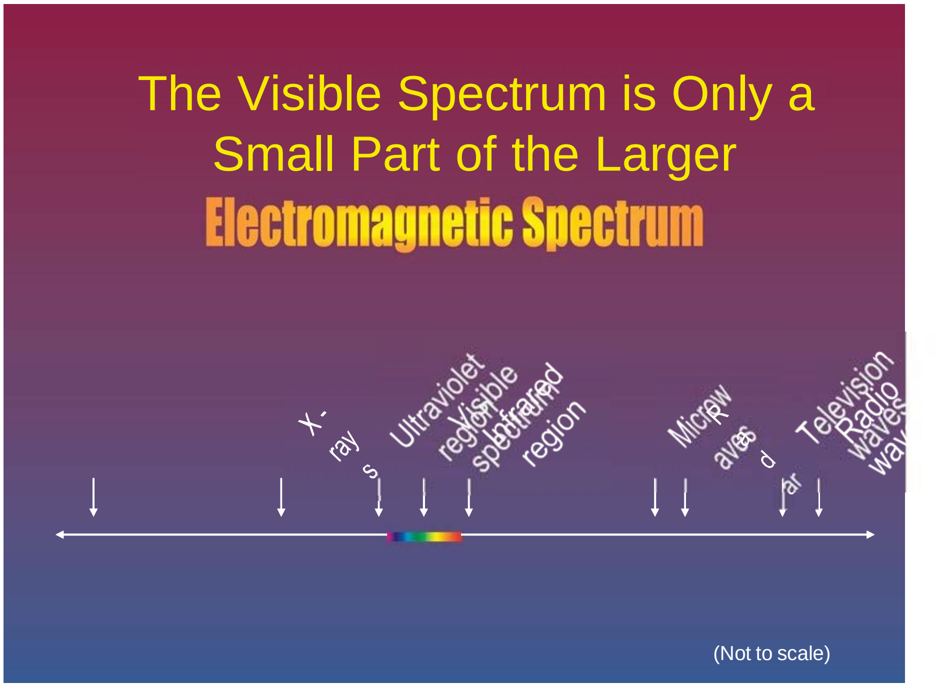
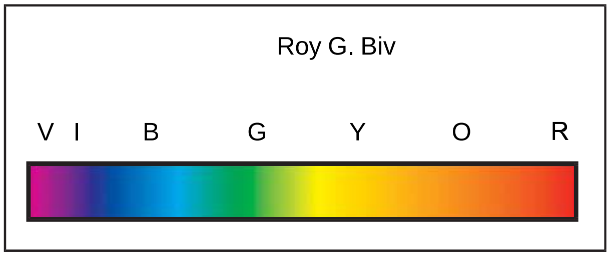


Figure 12-4. Visible light is only a small part of the larger electromagnetic spectrum that includes everything from very short gamma rays to extremely long radio waves.



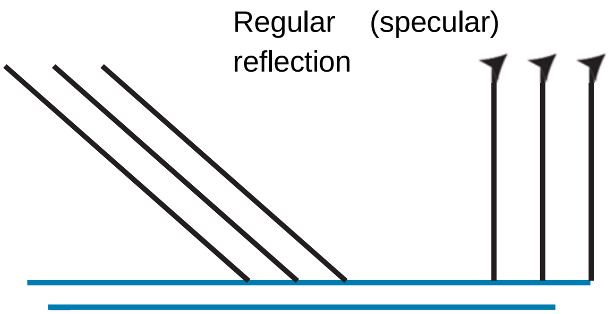


Figure 12-5. When we consider light, we generally go

from left to right, starting with the shortest violet wavelengths and ending with the longer red wavelengths. So when looking at the order of the colors, the traditional acronym, “Roy G Biv,” will be spelled backwards.

Reflecting surface

Figure 12-7. Specular or regular reflection occurs with a smooth surface.

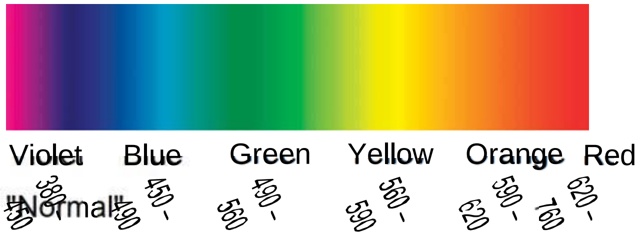


Figure 12-6. How color and wavelength correspond.

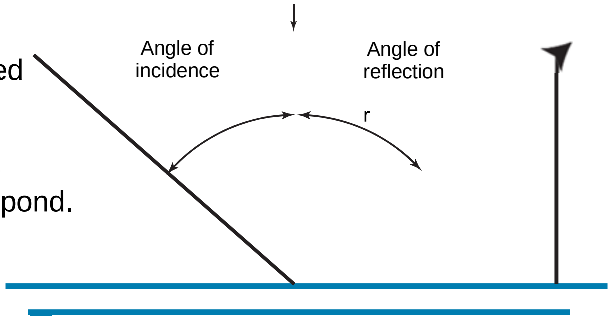
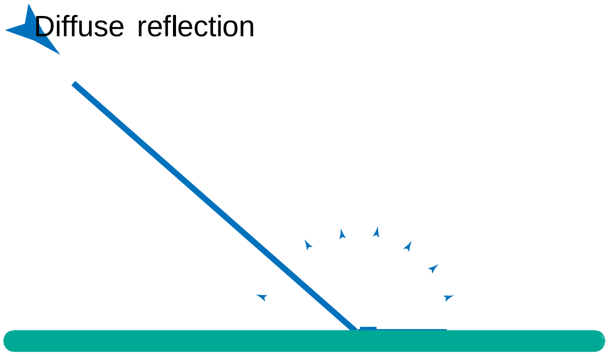


Figure 12-8. For reflected light, the angle of reflection always equals the angle of incidence. Both angles are measured from a line perpendicular to the reflecting surface known as the normal.



Diffuse reflecting surface

Figure 12-9. Diffuse reflection occurs when light strikes a surface that is matte or irregular.

THE SPEED OF LIGHT AND REFRACTIVE INDEX

Light is able to travel faster through some materials than through others. Simply stated, some materials have more resistance to the speed of light than others. There is no resistance to light in a vacuum because there is nothing in a vacuum. Light travels at its maximum speed of about 186,355 miles/sec (or 299,792,458 m/sec). However, when light enters a clear medium, such as water, there is resistance, and the speed of light slows. The medium of less resistance (such as air) is said to be the *rarer* medium. The medium of more resistance is said to be the *denser* medium.

The amount of resistance to the speed of light that slows it down is represented by a number. This number is referred to as the *refractive index*. The more the material slows the passage of light, the higher is its refractive index.

The number for the refractive index of a given substance is obtained by comparing the speed of light in a vacuum with the speed of light in the new subtance. It is written as a fraction. The speed of light in a vacuum is on top (the numerator) and the reduced speed of light in the new substance on the bottom (the denominator). The speed in the denominator is always the slower speed and smaller number; thus the fraction will always come out greater than 1. Here is how it is written:

SpeedofLightinaVacuum Speed of Light in New Substance
D Absolute Refractive Index

Because there cannot be less resistance to the speed of light than nothing at all (a vacuum), this number for the refractive index is called the *absolute refractive index*.

However, we live on earth where most everything is surrounded by air. Since light travels almost as fast in air as in a vacuum, we use air instead of a vacuum as the standard when calculating refractive index. Since the value for refractive index obtained is relative to air instead of to a vacuum, the refractive index obtained in this manner is called the *relative refractive index*. This is expressed as the fraction:

Speed of Light in Air Speed of Light in New Substance
D Relative Refractive Index

Refractive index is commonly abbreviated as *n,* and the number we use when speaking of refractive index is really relative refractive index.

REFRACTION

When light strikes a new, transparent medium straight on (at a 90-degree angle, perpendicular to the surface), the light slows down, but continues on in the same direction.

But when light strikes a new substance or medium at an angle, the change in speed in the new media causes the light to change direction. Consider, for example, the case of light passing from a low refractive index medium, such as air, to a higher refractive index medium, such as water or even glass, which are both denser than air. To understand what is happening and why, consider the analogy of a car traveling on a smooth substance with little resistance, such as a smooth, paved road. In a moment of inattention, the car drifts to the side and encounters a rough substance, such as the gravel shoulder of the road. When the right wheel hits the rough gravel, in which direction does the car want to go? Because the right side of the car slows faster than the left side, the car pulls to the right.

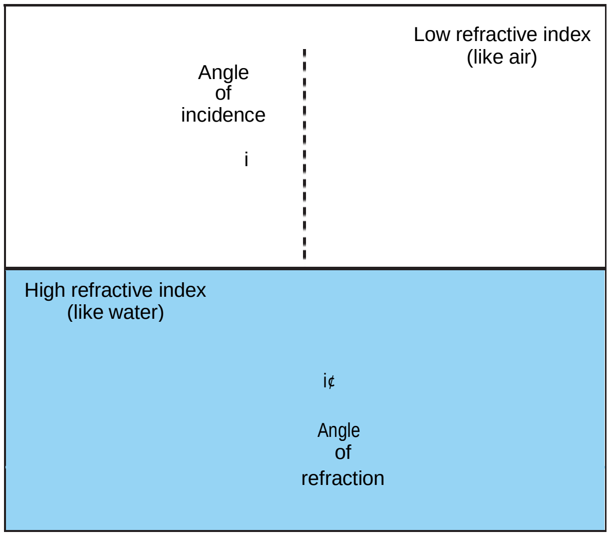
When a light ray passes from a rarer medium (low refractive index) and strikes a denser medium at an angle, the light will be bent, or *refracted*. The direction of the refraction is toward the normal to the surface (Figure 12-10). Remember, the “normal” to the surface is a line perpendicular to the surface at the place where the light strikes the surface.

Snell’s Law

If the refractive indices of both media through which light is traveling are known, the angle of refraction for a given angle of incidence is predictable. It may be calculated geometrically using the sines of the angles of incidence and refraction. It is expressed algebraically as:

n sin i D nD sin iD.

This is known as *Snell’s law*.



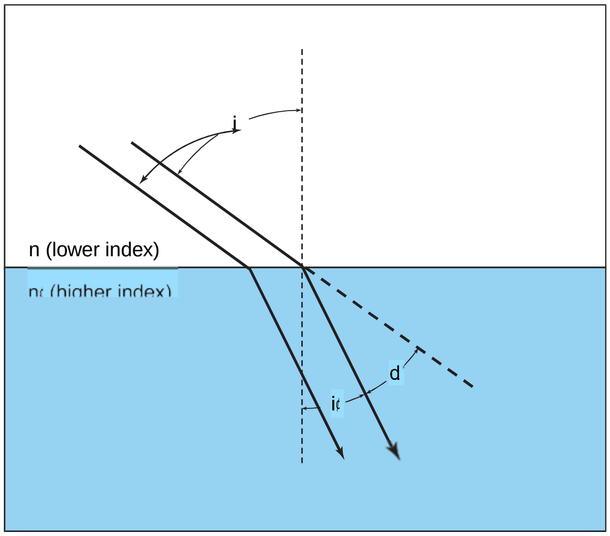


Figure 12-10. The figure shows the bending or refraction of light going from a rarer to a denser medium. To see how light is bent going from a denser to a rarer medium, simply turn the figure upside down and visualize it traveling in the opposite direction.

Figure 12-11. The angle of deviation is the angular change in light direction from its original path.

Angle of Deviation

The angle of refraction is the angle of the refracted ray with reference to a line perpendicular to (normal to) the refracting surface. It does not directly tell how much the ray has deviated from its original path. This amount of that the light has deviated from its original path is called the *angle of deviation* (d) (Figure 12-11).

It can be seen from the geometry of the figure that for light leaving a rare and entering a dense medium, i D d D iD. Therefore the angle of deviation is d D i − iD.

In prev. example, asked for the angle of refraction for light enter-ing a new medium at an angle of incidence of 30 degrees. The angle of refraction was found to be 19.2 degrees. Knowing this, what is the angle of deviation?

We know that the angle of deviation is:

d D i − iD.

Since the angle of incidence (i) is 30 degrees and the angle of refraction (iD) is 19.2 degrees, then:

d D 30 − 19.2
D 10.8 degrees.

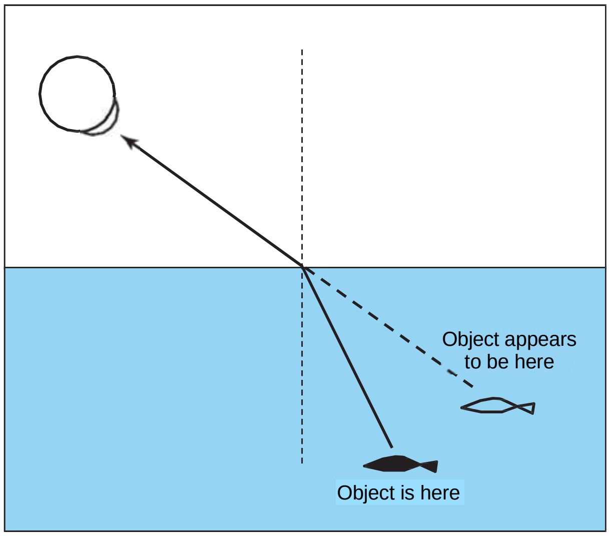


Figure 12-12. When light from an object in another media, such as water, is seen at an angle, the light rays are bent, making the object appear to be somewhere other than its actual location.

Figure 12-13. A ray of light entering a parallel-sided slab of glass perpendicular to both surfaces will pass through without ever changing direction.

The angle of deviation is calculated as d D i − iD because light is leaving a rare medium and going into a dense one. When the opposite situation exists and light is trav- eling from a dense medium and entering a rare one, the angle of deviation would become d D iD − i. An example of light coming from a dense medium, like water, and traveling into a rare medium, like air is shown in Figure 12-12. This figure helps to explain why objects that are viewed below the surface of water are not always where they appear to be. Attempts to spear the fish in figure 12-12 would be unsuccessful unless the spear fisherman compensated for the apparent location of the fish.

PRISM

When Light Goes Straight ThroughParallel Surfaces

When light leaves air and enters a slab of glass, the light travels more slowly in the glass. If the two sides of the glass slab are parallel and the light enters perpendicular to the front surface, it does not bend at all. It simply slows down. And when the ray of light strikes the back surface of the glass, it is still perpendicular to the surface and does not bend. It comes out the other side of the slab of glass unchanged in direction. The light leaves the other side of the glass at exactly the same 90-degree angle that it first entered (Figure 12-13). (Incidentally, when the light leaves the glass and goes back into air, it speeds back up to its original, expected speed in air.)

When Light Goes Through Parallel Surfaces atan Angle

If light strikes a parallel-surfaced slab of glass at an angle, the ray will be bent at each surface in accordance with

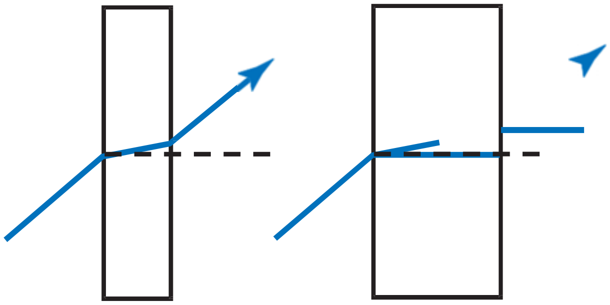
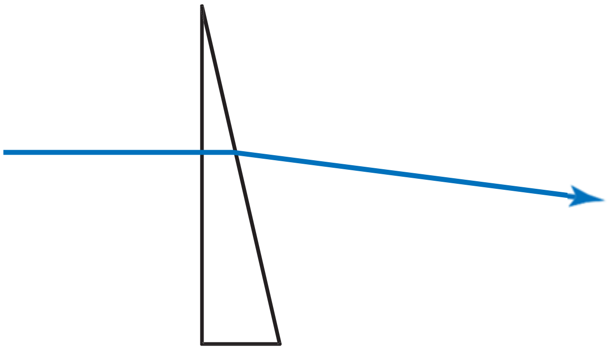


Figure 12-14. Light entering a parallel-sided slab of glass at an angle is bent at both front and back surfaces. If the media on both sides of the material are the same, as when the slab is surrounded by air, the ray of light will leave parallel to its original direction. Although traveling in exactly the same direction, the ray of light will be displaced laterally. The amount of displacement depends on the thickness of the slab.

the rule of refraction. Since the indices of the glass and of air at both surfaces are the same, the emergent ray and the incident ray will be parallel, just as when the ray struck the glass from straight ahead. The only difference is that it will be slightly displaced laterally. The amount of displacement depends upon the angle at which the incident ray struck the glass and the thickness of the glass (Figure 12-14).

When the Two Surfaces Are Not Parallel Suppose that the two surfaces of glass are not parallel to one another as shown in Figure 12-15. In this figure a ray of light strikes the first surface straight on, at a 90-degree angle. It is not bent from its original path. However, the second surface is at an angle to the first surface, giving the glass a prism shape.
The ray of light continues to pass through the glass and strikes the second (angled) surface at an angle. In



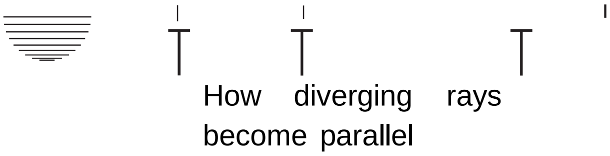


Figure 12-17. By looking at light passing through a series of apertures, it is easier to see that the farther from a source light rays travel, the less they diverge from one

another. And the less they diverge from one another, the more parallel they become.

Figure 12-15. Here light strikes the first surface straight on and is not bent until it reaches the second angled surface. Now it is bent and leaves in a different direction.

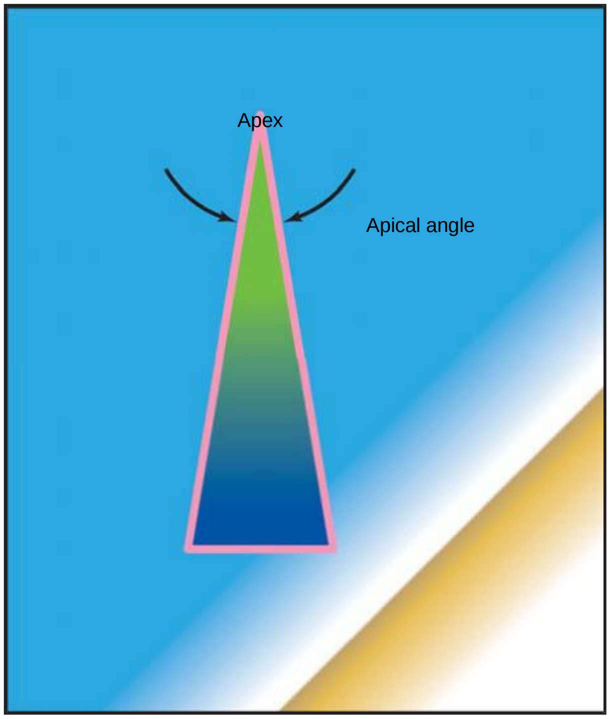


Figure 12-16. Basic prism terminology.

this case the angle that the light strikes the surface is equal to the angle of tilt of the second surface. Because the ray of light is going from a denser to a rarer medium, it will be bent away from the normal to the surface by an amount greater than its angle of incidence. This will cause the light to be bent downward toward the base of the prism. The amount of this deviation is predictable using Snell's law. *Light is always bent toward the base of a prism*.

The tip of a prism is called the *apex*. The wider, bottom part of a prism is called the *base* (Figure 12-16).

More information on how prism works will be found in Chapters 15 and 16.

HOW CURVED LENSES REFRACT LIGHT

Refraction of Multiple Light Rays

Up to this point, we have seen how light acts when it is viewed as a single ray and strikes a flat surface. However, light does not come as a single ray, but many.

And lenses have curved surfaces instead of flat surfaces. With a curved refracting surface, multiple rays will all be either directed toward or away from a specific point in space.

Light rays emanate from a light source or object in an ever-increasing circle similar to the way a ripple goes out from the place where a stone is thrown into water. As these rays go out from their source, they are said to be *diverging*. The outer border of this ever-growing circle of light is called the *wave front*. The farther from the object source this wave front is, the less that light rays passing through an *aperture* or “hole” of a certain size will be diverging. In essence they become more parallel, as seen in Figure 12-17. After traveling far enough away from the object, these light rays no longer appear to be diverging. At an infinite distance from the object, they become parallel.

Focusing Light

Suppose it becomes desirable to divert parallel rays coming from an object at infinity to bring them to focus at one image point. If it were only a question of two parallel rays, the problem could be solved easily using principles explained earlier in the chapter. Since a prism deviates light at a known angle, if two prisms were placed base to base so as to interrupt these two rays, the rays could be caused to meet at a specified point, known as the *focal point* (Figure 12-18). Rays traveling toward one specific point are said to be *converging*. In our example, the position of the focal point can be arbitrarily changed by merely increasing or decreasing the power of the two prisms.

If there were four parallel rays to be focused, however, the two-prism concept would no longer be feasible (Figure 12-19). Stronger prisms would be required to deviate the two outer rays enough to bring them to the same focal point. It would be possible to stretch this system by cutting off the tops of the original prisms and replacing the tops with prisms of stronger power (Figure 12-20). It quickly becomes obvious, however, that the

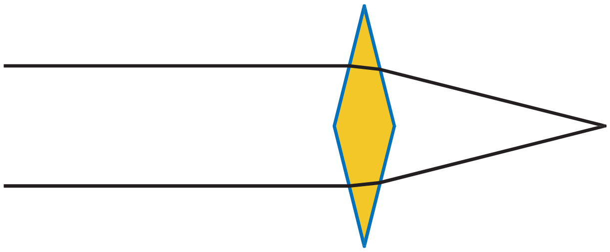
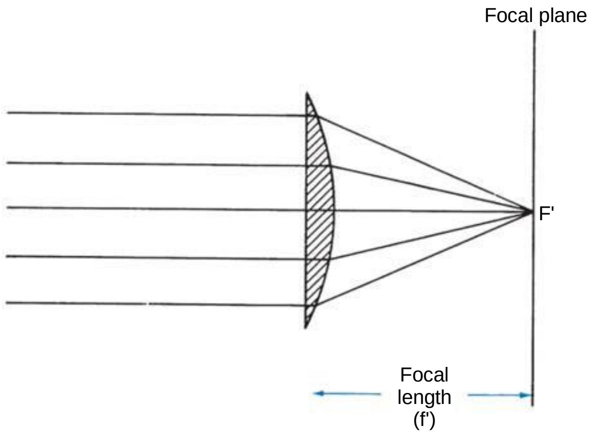


Figure 12-18. If only two parallel rays of light have to be brought to a single point of



focus, the job would be fairly simple. Just use two prisms placed base to base.

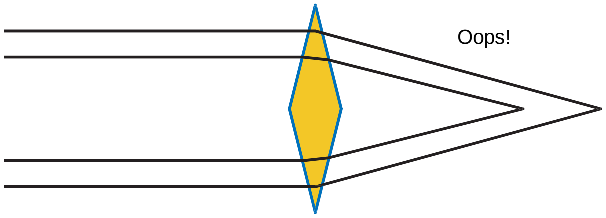


Figure 12-19. A two-prism system cannot be expected to bring light to a single point of focus if there are more than two rays of light.

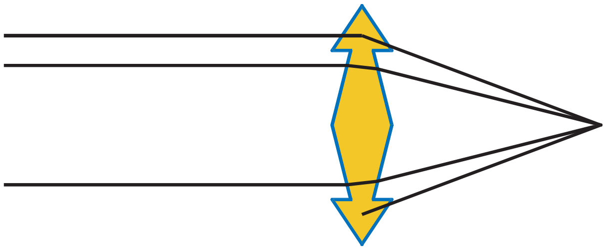


Figure 12-20. If just prisms were used to bring light to a focus, a different prism would be necessary for each incoming parallel ray to form a single point focus.

more parallel rays there are, the more new prisms will be required.

Fortunately the problem may be solved by creating a curved surface to replace the theoretical series of stacked prisms. The curve of the surface is in the form of an arc of a circle (Figure 12-21).

The shorter the radius of curvature, the more light is bent when striking the surface and consequently the closer to the lens the focal point will be.

FOCAL POINTS AND DISTANCES

For a source at infinity, the specific point at which an image will be focused is known as the *second principal focus* (FD) of the lens. The distance from the lens to the second principal focus is known as the *second (or second- ary) focal length* of the lens (fD) (Figure 12-22).

The *first principal focus* (F) of a lens is that point at which an object may be placed so that the lens will form an image of that object at infinity. In other words, the

Figure 12-21. The point where parallel light entering a lens is brought to focus is known as the second principal focus of the lens. The distance from the center of the lens to this prin- cipal focus is the second focal length. In this figure, parallel light rays coming from an object at infinity converge to form a real image of the object. The lens is drawn with the front surface flat so that it is easier to see how the curved back surface has a changing angle. If a ray of light strikes the lens at the exact center, the curved back surface is actually flat, and the light ray passes through without being bent. The farther toward the outside edge of the lens, the more the back surface will be angled. The more the back surface is angled, the more the incoming ray of light will be bent.

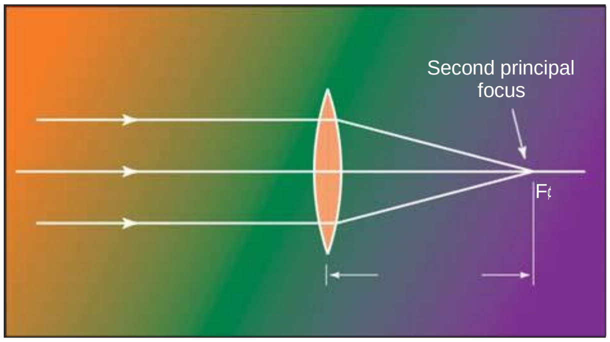


Figure 12-22. When parallel light enters the front surface of a lens, light is brought to a focus at what is called the *second principal focus* of the lens.

object is placed so that light rays *leaving* the lens are now parallel. The distance from the lens to the first principal focus is the *first (or primary) focal length* of the lens (Figure 12-23.

For spectacle lenses the more important focal point is the second principle focus.

QUANTIFYING LENSES

Sign Convention

Up to this point, when prisms or lenses have been shown, the first surface has usually been a flat surface and perpendicular to the light. (In optics a flat surface is called a *plano* surface.) All light entering the prism or lens has been parallel light. If the first surface is flat and perpendicular to the entering light, then light passes through the first surface undeviated (without being bent). It is not bent until it reaches the tilted or curved second surface. There has therefore been only one factor to consider: the second surface.

To have a common groundwork for understanding the action of a lens on other than parallel light and lenses with both surfaces curved, it is necessary to adhere to accepted conventions.

These *sign conventions* serve to prevent confusion and errors in describing the optics of lenses. Some of these conventions include the following:

1. Light is traditionally represented in optical drawings as traveling from left to right.
2. Any measurements are made with the lens at the center of the system. It is as if the lens is at the zero point of a number line. All distances to the right of the lens are expressed as positive and all distances to the left as negative (Figure 12-24).

3. When measurements must be made anywhere other than left or right of the lens, all positions above a horizontal line passing through the lens center are considered positive; all positions below a horizontal line passing through the lens center are negative.
4. Lenses that cause parallel rays of light to converge are designated as having *plus* power, whereas those causing parallel rays of light to diverge are identified as being *minus*.

Surface Curvature

To enable the steepness of curvature of a surface to be quantified, a unit of measure based on the radius of curvature (abbreviated r) has been chosen (Figure 12-25). So a surface can be quantified by its radius of curvature. But the reciprocal of the radius of curvature in meters

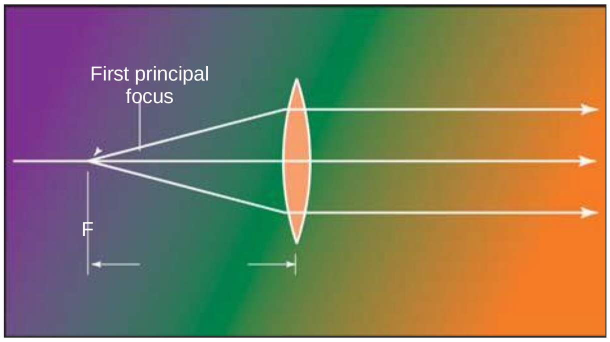


Figure 12-23. When an object is placed at the first principal focus of a lens, light rays will leave the lens parallel to one another.

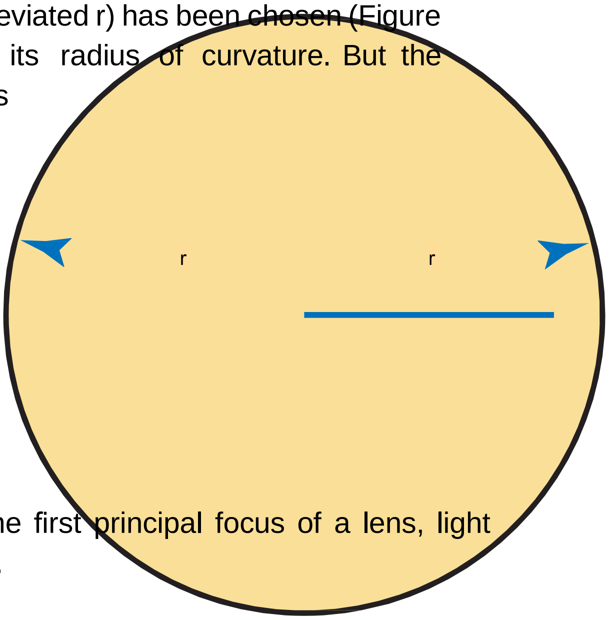


Figure 12-25. A spherically curved surface may be quantified by the radius of curvature of that spherical surface.

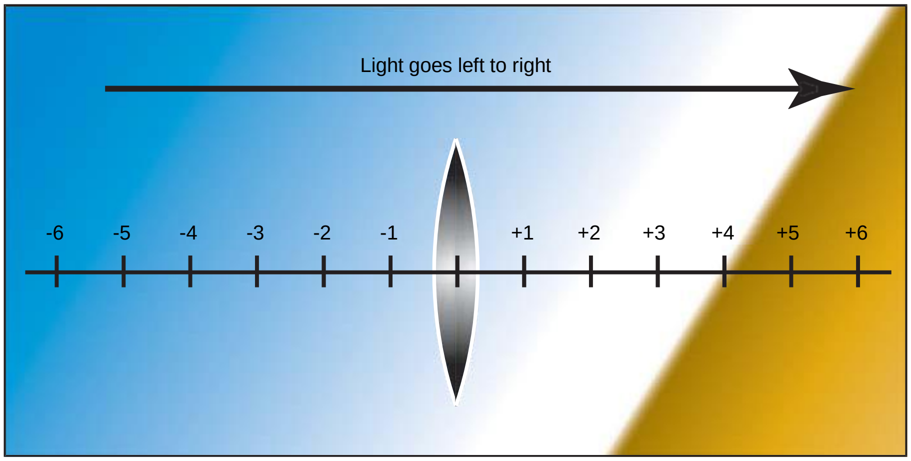
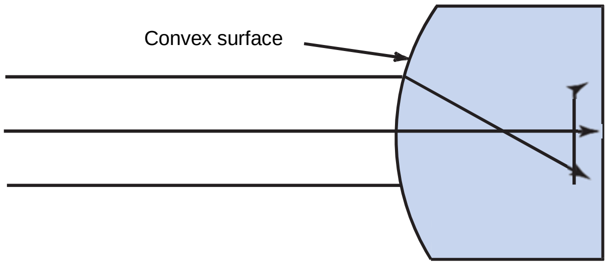


Figure 12-24. Sign convention for lens optics.



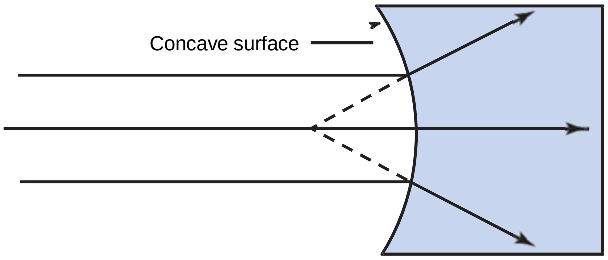


Figure 12-26. A convex surface.
Figure 12-27. A concave surface.

is the measure commonly used and is referred to as *Curvature*. Curvature is expressed in units of reciprocal meters (m^{-1}) and is abbreviated R.

$$R\ D\ \frac{1}{r}$$

If a lens has a surface that would complete a circle having a radius of D5 cm, what is its Curvature?

The radius of curvature is plus. This means that the center of the circle with this radius falls to the right of the lens surface. To find Curvature, the radius of curvature must first be converted to meters:

$$D5\text{ cm }\ D\ D0.05\text{ m.}$$

Then we take the reciprocal of the radius in meters to find Curvature (R).

$$R\ D\ \frac{1}{D0.05}\ D\ D20\text{ m}^{D1}$$

Convex and Concave Surfaces

Suppose the front surface of a lens has a radius of curvature of 20 cm. If the center of the radius of curvature is to the right of the front lens surface, then the surface is a convex surface (Figure 12-26).

If the radius of curvature of the front surface of a lens is centered to the left of the lens surface, the front surface is a concave surface (Figure 12-27). For a lens in air, convex surfaces are positive (plus) in power, and concave surfaces are negative (minus).

Units of Lens Power

The total power of a lens or lens surface to bend light is referred to as its *focal power*. Units of focal power are expressed as diopters (D) and are related to the focal length of the lens or lens surface. The *focal length* is symbolized by *f* or *f* D*,* for primary or secondary focal length, whereas the focal power (in diopters) of the lens

is symbolized by *F*. Because ophthalmic lenses are generally referenced by their second focal length and are worn in air, the relationship between focal length and focal power is expressed by the formula:

$$F \text{ D } \frac{1}{f \text{ D}}$$

The focal length (*f* D) must be in meters when calculating lens power.

$$F \text{ D } \frac{1}{f \text{ D}}$$

Positive Lenses and Real Images

Up to this point, the type of lens spoken of has been the type that causes parallel light rays to converge, or come together. This type of lens is referred to as a *positive* or a *plus* lens.

Light from an object brought to a focus by a lens will form an image of that object. In the case of converging rays, this image can be intercepted, forming an image on a screen, just like a camera forms an image on the film in the back of the camera. This type of image is known as a *real image*.

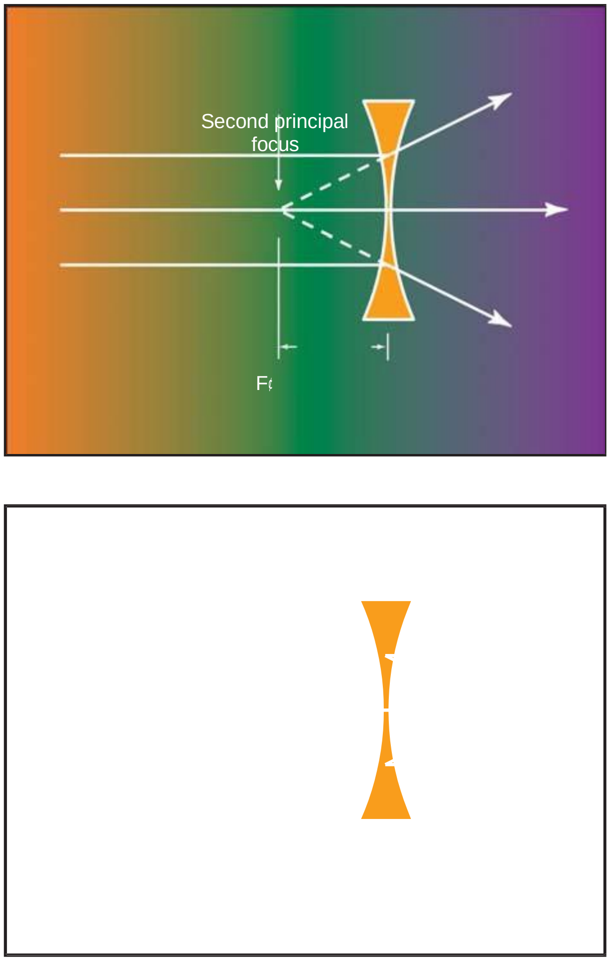


Figure 12-28. A minus lens causes parallel incoming light to diverge. The point from which light appears to diverge is called the second principal focus. The image formed by the backward projection of these diverging rays is a virtual image.

Negative Lenses and Virtual Images

According to sign convention, a lens whose focal point is to the left of the lens will have a negative focal power. When parallel rays enter a lens that has a negative focal length (and therefore also a negative power) rays leaving the lens diverge or spread away from one another instead of converge toward one another.

Whereas a positive lens was described as analogous to prisms placed base to base, a negative lens can he com- pared with the action of two prisms placed apex to apex. The focal point of a negative lens is found by extending the diverging rays backward to a point from which they appear to originate (Figure 12-28). This is called the *second principal focus* of the lens.

However, if rays of light leave the lens parallel, they must have been converging when entering the lens. The point toward which they are converging is called the *first principal focus* of the lens (Figure 12-29).

When rays diverge on leaving a lens as shown in Figure 12-28, the image of the object cannot be focused on a screen. This is because the image is formed by a backward projection of the diverging rays to their apparent point of origin. Even though they do not originate from that point, they appear as if they do. This type of image is referred to as a *virtual image*.

Figure 12-29. For light to leave the second surface of a lens as parallel rays, entering light rays must be converging toward the first principal focus of the lens.

Next the focal power is found by taking the reciprocal of the focal length.

$$F\ \mathrm{D}\ \frac{1}{f\mathrm{D}}$$

$$\mathrm{D}\ \frac{1}{\mathrm{D}0.40}$$

$$\mathrm{D}\ \mathrm{D}2.50\ \text{diopters}$$

The lens is found to have a power of −2.50 D.

Surface Power and the Lensmaker’s Formula

When a lens is thin, that lens derives its total power from the combined powers of its front and back surfaces.

The amount light is bent by a lens surface depends on the radius of curvature of that surface and on the refractive index of the lens material. The formula taking these two factors into consideration when light is passing into the first surface of a lens is:

$$F_1\ \mathrm{D}\ \frac{n\mathrm{DD}n}{r}$$

where F_1 D the surface power of the first surface expressed in diopters,

nD D the refractive index of the lens (i.e., the medium into which the light is entering),

n D the refractive index of air (the medium the light is leaving), and

r D the radius of curvature of this first lens surface in meters.

This formula is often referred to as the *Lensmaker’s formula*.

It can be seen from this formula that just because two lens surfaces have the same radius of curvature it does not necessarily mean that they will have the same ability to refract (or bend) light. The index of refraction of the material also has an effect. Therefore two surface powers will not be the same if the index of refraction of the two materials is different. Consider, for example, a CR-39 plastic lens of index 1.498 and a higher index plastic lens of index 1.66. Both have a front curve with a radius of curvature of D8.66 cm. Using the Lensmaker's formula, we find the lens surface power of the CR-39 lens to be:

no longer come to a focus at the secondary focal point of the lens, but at some other point. That point may be determined by using both:

1. A quantitative value for the vergence of light entering the lens and
2. The power of the lens.

THE ACTION OF A LENS ON OTHER THAN PARALLEL LIGHT

The Concept of Vergence

Up to this point, only parallel light that is entering the lens from straight ahead has been considered. Such light is brought to a focus at the focal point of the lens. If light entering the lens is *not* parallel, light leaving the lens will

$$\underline{1}\ \mathrm{D}\ L\mathrm{D}l\mathrm{D}$$

There is a relationship between the entering vergence of light and the exiting vergence of light. It is as follows: The vergence of the light entering the lens added to the dioptric value of the lens is found to equal the vergence of the light leaving the lens. This can be expressed in the form of an equation:

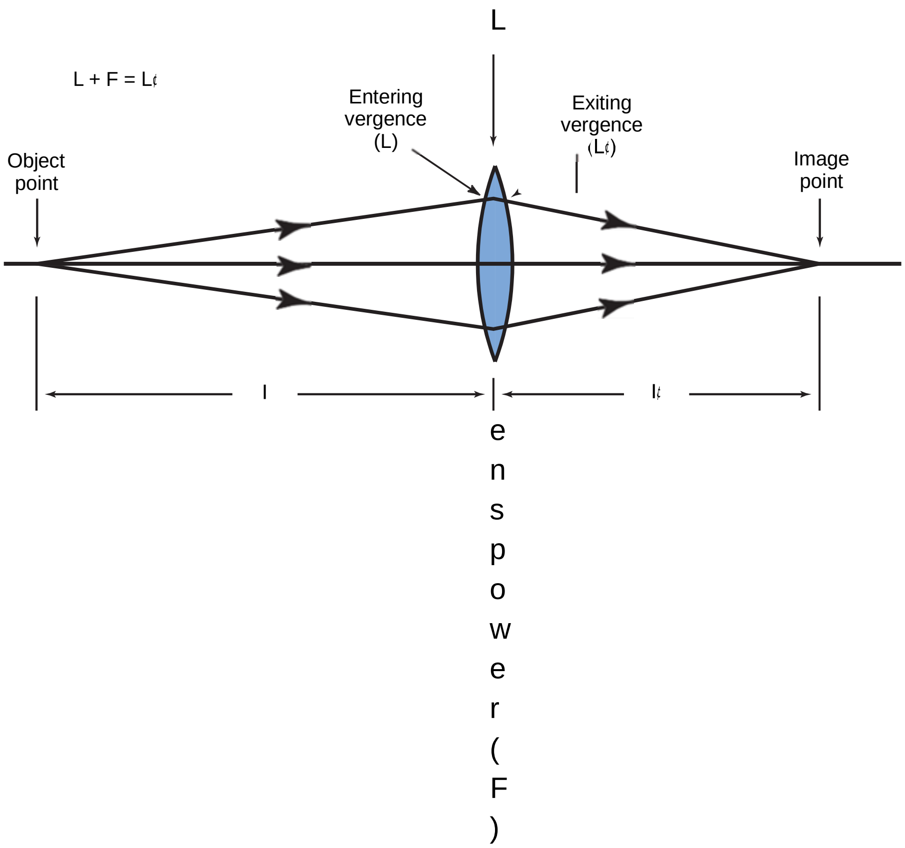
$$L\ \mathrm{D}\ F\ \mathrm{D}\ L\mathrm{D}$$

This equation is commonly expressed in transposed form as $F\ \mathrm{D}\ L\mathrm{D}\ \mathrm{D}\ L$, called the Fundamental Paraxial Equation. For single refractive surfaces it is written in the more basic form:

$$F\ \mathrm{D}\ \frac{n\mathrm{D}}{l\mathrm{D}}\mathrm{D}\ \frac{n}{l}$$

–

where $n\mathrm{D}$ is the refractive index of the second media into which light is entering and n is the refractive index



In air, 1/l = L, and 1/l¢ = L¢.

Figure 12-30. Diverging or converging light may be quantified using vergence. Object and image points that correspond (as shown here) are referred to as *conjugate foci*.

This *fundamental paraxial equation* is a *paraxial* equa- tion because it remains valid for those rays in the par- axial or central region of the refracting surface. (Rays that are a great distance away from the center of the lens are affected by lens aberrations. They no longer fall exactly at the focal point.)

SPHERES, CYLINDERS, AND SPHEROCYLINDERS

Spheres

All lenses considered thus far have a single point where light is brought to a focus. This is true even if that point must be found by extending diverging rays backward as in the case of minus lenses. When a lens has a single point focus, it is referred to as a *spherical* lens.

The surface curvature of a spherical lens duplicates the surface curvature of a sphere, or ball. A plus spherical surface can be compared with a slice off the side of a glass ball, whereas a minus spherical surface would form an exact mold for a ball of equal radius of curvature (Figure 12-32).

$$-2.00\ \mathrm{D}\ \mathrm{D}\ (-10.00\ \mathrm{D})\ \mathrm{D}\ L\mathrm{D}$$

so

$$L\mathrm{D}\ \mathrm{D}\ -12.00\ \mathrm{D}$$

The vergence of light leaving the lens has a dioptric value of −12.00 D. Knowing this we can find the image point. Knowing that

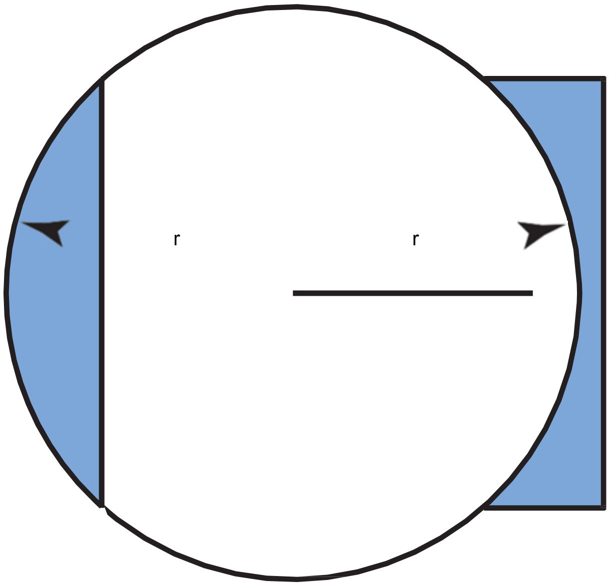
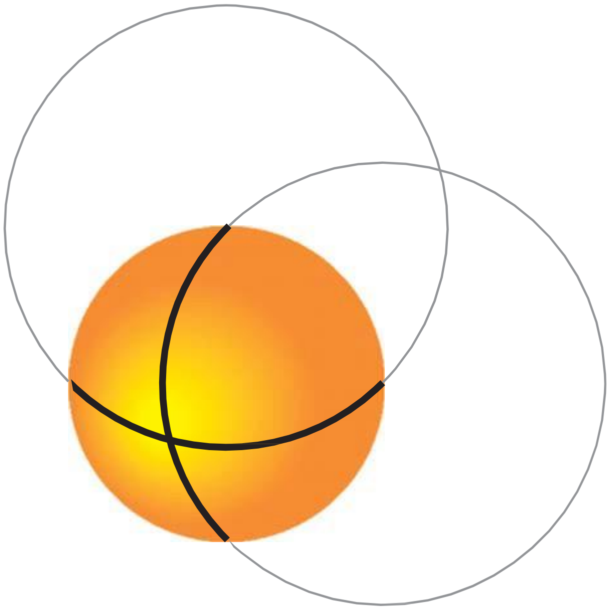


Figure 12-32. A plus spherical surface has a shape as if cut from the side of a sphere, whereas a minus spherical surface is shaped as though molded from a sphere.



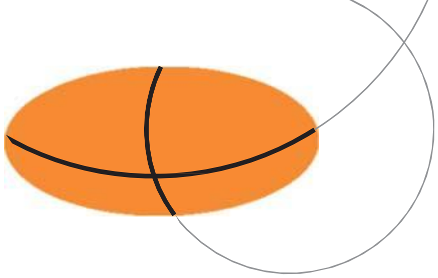


Figure 12-33. A spherical surface has the same radius of curvature in every meridian.

Spheres Correct for Nearsightedness and Farsightedness

The *sphere* is the most basic type of ophthalmic lens used and is used to correct both nearsightedness and farsightedness.

Plus spheres are used for the correction of *hyperopia,* or *farsightedness*. This occurs when light focuses behind the retina of the eye. A plus lens adds more convergence to incoming light and draws the focus point up onto the retina.

Minus spheres correct for *myopia,* or *nearsightedness*. Myopia occurs when light focuses in front of the retina. A minus lens causes the light to diverge (or converge less) before entering the eye and allows the focal point to drop back onto the retina.

The Problem of Astigmatism

If a refracting surface of the eye is not spherical, the eye cannot bring light to a single point focus on the retina. For example, the front surface of the eye (the cornea) should have a front surface that is spherical, like a spherical ball, such as a basketball (Figure 12-33). But instead it may be shaped more like the surface of a football. There are now two different curves to consider: one being from tip to tip of the football and the other running around the central part at right angles to the first curve (Figure 12-34). Each of these two curves has its own radius of curvature. When this happens, a single point focus is no longer possible.

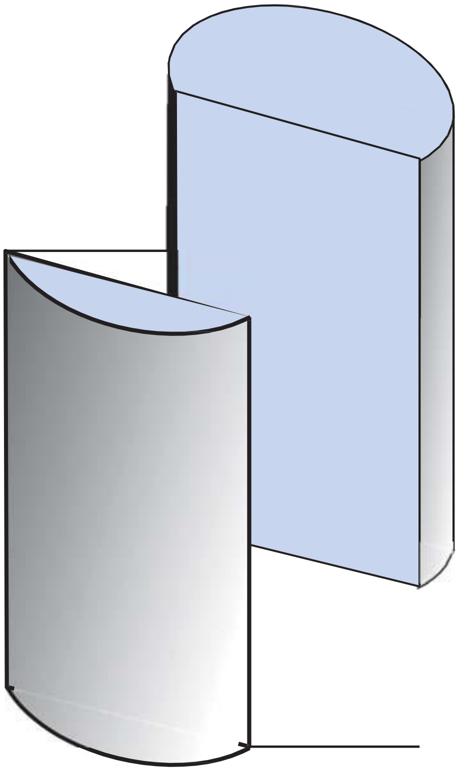
When an eye has two different curves on a single refracting surface, the condition is known as *astigmatism*. A situation can occur that may require a correction in only one of those two refracting meridians.

Figure 12-34. A toric surface has different radii of curvature in each of two major meridians.

Cylinder Lenses

A lens that only has power in one meridian can be visualized as one that is cut from the side of a clear glass cylinder (Figure 12-35). A commonly occurring example of something cylindrical in shape is a pillar used to support the porch of a house. A rod is also cylindrical in shape. The lens that optically behaves as if it were cut from the side of a glass cylinder takes on the name of the structure from which it is cut. It is therefore known as a *cylinder*.

Because a cylinder lens can be turned from an up-and-down to a sideways position (or to any orientation between the two), a method for specifying its exact orientation must be chosen. That method is to specify the *axis* direction. The axis of a cylinder can be thought of as being equivalent to the string threaded through the center of a cylindrical bead (Figure 12-36). As this “string” is tilted, the angle of tilt is specified by degrees. Horizontal is considered zero. The angle in degrees the “string” or cylinder axis makes with this horizontal line specifies orientation (Figure 12-37). When the cylinder axis is horizontal, instead of writing 0 degrees, it is conventional to write 180 degrees. Zero and 180 are both on the same horizontal line and, for cylinder axes, are the same. Only degrees 0 through 180 are necessary for complete specification because, as in the example of Figure 12-37, 210 degrees is the same as 30 degrees.



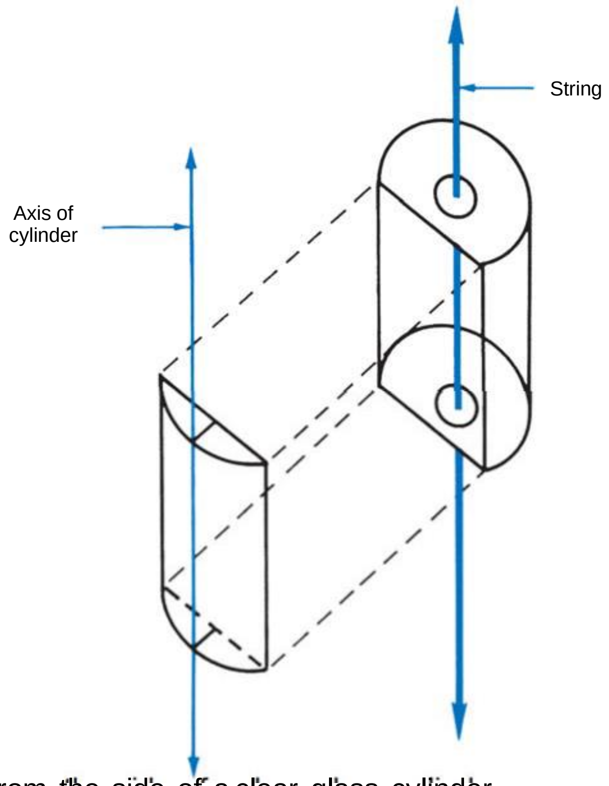


Figure 12-35. A lens shaped as though cut from the side of a clear glass cylinder is referred to as a *cylinder lens*.

Figure 12-36. The axis of a cylinder is the reference for determining its orientation. The axis of a cylinder parallels an imaginary string running through the center of a cylindrical bead.

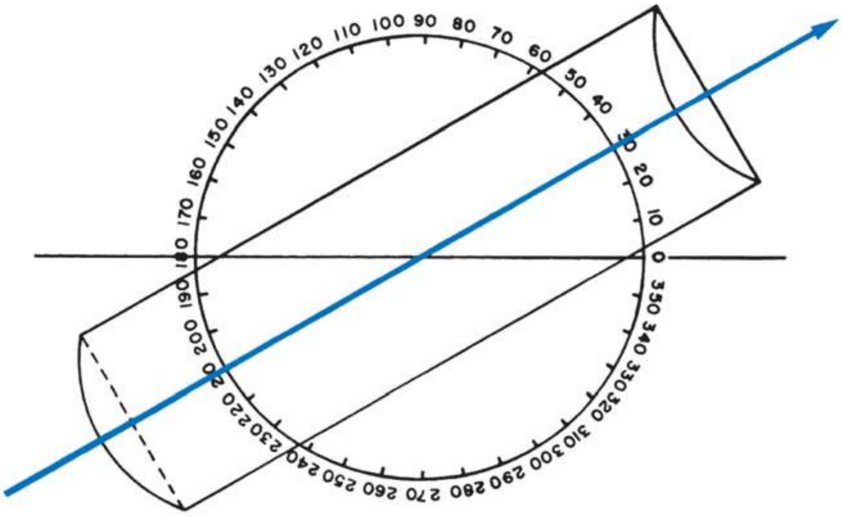


Figure 12-37. The orientation of a cylinder is specified in degrees from 0 degrees through 180 degrees. Specifying beyond 180 degrees is unnecessary because it duplicates 0 degrees through 180. (Zero degrees and 180 degrees are really the same axis. By convention 180 is used instead of 0.) In this figure, the axis of the cylinder shown is oriented at 30 degrees.

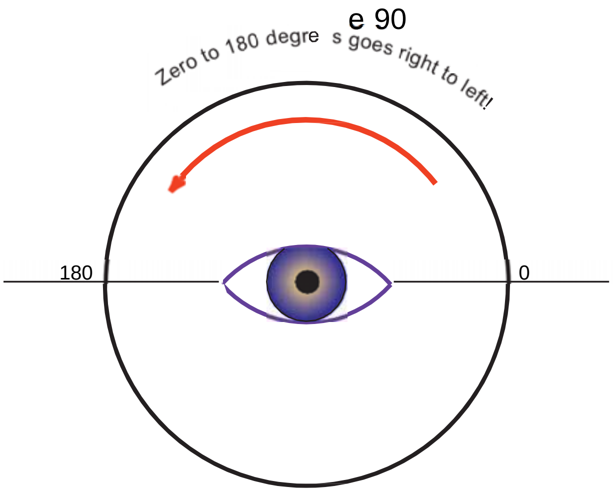


Figure 12-38. When looking at the person wearing spectacle lenses, the cylinder axis degree scale goes counterclockwise, from right to left. This is the same for both right and left eyes.

If a person is wearing a cylinder lens in a pair of glasses, the scale is always counterclockwise, or right to left, as shown in Figure 12-38. It is as if the wearer's eye was directly *behind* the scale, looking *through* it. This is true for both right and left lenses.

Optics of a Cylinder Lens

As previously stated, a cylinder can be used to compen- sate for the eye that does not bring light to a point focus. This can happen if the shape of the cornea in the 90-degree meridian is more curved than it is in the 180- degree meridian. A cylinder lens is suited for correcting this difference because light that strikes the lens along the axis of the lens will pass through that lens undeviated (Figure 12-39).

The meridian of the lens paralleling the cylinder axis is called the *axis meridian*. Along the cylinder axis, both the front and back surfaces of the cylinder are flat. So the cylinder lens has no light refracting power along the axis of the cylinder.

Light striking the cylinder at any other point on the lens will be bent in accordance with the power the curved meridian of the cylinder has (Figure 12-40).

The meridian of the cylinder lens at right angles to its axis has one flat surface and one curved surface. This means the lens has power in this meridian. This meridian is called the *power meridian* of the cylinder. *The axis of a cylinder is always at right angles to the power meridian of the cylinder* (Figure 12-41).

Writing Cylinder Power

As with spherical lenses, the power of a cylinder is also specified in dioptric units. Remember that the full power of the cylinder is only in the meridian opposite the axis

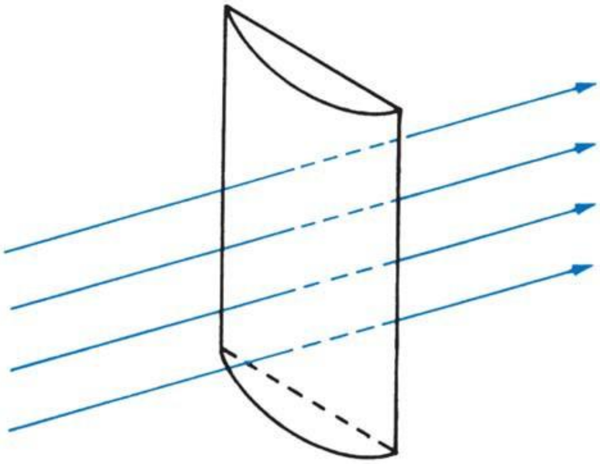


Figure 12-39. Light striking a cylinder along the cylinder axis is not bent. For a plano cylinder, such as the one shown, both surfaces are flat along the axis.

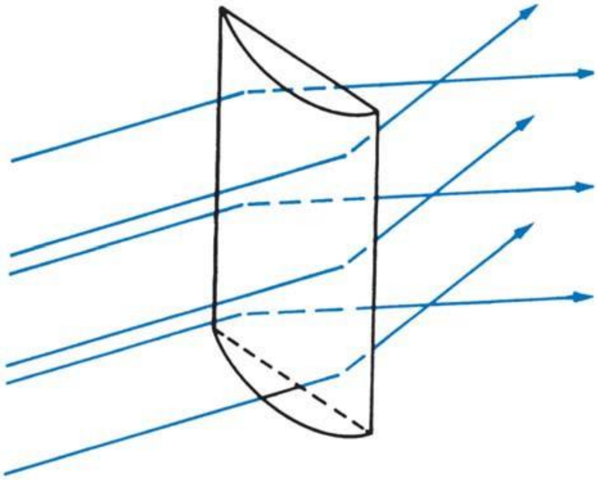


Figure 12-40. Light striking a cylinder at any other location than on the axis will be focused along a line parallel to the cylinder axis and at a constant distance from the lens.

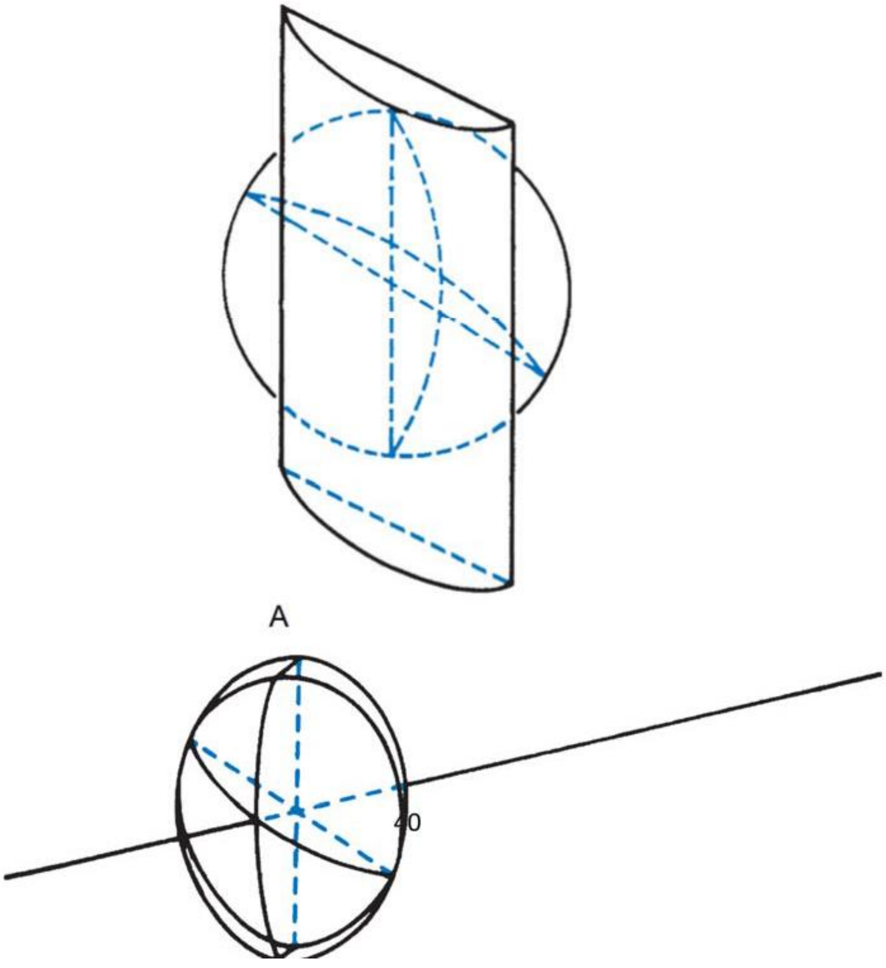
of the cylinder. As a result, when quantifying a cylinder lens, not only must a dioptric power be specified, but also the orientation of the lens axis. For instance, a cylinder may have D3.00 D of power in the horizontal meridian and zero power in the vertical meridian. The specification would therefore be D3.00 D cylinder power with axis at 90 degrees. This may be abbreviated D3.00 × 90, with the *x* being short for “axis.” Because any lens with an axis orientation *must* be a cylinder, it is unnecessary to write “cylinder” or “cyl.”

Minus Cylinder Lenses

Cylinder lenses previously described and used in examples have all been plus in power. It is also possible to have a cylinder lens that is minus in power. As with a minus sphere, a minus cylinder lens has an oppositely curved, or concave, refracting surface. The surface is such that it would cradle a cylindrical rod of equal radius (Figure 12-44). It is as if it were molded from a cylindrical rod.

As with the plus cylinder lens, the axis of a minus cylinder parallels the area of equal lens thickness. On a plus cylinder, this is along the line of maximum lens thickness; with the minus cylinder, the axis runs along the line of minimum lens thickness. To continue the analogy, a minus cylinder axis can be thought of as the imaginary string through the center of a cylindrical rod or bead against which a minus cylinder lens could rest. This meridian on the lens where the axis is found is referred to as the *axis meridian*.

There is also no power found in the axis meridian of a minus cylinder; maximum power is found 90 degrees away from it. The meridian of maximum power in a minus cylinder is still referred to as the *power meridian* (Figure 12-45).



B

Figure 12-42. A spherocylinder combination can be thought of as just that—a sphere lens and a cylinder lens placed together **(A).** This combined power combination may be con- structed as a single lens with two curves on one surface **(B)**.

LENS FORM

Lenses can be made in a variety of forms, with many forms possible for a lens of the same power. One lens form may be steeply curved, whereas another of identical power may appear quite flat. It is also possible to manufacture a lens of a specified power with a cylinder com- ponent on either the front or back surface.

Lens Forms a Sphere May Take

The *nominal power* of a lens is the sum of its front and back surface powers. When expressed as an equation, this is F_1 D F_2 D F_{TOTAL}. Up to this point, most lenses have been shown with one flat surface of no power and one curved surface. The curved surface makes the lens either plus or minus in power. The flat surface is referred to as *plano,* or without power.

If one surface is plano and the other an outward- curved plus surface (i.e., a *convex* surface), the lens is referred to as *planoconvex*. If one surface is plano and the other curved inward for minus power (i.e., a *concave* surface), the lens is *planoconcave* (Figure 12-46). If both surfaces are convex or both concave, the lens is *biconvex* or *biconcave* (Figure 12-47). This form does not specify that both surfaces necessarily be equal in power. If this were the case, the lens could be further classified as *equiconvex* or *equiconcave* (Figure 12-48). For example, a biconvex lens of D4.00 D of power could have surface powers, such as the following:

F_1 D F_2 D F_T
(D2.00 D) D (D2.00 D) D D4.00 D (D3.00 D) D (D1.00 D) D
D4.00 D (D0.50 D) D (D3.50 D) D D4.00 D

It is also possible to have a lens with one side convex (plus) and the other concave (minus). This is the most

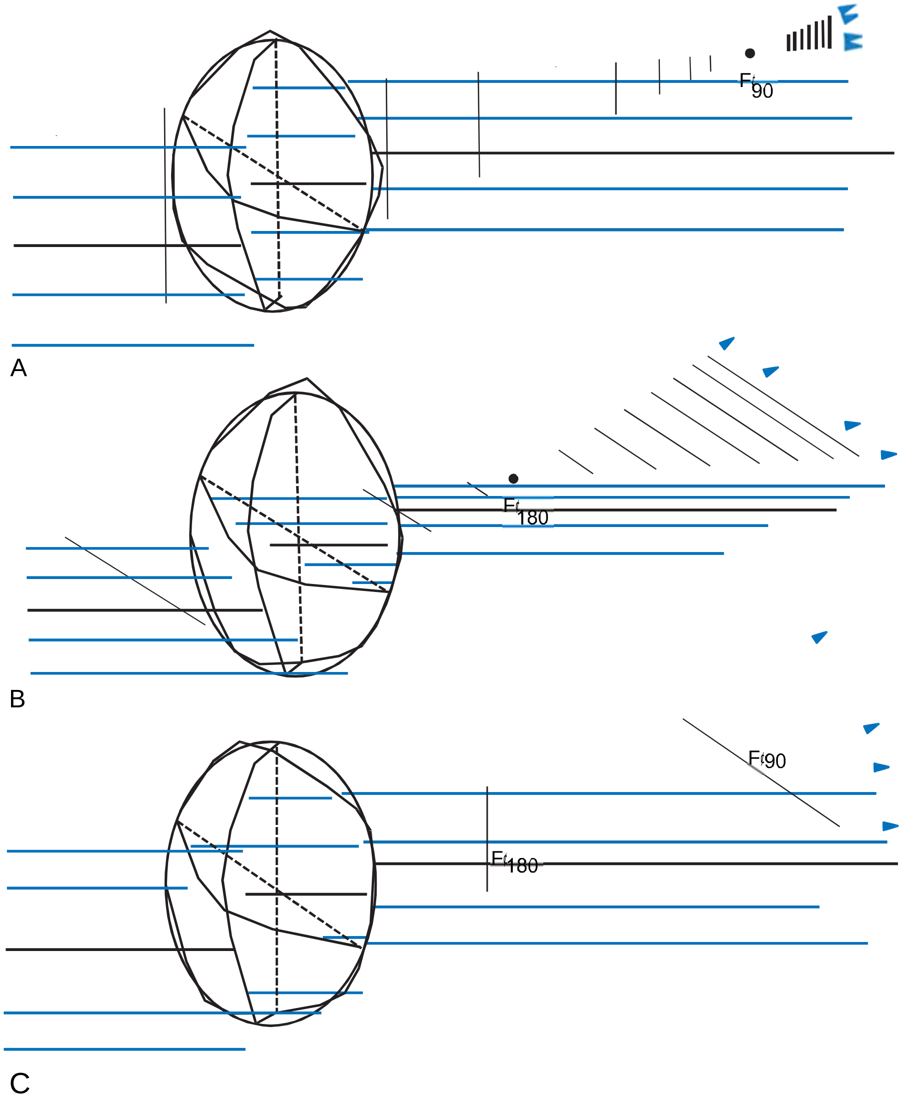


Figure 12-43. This lens is the same spherocylinder lens combination as was shown in Figure 12-42. **A,** Rays previously unbent in the 90-degree cylinder axis meridian are now brought to a focus because of the addition of a plus sphere component. **B,** Rays in the 180-degree power meridian of the cylinder that were previously brought to a line focus by the cylinder are now refracted more by the additional plus sphere power. **C,** The net effect of both sphere and cylinder components results in two line foci.

common ophthalmic lens and is referred to as a *meniscus** lens (Figure 12-49). The same D4.00 D lens power might then have any one of the following forms, which represent only a fraction of the possibilities.

F_1 D F_2 D F_T
(D7.00 D) D (−3.00 D) D D4.00 D (D8.00 D) D (−4.00 D) D D4.00
D (D10.00 D) D (−6.00 D) D D4.00 D

* Originally a meniscus lens was one that had a 6.00 D surface curve either on the front (D6.00 D) or on the back (D6.00 D). Now it has come to mean a lens with a convex front surface and a concave minus surface.

Lens Forms a Cylinder May Take

Even a pure cylinder may take several forms. These forms are limited only in that one meridian must have a net power of zero and the other a net power equal to the cylinder value. To keep the two meridians of a cylinder separate, it is helpful to use the concept of a power cross. A *power cross* is a schematic representation of the two major meridians of a lens or lens surface. For a pure cylinder, these two meridians, at right angles to each other, are the axis meridian and the power meridian. A D4.00 D × 90 cylinder is schematically represented on a power cross in Figure 12-50.

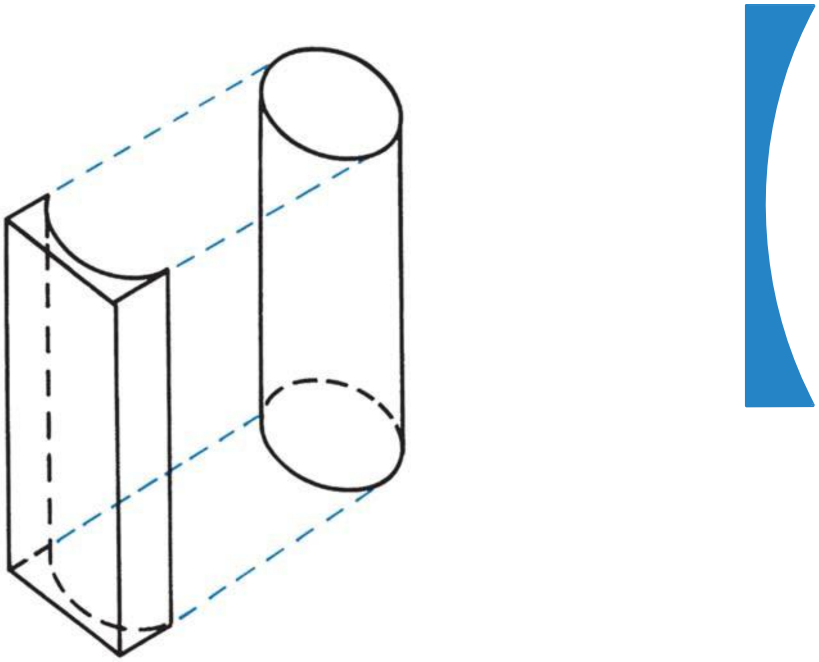


Figure 12-44. A minus cylinder lens can be thought of as if molded from a cylindrical rod.

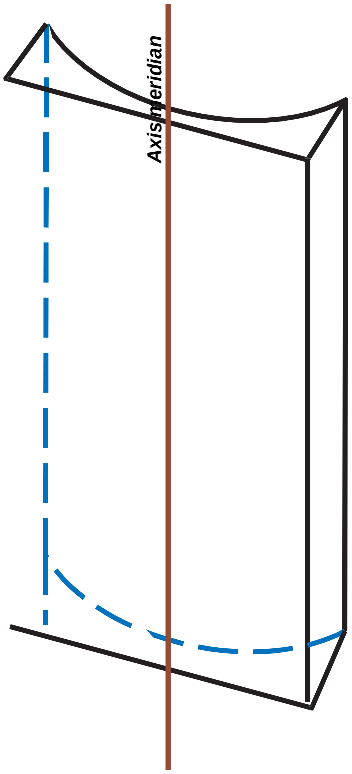


Figure 12-45. Power and axis meridians shown for a minus cylinder.

Figure 12-46. Two planoconvex lenses are shown on the left, two planoconcave on the right.

Figure 12-47. Two biconvex lenses are shown on the left, two biconcave on the right.

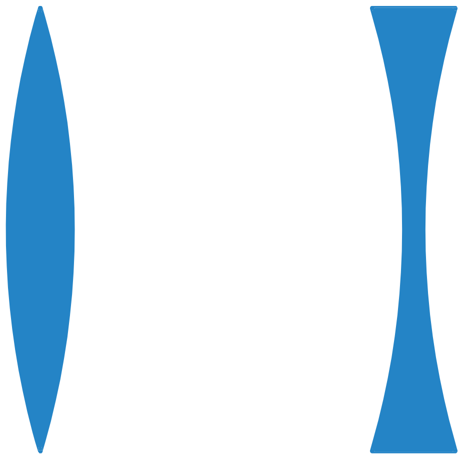


Figure 12-48. Equiconvex and equiconcave lenses must have the same

curvature on both front and back surfaces.

Figure 12-49. A meniscus lens has a plus (convex) surface on the front and a concave (minus) surface on the back.

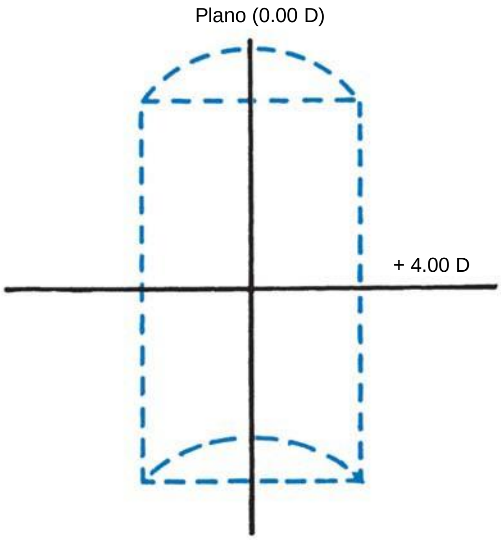


Figure 12-50. This is a power cross for a D4.00 × 090 cylinder lens. The outlined cylinder is for reference only, never appearing on an actual power cross.

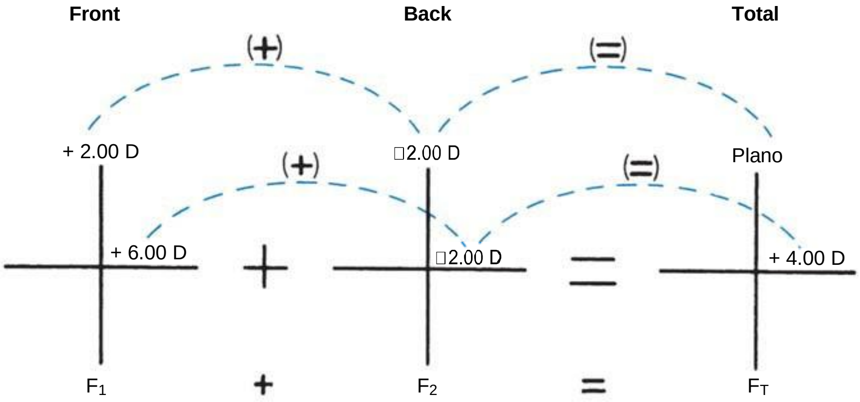


Figure 12-51. For this lens, the front surface is the toric surface with two different lens powers. The

back surface is spherical, so both 90-degree and 180-degree back surface meridians have the same power. The total power of the lens can be found by adding corresponding surface meridians together—90 with 90 and 180 with 180.

In the “original,” or most easily visualized form, this lens has two front curves. One is a plano surface “curve” of zero power in the 90-degree meridian, the other a D4.00 D powered curve in the 180-degree meridian. The back surface is flat, or plano, in both meridians. In this lens form, since the back surface has zero power, the front surface creates the total power of the lens.

Suppose, however, that the back surface of the lens has a power of −2.00 D in both meridians. It is still possible to construct a cylinder lens with the same total power.

For example, suppose the front surface powers are as follows:

of three power crosses—one for the front surface, one for the back surface, and a third power cross for the total lens power. Both 90-degree surface meridians are added together to obtain the total lens power in the 90-degree meridian, and both 180-degree meridians are added together to obtain the total lens power in the 180-degree meridian.

When a lens has two separate curves on a surface, neither being plano but both having power, the surface is said to be *toric*.

F_1 at 90 D D2.00 D
F_1 at 180 D D6.00 D

With the back surface power of F_2 D −2.00 D, the total lens power is still D4.00 × 90. Figure 12-51 shows a series

Figure 12-52. Steps in solving lens form power problems consist of: **A,** drawing the appropriate series of crosses; **B,** writing all known lens powers on the crosses; and **C,** solving for the remaining unknown factors.

Plus and Minus Cylinder Form Lenses

When the lens obtains its cylinder power from a difference in power between two *front* surface meridians (i.e., a toric front surface lens), the lens is said to be ground in *plus cylinder form*. If, on the other hand, a lens has a cylinder component, but the cylinder power is a result of a difference in power between two *back* surface meridians (i.e., a toric rear surface lens), it is a *minus cylinder form lens*. In other words, the plus cylinder form lens has two curves on the front and one spherical curve on the back, whereas a minus cylinder form lens has one spherical curve on the front and two curves, making up the cylinder component, on the back.

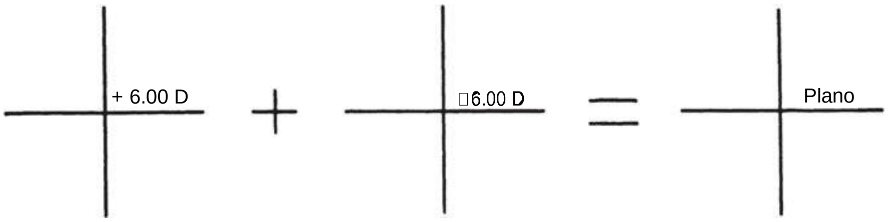
Lens Forms a Spherocylinder May Take

Minus Cylinder Form

As seen earlier, either a sphere or a cylinder lens may be constructed in several different forms, all having the

Front
+ 6.00 D

Back	**Total**
▪ 8.00 D	▪ 2.00 D



F_1 F_2 F_T

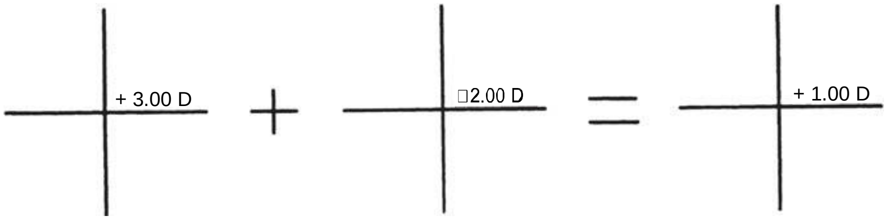
Figure 12-53. The lens represented on this power cross series is minus cylinder in form since the toric surface is on the back of the lens.

Front **Back** **Total**

+ 3.00 D

Plano

+ 3.00 D



F_1 F_2 F_T

Figure 12-54. Front and back curves and total lens power for a spherocylinder lens.

same total power (F_T). In the same way it is also possible to construct a spherocylinder lens in several different forms, all having the same total spherocylinder power.

Toric Transposition

It has been shown that it is possible to have a spherocylindrical lens of the same power expressed in at least two different lens forms and written in two different ways, either the plus or the minus cylinder form of prescription writing. Most logically one would assume that the plus cylinder form of prescription writing would be used exclusively for lenses with a toric front surface and the minus cylinder form of prescription writing for lenses with the toric surface on the back. This, however, is not the case. Instead of indicating the location of the toric surface for the prescribed lens, the written form usually only indicates the type of lenses used during the examination process. In the past, optometrists wrote prescriptions in minus cylinder form, and ophthalmologists wrote prescriptions in plus cylinder form. This is no longer universally true. However, prescriptions of both forms are commonly seen.

However, there is a high consistency in how spectacle lenses are made. Almost every lens used for prescription eyewear in the United States has the toric surface on the back and is thus a minus cylinder form lens.

Because lens prescriptions may be written in either plus or minus cylinder form, it is necessary to be able to convert or *transpose* from one form to another. This process is known as *toric transposition*.

Steps for transposing from one form to the other are as follows:

1. Add the sphere and cylinder values to obtain the new sphere value.
2. Change the sign of the cylinder (plus to minus or minus to plus).
3. Change the axis by 90 degrees. (This can be done by addition *or* subtraction since the end result is the same. The answer for the axis, however, must be from 1 to 180 degrees. An answer of 190 degrees, for example, is not acceptable.)

The Spherical Equivalent

A spherocylinder lens will correct for astigmatism and myopia or hyperopia. If it was necessary to correct a nearsighted or farsighted person who also has astigma- tism, but there were no cylinder lenses available, what would be the best correction using only a sphere lens? We know how a sphero- cylinder lens has two focal lines. If only a sphere lens is to be used, the best lens will be one that has a focal point at a dioptric value that is halfway* between these two focal lines. (The location that is halfway between the two dioptric values of the spherocylinder lens is called the *circle of least confusion*. The rays of light do not come to a point focus, but instead form a circle at this location.) That compromise sphere lens is called the *spherical equivalent*.

*The halfway location is not at the physical halfway point between the two focal lines. Instead it will be at a point that is based on the dioptric value halfway in between. For example, a lens with a power of D1.00 D2.00 x 180 has two focal lines—one for the D1.00 D power meridian, the other for the D3.00 D power meridian. These lines are at 100 cm and 33.3 cm from the lens. The physical halfway point would be 66.7 cm from the lens. However, the location of the circle of least confusion is determined by the spherical equivalent of the lens. The spherical equivalent is D2.00 D. The focal point of D2.00 is at 50 cm, not 66.7 cm. Therefore the circle of least confusion is at 50 cm.

Sample Questions:

1. What is the spherical equivalent for this lens?

D3.00 − 1.00 × 180

Solution

Using the formula for the spherical equivalent we have:

D

2. What is the spherical equivalent for a lens having a powerof −4.25 −1.25 × 135?

Solution

Again using the formula we find the spherical equivalentas:

Spherical Equivalent D DD4.25D D D1.25

Spherical Equivalent D DD3.00D D

1.00

2

2

D DD4.25D D DD0.625D

D DD3.00D D DD0.50D

D D2.50 D

3. Suppose a ray of light is traveling from air of refractive index 1 to glass of index 1.523. If the ray strikes the glass at an angle of 30 degrees, what will be the angle of refraction?

Solution

We know that:

n D 1 (refractive index of air)

nD D 1.523 (refractive index of glass) i D 30 degrees (angle of incidence).

But we do not know the angle of refraction.

iD D ? (angle of refraction)

Ifn sin i D nD sin iD,

then for our example

(1) (sin 30) D (1.523) (sin iD).

Since sin iD is the unknown, the above formula can be rear- ranged algebraically as follows:

D1DDsin30D D Dsin iDD 1.523

Using a calculator capable of generating trigonometric functions, it is found that:

sin 30 D 0.5.

The angle of deviation is the angular change in light direction from its original path.

Therefore

sin iD D D1DD0.5D
1.523
D 0.3283

Again using a calculator it is determined that 0.3283 is the sine of 19.2 degrees. (This is done by finding the inverse sin[sin^{D1}] of 0.3283.) Thus the resulting angle of refraction is 19.2 degrees.

Angle of Deviation

The angle of refraction is the angle of the refracted ray with reference to a line perpendicular to (normal to) the refracting surface. It does not directly tell how much the ray has deviated from its original path. This amount of that the light has deviated from its original path is called the *angle of deviation* (d) (Figure 12-11).

It can be seen from the geometry of the figure that for light leaving a rare and entering a dense medium, i D d D iD. Therefore the angle of deviation is d D i − iD.

4. Describe the procedure to calculate spherical equivalent?

How to Find the Spherical Equivalent

To find the spherical equivalent of a spherocylinder lens:

1. Take half the value of the cylinder and
2. Add it to the sphere power.

In other words, as a formula the spherical equivalent is

$$\text{Sphere D } \frac{\text{Cylinder}}{2} \text{ D Spherical Equivalent}$$

Unit 3:

Lens Curvature and Thickness:

Learning Objective:

A major factor in how a lens will perform depends upon how the lens is shaped. Shape is defined by how the lens is curved, starting with the base curve.

Participants will learn:

1. How lenses are shaped, and how that shape, or curvature, is measured.
2. How Lens curvature and lens thickness are related.
3. How a lens with a given prescription will look in a frame, an understanding of lens thickness is needed. The latter part of the chapter explains how lens thickness can be predicted from lens power.

CATEGORIES OF OPHTHALMIC LENSES

Ophthalmic lenses may be divided into the following three broad categories:

- Single vision lenses
- Segmented multifocal lenses
- Progressive addition lenses

Single Vision Lenses

Single vision lenses are the most basic type of lens. These lenses have the same power over the entire surface of the lens. Single vision lenses are used when the same optical power is needed for both distance and near vision. They are also used when a person requires no prescription for distance, but needs reading glasses. Whenever possible single vision lenses are edged from lenses kept in stock at the laboratory. Because these lenses are finished optically to the correct power on both the front and back surfaces, they are called *finished lenses*. Finished lenses are also referred to as *uncuts* because they have not yet been "cut" to the correct shape and size (Figure 13-1, *A*). When single vision lenses are in uncut form and do not require that a surface power be ground onto the lens, they are called *stock single vision lenses*.

A stock single vision uncut lens is less expensive than a custom surfaced lens. However, if the stock lens is too small for the frame, then a stock single vision lens will not work. Instead the lens must be produced in the sur- facing section of the optical laboratory. The surfacing laboratory puts surface power on the lens. They start with a lens having only one surface that is ready to use, or "finished." This is usually the front surface. The laboratory must grind and polish the second surface to the required power. A lens with only one of the two surfaces finished is called a *semifinished* lens because it is only half finished. The prefix *semi-* means half (Figure 13-1, *B*).

Finished uncut and semifinished lenses have not been edged. Before a lens has been edged, it is called a *lens blank*.

Segmented Multifocal Lenses

Segmented multifocal lenses have more than one power. Each power is located in a distinct area of the lens bordered clearly by a visible demarcation line. When two different areas exist, the lens is called a *bifocal* (Figure 13-2, *A*). When three areas exist, the lens is called a *trifocal* * (Figure 13-2, *B*).

Multifocal lenses may be created in one of several ways. Here are the two ways most often used:

1. Multifocals may be individually ground and polished to power by a surfacing laboratory from a semifinished lens blank.
2. Multifocals may be individually cast molded to the prescribed power. Cast molding creates the lens from a liquid resin material. It is the same process used to make both plastic semifinished lenses and stock single vision plastic lenses. Cast molding multifocal lenses to power skips the semifinished lens stage. Cast molding to power may be done by a larger wholesale facility or, if equipment is available, on a small scale in conjunction with a finishing laboratory.

Progressive Addition Lenses

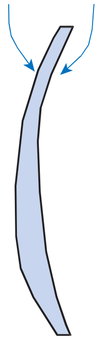
Progressive addition lenses are used as an alternative to a segmented multifocal lens. They have distance power in the upper half of the lens. Lens power gradually increases as the wearer looks down and inward to view near objects. With exception of some high-end product, progressive addition lenses are prepared for the finishing laboratory in the same way as segmented multifocal lenses.

There are a few exceptions. For example, a lens with a near section at the bottom and a second near section at the top will have three sections, but is a double segment occupational lens and not a trifocal.

Finished surfaces

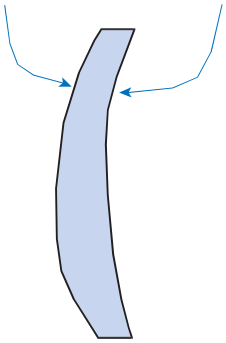
Finished surface

Not yet finished



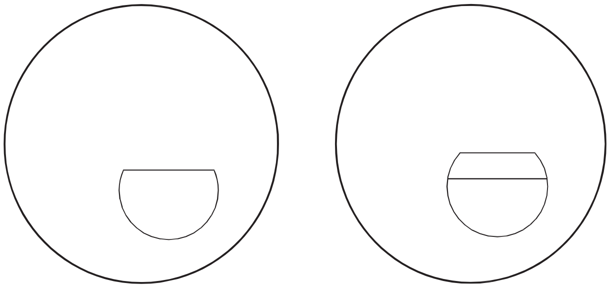
Finished lens (an “uncut”)

A



Semifinished blank

B

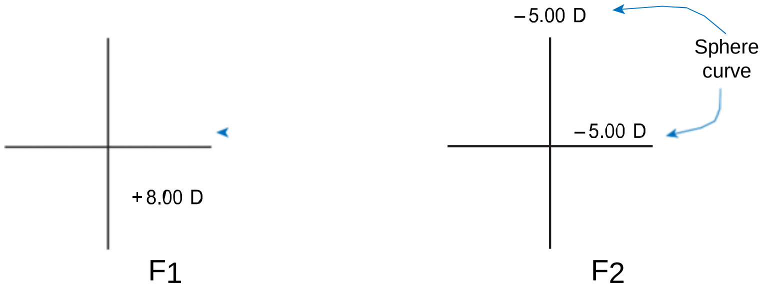


A B

Figure 13-2. When a lens has a different power for near vision than distance vision, the lens area is divided between distance and near powers. **A,** A segment area for near vision is placed within the distance power lens. A lens with two different powers is a bifocal lens. **B,** Two segment areas are included: one for intermediate viewing and one for near viewing. This type of lens is a trifocal lens. Both lenses are flat-top-style multifocals.

Figure 13-1. A, A finished lens is also referred to as an *uncut*. Most single vision lenses are premanufactured to power as finished lenses and are also referred to as *stock single vision lenses*. **B,** Most any type of lens of any material may be made beginning with a semifinished lens.

Figure 13-3. The base curve of a plus cylinder form single vision lens is the weaker curve on the front surface.



BASE CURVES

Single Vision Lens Curves

In constructing an ophthalmic lens, one of the lens curves of one surface becomes the basis from which the others are determined. This beginning curve, on which the lens power is based, is called the *base curve*. In single vision prescription ophthalmic lenses, the base curve is always found on the front surface.

- ***For spherical lenses:*** In the case of spherical lenses, the front sphere curve is the base curve.
- ***For plus cylinder form spherocylinder lenses:*** If the lens is in plus cylinder form, there are two curves on the front. The base curve is the weaker, or flatter, of the two curves. The other curve becomes the *cross curve* (Figure 13-3). The back surface is quite naturally referred to as the *sphere curve* since it is spherical.
- ***For minus cylinder form spherocylinder lenses:*** If the lens is in minus cylinder form, the front spherical curve is the base curve. The weaker back-surface curve is known as the *toric base curve;* the stronger back-surface curve is known as the *cross curve* (Figure 13-4). Optical laboratories refer to the toric base curve of a minus cylinder form lens as the *back base curve*. (On a plus cylinder form lens the "base curve" and "toric base curve" are the same curve.)

Multifocal Lens Base Curves

The base curve of a segmented multifocal lens is always on the same side of the lens as the segment. If the bifocal or trifocal segment is on the front, so is the base curve. If on the back, the base curve will be on the back as well, contrary to single vision lenses. Because a toric surface will not be ground on the same side as the multifocal seg, the base curve is always a sphere curve.

MEASUREMENT OF LENS CURVATURE

When ordering a replacement lens or supplying the wearer with a duplicate second pair of glasses some time after the initial order, one factor in wearer acceptance of the new glasses is consistent duplication of base curves. A change in base curve will change the way peripherally viewed objects are perceived, even though lens power may be identical. To measure a preexisting lens curve for accurate duplication or verification, a *lens measure* (some- times referred to as a *lens clock*), is used (Figure 13-7).

The Lens Measure

The lens measure operates on the principle of the *sagittal depth* (sag) formula. The sagittal depth, or "sag," is the height or depth of a given segment of a circle (Figure 13-8). If both the sag of a lens surface and the index of refraction of the lens material are known, the surface power may be calculated.

The lens measure has three "legs," or points of contact with the lens surface. The outer two are stationary, and the center contact point moves in and out. The vertical difference between the positions of the two outer contact points in reference to the position of the center contact point is the sag for the arc of a circle. This circle can be thought of as having a chord, the length of which is the distance between the outer contact points of the lens measure (Figure 13-9).

The lens measure does not have a scale showing a direct measure of the sag, but rather shows dioptric value for the surface power. This power is based on an

assumed index of refraction of 1.53. (Most tools found in a U.S. optical laboratory are based on an assumed index of 1.53.) The power shown on the lens measure is obtained by using the sagittal depth of the surface.

The Sagittal Depth Formula

Steps for finding the dioptric value for a lens surface begin with a geometric construction, as shown in Figure 13-9. We need to know *r,* the radius of the circle, to find the front or back surface powers of a lens (F_1 or F_2).

From the geometry of right triangles, the triangle FGC has a relationship between its three sides that,

Figure 13-7. A lens measure may use direct plus and minus scales as shown here, or an outer minus scale for concave sur- faces and an inner plus scale for convex surfaces.

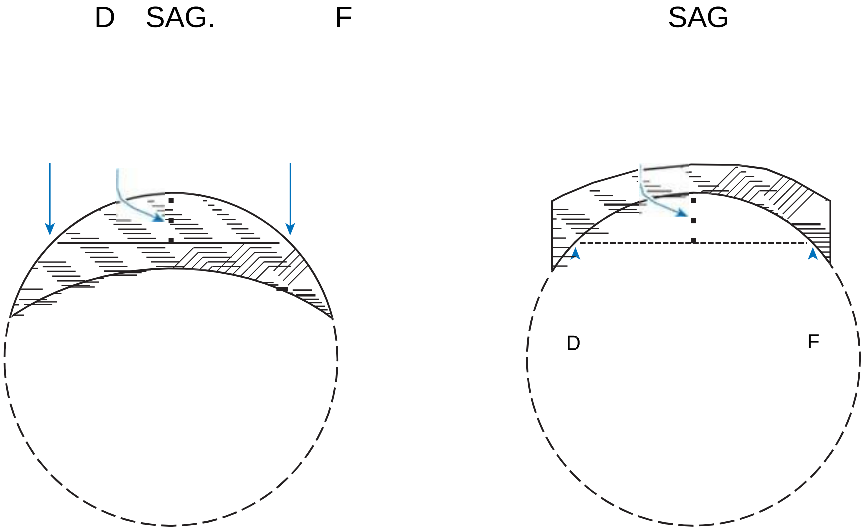
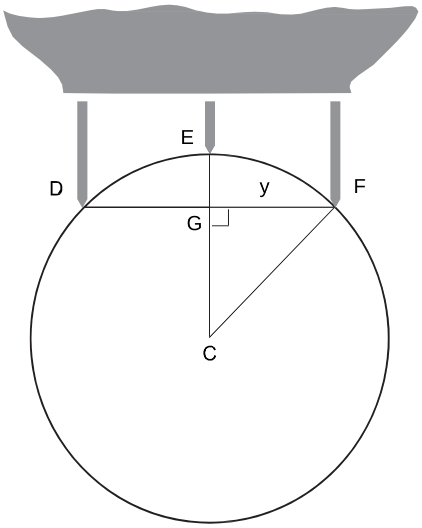


Figure 13-8. The sagittal depth or height of the chord of a circle is shown as it applies to lens surface measure- ments. The chord of the circle is rep- resented by lines DF.



Using the Lens Measure to Find the NominalPower of a Lens

Because it is possible to measure lens surface values directly for materials at or near an index of 1.53 using a lens measure, it is also possible to use a lens measure for finding the nominal or approximate power of such lenses. Examples of lenses with an index of 1.53 would be the plastic materials Spectralite and Trivex. Crown glass has an index of index 1.523. (Remember, the nominal power of a lens is the sum of the front and back surface powers. Nominal lens power ignores the effect lens thickness may have on lens power.)

For example, if a spherical lens has a measured front curve (F_1) of 06.00 D and a measured back curve (F_2) of
04.00 D, then the nominal power of the lens will be
02.00 D.

Not all lenses are spherical. This makes it necessary to check more than one lens surface meridian for differences in power. To do this, hold the lens measure such that the center contact point of the lens measure is at the center of the lens and is perpendicular to the lens surface (Figure 13-10). The lens measure is rotated around this center contact point with all three contact points against the lens.* If the indicator on the lens measure dial remains stationary, the surface is spherical. The spherical surface value is as shown on the lens measure. If the indicator shows a changing value, the surface is toric, with two separate curves. The values of these curves are indicated when the lens measure shows its maximum and minimum values. The orientation of the three contact points on the lens at maximum and minimum readings corresponds to the major meridians of lens power.

Use of the Lens Measure With Multifocals When the lens measure is used on a segmented multifocal lens, positioning of the contact points depends on lens construction. Multifocals may be fused or one piece.

The *fused* multifocal segment uses glass of a different refractive index from that in the rest of the lens. The junction between distance and near portions is visible, but cannot be felt since the glass segment is fused into the lens such that there is no change in lens surface curvature. A lens measure may therefore be used normally on the lens surface. Its reading will indicate only the surface power for the main lens. It does not read segment power.

A *one-piece* multifocal lens construction uses the same lens material for distance and near portions. Power differences between distance and near portions are brought about by a change in lens curvature. One-piece bifocals may be identified by either a ledge or by a change in the surface curve. The change may be felt by rubbing the finger over the juncture. In this case to determine lens surface power for the main lens accurately, none of the three contact points must rest on the segment portion. To measure a one-piece bifocal, the lens measure is placed on the lens with all three contact points horizontally positioned in the center of the lens and above the multifocal line.

Front

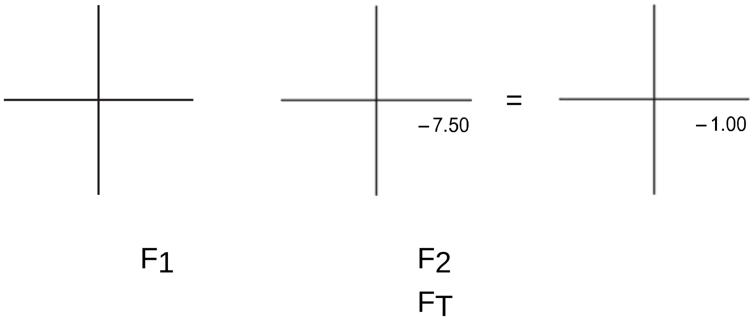
Back

Total

+ 6.50 –
6.00 + 0.50

Figure 13-11. Lens clock readings may be transferred directly to power crosses for lens power calculation.

+ 6.50
+



Why Measured Base Curves Do Not Always Come Out As Expected

When using a lens clock to measure the base curve of a lens, the values measured do not always come out the same as the manufacturer's stated value. A semifinished glass lens may arrive at the optical laboratory with a base curve of 08.25 D marked on the box. But when the front lens surface is measured, it may be slightly less than 08.25 D. Or a plastic lens could be marked as having a base curve of 010.25 D, but measure as 010.50 D. Some assume that the lens measure is inaccurate; others assume that variations are due to differences in the index of refraction of the lens and the lens measure scale. Actually, neither assumption is correct.

The real reason for the mismatch stems from the fact that there are several different front-surface lens curve terms used to describe the same lens surface curve. These terms are:

1. The nominal base curve
2. The true base curve (or so-called true power)
3. The refractive power

The Nominal Base Curve

The *nominal base curve* was originally established as a reference number for the convenience of the optical laboratory. When low-powered crown glass lenses had their surfaces ground to power without the help of computerized lens surfacing programs, the correct back curve was found by subtracting the front surface from the needed lens power. For example, if the lens is supposed to have a power of

01.25 D and the base curve of the lens is 06.50, then the back surface curve should be:

01.25 0 6.50 0 05.25 D

As the plus power of the lens increases, however, so does its thickness. Because of increased thickness, simple subtraction will not work. To make it possible for laboratory personnel to continue using the same simple calculation, lens manufacturers changed the front curve of the lens slightly to compensate for the effect of increasing thickness; but they left the listed base curve as the same number. When this is done, the value of the base curve is not the real power of the surface. Thus it is called the nominal base curve. (This is not to be confused with nominal lens power, which is the sum of the first and second surface powers.)

With plastic lenses, the base curves vary from their marked values for a different reason. Plastic lenses start out as liquid resin and are molded. When their surfaces cure during manufacture, once removed from the mold, the final curve of the surface may vary from the curve of the mold. Initially, it was difficult to predict the exact final lens curve value. Although the final curve of the lens after being removed from the mold is now predict- able, the difference between marked surface power (the nominal base curve) of a plastic lens and measured surface power remains.

True Base Curve ("True Power")

The so-called *true base curve* of a lens is the value of the front surface as measured using a lens measure. Synonyms for true base curve are "*true power*" and "*actual power*." This lens clock used to measure surface curvature is calibrated for an index of 1.53. Lenses at or close to this refractive index are Spectralite and Trivex plastic at 1.53, and crown glass, having an index of 1.523. The *true base curve* is the 1.53 indexed value. Many, or perhaps even most, lenses are not at all close to an index of 1.53. Because of differences in refractive indices, it is easy to see that the "true" base curve measured with a lens clock is unlikely to be the refractive power of the lens surface.

The Refractive Power of the Lens Surface

The *refractive power* controls what happens to light at the surface of the lens. It will be recalled that surface power is dependent on three factors. These are:

1. The refractive index of the lens surface
2. The refractive index of the media surrounding the lens
3. The radius of curvature of the lens surface

As previously stated, lens clocks are calibrated for lens material having a refractive index of 1.53. If a lens made from material of a different refractive index is used, compensation must be made so that surface refractive power can be found using a lens clock.

Finding the Refractive Power of a Lens Surface Using a Lens Measure

To find the refractive power of a lens surface using a lens clock, the “true power” reading from the lens clock must be converted to refractive power. This is done with the help of the lens maker’s formula shown above.

The front surface refractive power for the CR-39 lens is 05.64 D. Because the lens has a lower refractive index, the lens surface does not have as much refractive power as shown by the lens clock.

Using a Conversion Factor

It is possible to reduce the process of converting from lens clock readings to surface refractive power by using a formula-generated conversion factor. This is done as follows:

If, for the lens measure,

When using the lens clock, we are indirectly determining the radius of curvature of the surface in question, regardless of its refractive index.

When ordering an identically powered second pair: Base curve should also be specified when ordering an identically powered second pair of glasses. This second pair of glasses will be worn interchangeably with the first pair. The curve of a lens affects how shapes and straight lines appear. Two pair of glasses made using different base curves will cause shapes to distort differently. Some individuals are more sensitive to this than others. To prevent the

When specifying a certain base curve, remember that semifinished lenses come in only so many base curves. Ordering a 08.00 base curve may result in one that is close, but not exactly 08.00. ANSI Z80.1 Prescription Standards allow a base curve tolerance of 00.75 D. To help in getting a lens with the exact same base curve, try ordering from the same optical laboratory that was used for the first pair. The brand of lenses they use is more likely to allow an exact match.

When Not to Specify Base Curve

There are some situations where a base curve should not be specified so that the laboratory can pick the best base curve for the prescription ordered.

Do not insist on matching the base curve of the new glasses to the wearer‘s previous lenses. Prescriptions change. And as the power of the lens changes, to prevent unwanted lens aberrations, the power of the base curve should be expected to change too. A base curve should not be expected to perpetually be the same for the life of the wearer.

- ***Do not request a flatter base curve to get a thinner, better-looking lens.*** Flattening a base curve will often make a plus lens look much better. It will usually reduce magnification, decrease thickness, and even reduce the weight a bit. However, there will be an increase in unwanted aberration in the periphery of the lens because of using a base curve that is not correct for the power of the lens.

- ***Do not change the base curve to solve ghost-image internal lens reflection problems.*** Before
  antireflection coating, the common solution for getting rid of ghost images was to change the base curve. Changing the base curve will shift the size and location of those ghost images, but will not drop them out like an antireflection coating will. Only use a base curve change to help with ghost images if an antireflection coating is not an option.
- ***Do not automatically steepen the base curve for people with long eyelashes.*** Try to solve the problem of lashes touching the lens with a good frame selection. It is true that steepening the base curve by

(03.00 D sphere) 0 (pl 0 1.50 0 180 cylinder)
0 (03.00 0 1.50 0 180)

In the same way that power crosses are used when adding front and back lens *surfaces* together to find total lens power, so also may power crosses be used as a help when adding two or more *lenses* together. To visualize how lens meridians add together for the sphere and cylinder lenses in the above example, see Figure 13-13.

Adding Cylinders Having the Same Axis or WithAxes 90 Degrees Apart

Just as spheres and spheres and spheres and cylinders may be added, so also may cylinders and cylinders be added. Here we will be looking at adding cylinders whose axes are either the same, or 90 degrees away from each other.

2 D will give about 1.2 mm of extra lash clearance.

But it will mean that optimal optics from a good base curve selection will be lacking.

ADDING CYLINDERS

Lenses are able to be added together. This is done routinely during the eye examination. Small spherically powered lenses are added to large spherically powered lenses. For example,

(03.00 D sphere) 0 (00.25 D sphere)
0 03.25 D sphere.

Sphere lenses are added to cylinder lenses, resulting in spherocylinder lens combinations, as with these two lenses.

LENS THICKNESS

Sagittal Depth

The formula that is the basis for determining lens thickness is the *sagittal depth,* or *sag formula,* which was introduced previously in the chapter. Sagittal depth is the depth of the lens surface curve and is shown in Figure 13-24. Remember that a chord is a straight line joining two points on a curve. In Figure 13-24, the two points on the curve are at the edges of the lens, and the length of the chord equals the diameter of the lens.

To find the sagittal depth, it is necessary to know the length of the chord and the radius of curvature of the lens surface. Figure 13-25 shows the radius (r) as the hypotenuse of a right triangle. (Notice that this uses the same principles as were discussed for the lens clock previously in the chapter. Figure 13-25 is another view of what was shown in Figure 13-9.) The other two sides are y, which is one half of the chord (or ½ the lens diameter), and (r 0 s), which is the radius minus the sag. Because this triangle is a right triangle, the Pythagorean theorem can be used to find the sag: (When discussing the lens measure we used the Pythagorean theorem to find the radius of curvature [r].)

G

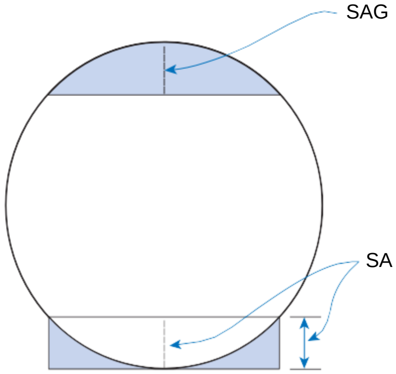


Figure 13-24. A knife-edged plus lens has the same center thickness that the edge of an infinitely thin minus lens would have when both diameters and curvatures are the same.

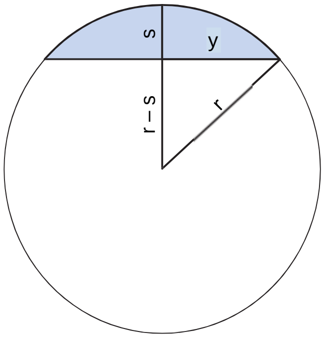


Figure 13-25. The geometry of the figure shows how the sag formula is derived from the Pythagorean theorem. Here y^2 0 (r 0 s)^2 0 r^2.

Sample questions:

1. What is the resulting sum of two cylinder lenses, both having a power of pl 0 2.00 0 180?

Solution

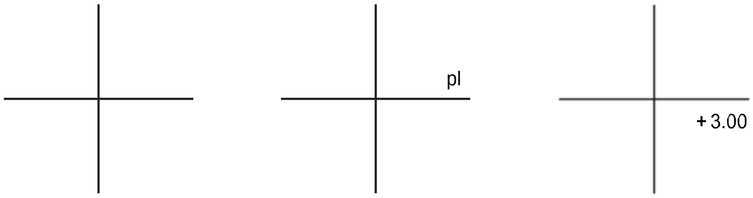
To find the solution, make three power crosses, with the first two adding to equal the third. Place the powers of the two cylinder lenses on the first two power crosses. Because both lenses are identical, they will look the same on the first two power crosses. The axis is 180, so there is zero power in the 180-degree axis meridian. The power is 02.00, so 02.00 is written on the 90-degree power meridian. This is shown in Figure 13-14.

Next the powers in the 180 are summed. Zero plus zero equals zero. Then the 90-degree powers are summed. (02.00) 0 (02.00) 0 (04.00).

+ 3.00 –
1.50 + 1.50

Power crosses allow a sphere and cylinder to be added together to form a spherocylinder.

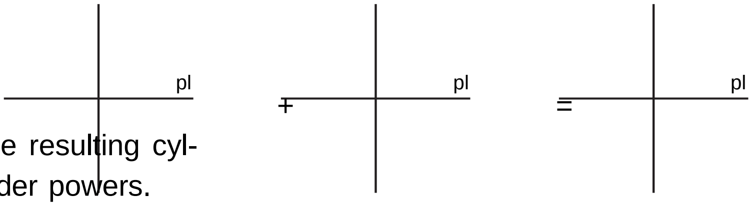
+ 3.00
+ =



Sphere Cylinder
Spherocylinder

– 2.00 –
2.00 – 4.00

When two plano-cylinder lenses are placed together axis-to-axis, the resulting cylinder power is the sum of the cylinder powers.



Cylinder

Cylinder Sum of the

lens powers
The resulting power cross may be written in minus cylinderform as pl 0 4.00 0 180.

2. We will now take the same two cylinder lenses, but with axes

and an equal and opposite amount of minus power in theother. An example of a Jackson crossed cylinder is shownin Figure 13-17.

A Jackson crossed cylinder is written as if the lens were two cylinders of equal and opposite powers.

oriented differently, and sum them. What is the sum of a pl
0 2.00 0 180 lens and a pl 0 2.00 0 090 lens?

Solution

Again placing these two lenses on power crosses helps in visualizing what is happening. The first lens has zero on the180-degree meridian and 02.00 on the 90-degree meridian.The second lens has zero on the 90-degree meridian and 02.00 on the 180-degree meridian. When the two lensesare added together in each meridian, as shown in Figure 13-15, the result is a 02.00 D sphere.

Example **3**

Add these two lenses to find the resulting spherocylinder lens.

pl 0 1.25 0 090

pl 0 2.25 0 180

Solution

Draw three power crosses and enter the cylinder lenses shown above on the first two, as shown in Figure 13-16. Sum the 90-degree meridians, then the 180-degree meridians. The result is a lens with a power of 01.25 0 1.00 0180.

Jackson Crossed Cylinders

A *Jackson crossed cylinder* (JCC) is a lens used in the eye examination process to help in determining cylinder axis and cylinder power. It has plus power in one meridian

Example **4**

What would a 01.00 JCC look like on a power cross? From what two plano cylinders is it derived?

Solution

A 01.00 JCC has a power of 01.00 in one meridian and 01.00 in the opposite meridian. Figure 13-18 shows what this could look like if the 01.00 were in the 90-degree meridian. It is the same as crossing two cylinders of equal and opposite value. In this case these two cylinders would be pl 0 1.00 0 180/pl 0 1.00 0 090.

By flipping the cylinder over using its handle positioned halfway between the major meridians of the JCC lens, the minus and plus powers trade places. When looking through first one orientation of the lens, then flipping the JCC by 90 degrees to the opposite orientation, exaggerated views through the opposing cylinders are seen. Exaggerating the differences makes it easier to know the answer to the familiar question asked during refraction, “Which (view) is better, one or two?”

Conceptual Questions for Anticipating the Sum of Two Obliquely Crossed Cylinder Lenses

In reality few people will be using either the formula method or the graphical method to find the result of two obliquely crossed cylinders. Instead a computer program will be used. However, it is useful to understand enough about lenses to know how two obliquely crossed cylinders or spherocylinders will interact. Here are some conceptual questions to help in understanding how two cylinder lenses will sum. Examples are included for two cylinders that are not at oblique angles with one another. Each question represents an important aspect in under- standing how cylinders add together. The answers were obtained by exact calculations. Exact calculations are not important, however. The important thing to notice is the relative power of the cylinder and position of the new axis.

Question 1. True or false? The sum of the spherical equivalents of the two obliquely crossed spherocylinders will always equal the spherical equivalent of the resultant lens.

Answer: True

Question 2. True or false? If the axes of either two plus cylinder or two minus cylinder lenses are the same, then the resultant cylinder power will be the sum of the two cylinders.

Answer: True

For example, if a pl 0 2.00 0 180 is combined with pl 0 2.00 0 180, the result equals pl 0 4.00 0 180.

Question 3. If the axes of two cylinders are very close to one another, what can be said about the power of the new cylinder?

Answer: The resultant cylinder power will closely approach the sum of the two cylinders. The sphere power will increase only slightly, closely approaching no change.

For example, pl 0 2.00 0 002 combined with pl 0 2.00 0 178 equals 00.02 0 3.96 0 180.

Question 4. If the axes of two equally powered cylinders are 90 degrees away from one another, what will be the result?

Answer: The cylinder power will be zero, and the sphere power resulting from the two combined cylinder components will change by the full power of the cylinder.

For example, pl 0 2.00 0 090 combined with pl 0 2.00 0 180 equals 02.00 sphere.

Question 5. True or false? If the powers of two obliquely crossed cylinders are equal, the axis of the new cylinder will be halfway in between the two.

Answer: True

For example, pl 0 2.00 0 030 combined with pl 0 2.00 0 070 results in 00.47 0 3.06 0 050.

Question 6. If the cylinder powers of two obliquely crossed cylinders are *un*equal, what happens to the axis of the cylinder?

Answer: The resulting cylinder axis will be pulled in the direction of the axis of the stronger cylinder.

For example, pl 0 2.00 0 030 combined with pl 0 1.00 0 070 results in 00.31 0 2.39 0 042.

Question 7. If the axes of two equally powered plano cylinders are very close to being 90 degrees away from one another, what will be the result in terms of sphere and cylinder powers?

Answer: The cylinder power will be close to zero, and the sphere power change resulting from the two combined cylinder components will change by nearly the full power of the cylinder. The cylinder axis of the resultant cylinder will be halfway between the axes of the original cylinders.

For example, pl 0 2.00 0 088 combined with pl 0 2.00 0 002 equals 01.86 0 0.28 0 45.

Question 8. If the axes of two *un*equally powered cylinders are 90 degrees away from one another, what happens to the resulting sphere and cylinder powers?

Answer: The new cylinder power will be the difference between the two cylinder powers, and the sphere power will increase by the amount of the smaller cylinder.

For example, pl 0 2.00 0 090 combined with pl 0 1.00 0 180 equals 01.00 0 1.00 0 090.

Question 9. If the axes of two *un*equally powered plano cylinders are very close to being 90 degrees away from one another, what happens to the resulting sphere and cylinder powers?

Answer: The cylinder power will be close to the difference between the two cylinder powers. The sphere power will increase by close to the amount of the smaller cylinder. (The axis will be close to the axis of the lens with the higher powered cylinder.)

For example, pl 0 2.00 0 088 combined with pl 0 1.00 0 002 equals 00.99 0 1.02 0 084.

Conceptually Understanding Obliquely Crossed Spherocylinder Lenses

By using the concept questions for adding cylinder lenses just presented in the previous section, it is relatively easy to apply these concepts to spherocylinders. To anticipate the resulting spherocylinder powers and axis when adding two spherocylinders together without doing actual calculations. Start with just the cylinders and ignore the spheres. First estimate the sum of the cylinders. Afterwards add back the sphere powers.

For example, in Question 5, when a pl 0 2.00 0 030 is combined with a pl 0 2.00 0 070, the exact result is a lens with a power of 00.47 0 3.06 0 050. Since the cylinder powers are equal, the resulting axis will be exactly halfway in between. (The resulting cylinder power could be estimated as greater than either cylinder alone, but less than both together. The new sphere would then be halfway between the sum of the two original cylinders and the new resultant cylinder.)

If the two lenses where spherocylinders with powers of –1.50 0 2.00 0 030 and –1.25 0 2.00 0 070, remove the spheres, then sum the cylinders. The cylinders by them- selves sum to 00.47 0 3.06 0 050. Now add the old spheres together [(–1.50) 0 (–1.25) 0 (–2.75)] and combine them with the new sphere [(–2.75) 0 (–0.47) 0 (–3.22)]. The new spherocylinder power is 03.22 0 3.06 0 050.

Unit 4:

Optical consideration with increasing lens power

Learning Objective:

As lens power increases, previously insignificant factors such as thickness and positioning before the eye affect lens power. Unless compensation for these influences is made, the finished product fails to perform as anticipated.
At the end of this unit, students will be able to learn relationship of optical system of the eye with power.

LENS POWER AS RELATED TO POSITION

A 05.00 D lens has a focal length of 020 cm. We know then that the mounting was originally 20 cm away from the screen. If the mounting is moved 5 cm farther from the screen, it is now 25 cm away. To cause parallel rays of light to focus on the screen, a lens with a focal length of 025 cm must be chosen. The reciprocal of 0.25 m is 4. Therefore a 04.00 D lens must be chosen.
The principal point of focus of a lens is always the same
istance from the lens. So when the lens is moved, the point of focus moves as well. If the lens position has to be changed, but the focal point must stay in the same place, a new lens power is required.
For example, if a camera has a distance of 010 cm from the lens to the film, there is only one power of lens that will cause an object at infinity to focus on the film. The proper lens power may be calculated knowing that the focal length of the lens must be 010 cm or 00.10 m.
Since

$$F\ 0\ \frac{1}{f\ 0}$$

then

$$F\ 0\ \frac{1}{00.10\ \text{m}}\ 0\ 010.00\ \text{D}$$

If, however, the camera has a distance of 012.5 cm from lens to film, the 010.00 D lens is inappropriate, since it would focus light 2½ cm in front of the film, producing a blurry image. This is true whether the film moves or the lens moves. As long as the distance between lens and film changes from 010 to 012.5 cm, the power

AS LENS THICKNESS INCREASES

As a lens becomes thicker, there is an increase in distance between front and back surfaces. Changing the position of the first lens surface with respect to the second means that the effective power of the first surface at the plane of the second surface is no longer the same. This in turn causes a change in total lens power. The actual amount of change may be calculated using vergences.

Vergence of Light As It Travels Through a Lens When light strikes a lens, it is refracted at the front surface and then travels through the thickness of the lens. It is again refracted when reaching the back lens

surface. For thin lenses, the distance traveled from front to back surfaces makes no appreciable change in total lens power. The thicker the lens becomes, however, the more of a discrepancy there is between nominal or approximate power (F_1 0 F_2) and the actual measured power of the lens. As light strikes the first surface of the lens (F_1), its vergence is changed, converging or diverging to a greater or lesser extent than previously. It has

an additional vergence change when reaching the second

So the new F_{180} 0 0

1

0.0939 m

0 010.65 D

surface (F_2).

To find the new power in the 90-degree meridian:

since F_{90} 0 014.00, then $f0_{90}$ 0 07.14 cm

New $f0_{90}$ 0 07.14 0 0.3 0 07.44 cm

Therefore

New F 0 1 ~~0013~~.44 D

90 00.0744 m

If new F_{180} 0 010.65 D and new F_{90} 0 013.44 D, then the new lens power will be 013.44 02.79 0 090. Not only has the sphere power changed, but also the power of the cylinder.

In this case it is *not* valid to calculate the power of the sphere (014.00 D), then calculate the power of the cylinder(03.00) independently. The cylinder value is the *difference* between two meridians and not an independent entity.

Vergence for Thin Lenses

For a thin lens, when the vergence of the entering light is zero (parallel rays), the light exiting the lens has a vergence equal to the dioptric powers of the first and second surfaces (F_1 0 F_2).

For example, if F_1 0 05.00 D and F_2 0 01.00 D, when light strikes F_1 it is caused to converge. It now has a vergence of 05.00 D. Because the lens is thin, it immediately strikes the back surface before its vergence changes. Now the back surface (F_2) causes light to converge an additional 01.00 diopter. So on leaving the second surface of the lens (F_2), the light now has a vergence of 06.00 D.

Vergence for Thick Lenses

For a thick lens, the converging light leaving the first surface would have a chance to travel a significant distance before reaching the second surface (F_2). As will be recalled from the previous section on effective power, as converging or diverging light travels through the lens, by the time it reaches the second surface, F_2, it will have a slightly different vergence value from what it had when it left the first surface, F_1. This is because it is now a different distance from its plane of reference. It is this *new* vergence (the effective power of F_1 at F_2) that is altered to produce a different vergence leaving the lens. However, with thick lenses, vergence is affected not only by the thickness of the lens, but by the refractive index of the lens material.

Reduced Thickness and Refractive Index

Light passing from one medium to another through a curved surface experiences a change in vergence, which, expressed as shown previously, is quantified by the equation:

$$F \ 0 \ L0 \ 0 \ L$$

This equation, called the *fundamental paraxial equation*, may also be written as: (The question really asks, “What effect will the refractive index of water have on the distance perceived com- pared with what it would otherwise appear to be in air?”) We can assume that the glass separating the air and water is thin enough to be of no concern in calculations. The situation is one in which light leaves the object (a snail), and diverges for 100 cm until it reaches a refractive surface (the front of the aquarium). Therefore since the side of the aquarium is flat:

F 0 0.00 D,
l0 0 0100 cm or 01.0 m,
n 0 1.33, and
n0 0 1.00

(The distance l0 is taken as minus, since the surface of the tank is the refracting surface and light is traveling first through water before it reaches the surface of the tank.)

The equation

$$F \; 0 \; \underline{n0} \, 0 \; \underline{n}$$

$$F \; 0 \; \underline{n0} \, 0 \; \underline{n}$$

results in

$l0 \quad l$

$l0 \quad l$

To see the interrelationship between distance (*l* or *l*0)

$$0 \; 0 \; \underline{1} \, 0 \; \underline{1.33}$$

and refractive index (*n* or *n*0), consider the familiar situation of looking into an aquarium filled with water.

Suppose the aquarium is 100 cm from front to back. The observer is standing in front of the aquarium observing a snail on the back surface (Figure 14-5). How far away from the front surface will the snail appear to be?

$l0 \; 01.0$

which algebraically transforms to:

$$\underline{1.33} \, 0 \; \underline{1}$$

$01.0 \;\; l0$

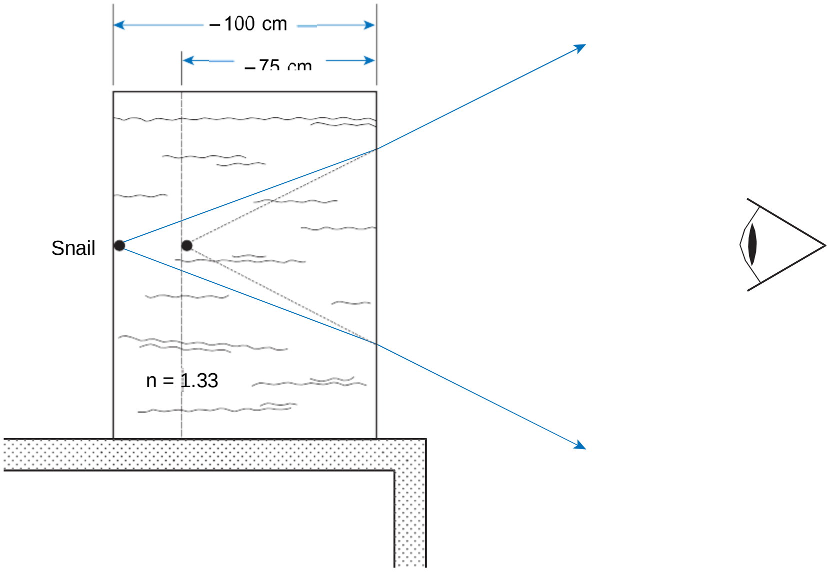


Figure 14-5. The most familiar example of reduced thicknessis seen with an ordinary aquarium. Looking at the contents through water makes individual objects seem

to be closer than they would otherwise appear if viewed only through air.

$$I0\ 0\ \frac{01.0}{1.33}$$

$$0\ 00.75\ \text{mm}$$

So the snail and the back surface of the tank appear to be 00.75 m or 075 cm from the front surface.

Interestingly enough, this example clearly shows that the light entering and leaving the front surface of the front glass has exactly the same vergence, for if $F\ 0\ 0$, then $L\ 0\ L0$. The distance in water as compared with that in air is reduced because the light is traveling more slowly in water than in air. This concept is referred to as *reduced thickness* because objects of a higher refractive index than air appear thinner than they actually are when compared with the equivalent air distance. The relationship between the *reduced thickness,* the actual

$$F_1\ 0\ L_1 0\ 0\ L_1$$

Substituting the correct numerical values, we find that:

$$012.00\ \text{D}\ 0\ L_1 0\ 0\ 0$$

or

$$L_1 0\ 0\ 012.00\ \text{D}$$

Light leaving F_1 has a vergence of 012.00 D.

The light is now converging toward a point to the right of the front surface. That point in air would be found by taking the reciprocal of the vergence.

$$L\ 0\ 0\frac{I}{1}$$

thickness (t), and the index of the medium in question (n) can be stated simply as:

reduced thickness 0 $\underline{t}$

and

$l_1 0$ $\underline{l}$

n

Vergence of Light Striking the Second Surface of a Thick Lens

For a thick lens, after light has left the first surface, F_1, it travels for a time inside the lens. The lens has a refractive index that is higher than that of air. Because vergence depends on the relationship between refractive index and distance:

L 0 $\underline{n}$

l

012.00 0

l 0

1

$l_1 0$ 0 00.0833 m

The distance in question is 00.0833 m.

The light must travel through glass for 7 mm before reaching air, however. To find the vergence of light at F_2, the *reduced thickness* of this lens must be subtracted from $l_1 0$ because the point of focus is now closer to the new plane of reference, which is the back surface of the lens.

Therefore the new distance (l_2) is:

l 0 l 0 0 $\underline{t}$

2 1

n

the vergence of light leaving F_1 and striking F_2 may not t

be calculated in terms of distance alone.

where

is the reduced thickness of the lens. (Thickness -

n

Initially, one would think that the new vergence would be found by directly adding or subtracting lens thickness from the image distance of light leaving the first surface (l0). This was the case in previous effective power problems because in air this proves true. But here it is necessary to find the new vergence at F_2 by adding or subtracting the *reduced thickness* of the lens from the reciprocal of the vergence. This keeps the reference medium as air. This is the better choice since calculations are easier when the final results are for rays converging or diverging in air.

FRONT AND BACK VERTEX POWERS

It has been shown that because of lens thickness the nominal or approximate power of a lens does not accurately predict the actual power of the lens. It will be recalled that when parallel light enters the front of a lens, it is refracted and exits from the rear surface of the lens. The image, be it real or virtual, falls at the *second principal focus*.

The reciprocal of the distance in air from the rear surface of the lens to the second principal focus is a specific measure of the power of this lens and is known as the *back vertex power* (F_v0). (This is the measure of power of most importance in ophthalmic lenses.)

If parallel light enters from the rear surface, the place where the image forms is known as the *first principal focus*. The reciprocal of the distance in air from the front surface of the lens to the first principal focus is another measure of the power of the lens. This measure is referred to as the *front vertex power* (F_v) (Figure 14-6). It is not unusual to find front and back vertex powers to be different. If the lens is equiconcave or equiconvex, the front and back vertex powers will be the same. If the lens has any other form and is thick, there may be a measurable difference between front and back vertex power.

Calculating Front and Back Vertex Powers

Front and back vertex powers may be found by finding vergence as light approaches and leaves each lens surface.

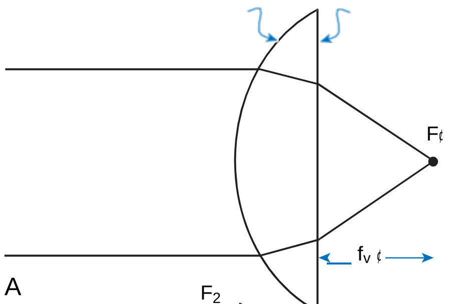
They may also be found using a formula summarizing C

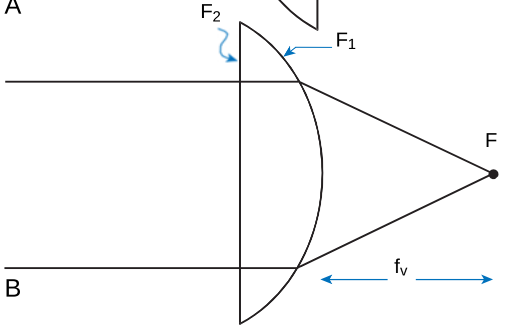
F_1 F_2

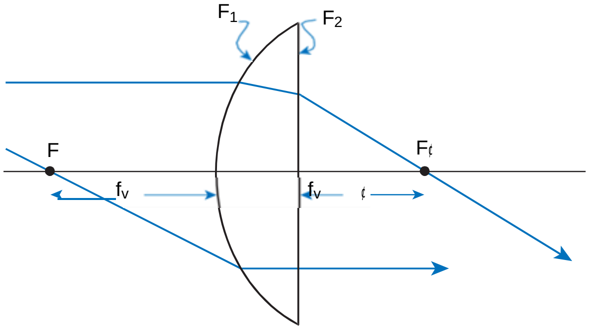
the necessary vergence factors. By following the vergence methods for solving this type of problem, it will result in a much better understanding of the action of a lens on light than will simple formula memorization. Both methods are described.

Solving for Front and Back Vertex Powers Using Vergence

If light enters the front surface of a lens as parallel rays, the back vertex power of a lens will be equal to the vergence these light rays have when leaving the back surface of the lens. If the form, thickness, and refractive index of that lens are known, the back vertex power may be found by systematically tracing the path light rays take through the lens.







Sample Questions:

1. Parallel light enters an optical system and must be made todiverge. A 012.50 D lens gives the correct amount of divergence. The system is redesigned, and this lens must be moved 2 cm to the right (light is assumed to be traveling from left to right). According to the new system, the light must still diverge as if from the same point. What new lenspower must be used at the new location to give the same effect?

Solution

The situation described is shown in Figure 14-2. In the old system, since the focal length of a 012.50 D lens is 08 cm, light appeared as if it were coming from a point 8 cm to theleft of the lens. The new system requires that this point bemaintained, but the lens must now be 2 cm farther from it.The old lens may not be used since moving it 2 cm to the right would also move the focal point 2 cm to the right. Tomaintain the integrity of the system, the focal length of thenew lens must be 2 cm longer than that of the old, which is8 cm 02 cm, or 10 cm to the left of the lens. The diverginglens that has a focal length of 010 cm has a refractive power of

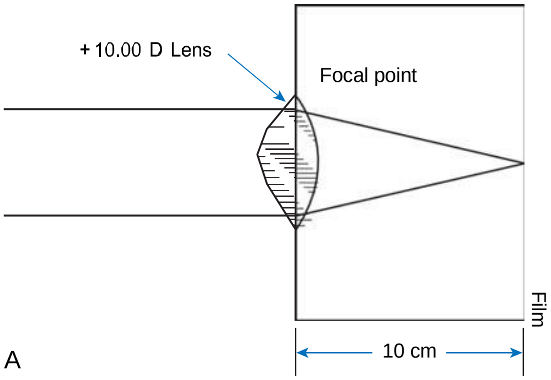
$$\frac{1}{00.10\text{ m}}0\ 010\text{ D}$$

of the lens must be changed. To focus on the film at a distance of 012.5 cm, a power of 08.00 D is required— less power than for the shorter distance (Figure 14-1).

2. If a lens of power 05.00 D is mounted so as to focus light on a small screen, what new power lens will be required if the lens mounting is moved 5 cm farther away from the screen?

Effective Power

The power of a lens is normally designated by its dioptric power. Dioptric power depends on focal length. When light leaves the lens, the exiting light rays are either parallel, converging, or diverging. The amount of con- vergence or divergence of light rays is a dioptric value. Lenses get their dioptric power based on the reciprocal of the distance from the lens to the point of focus. However, as the light travels closer to the point of focus, its vergence value changes.



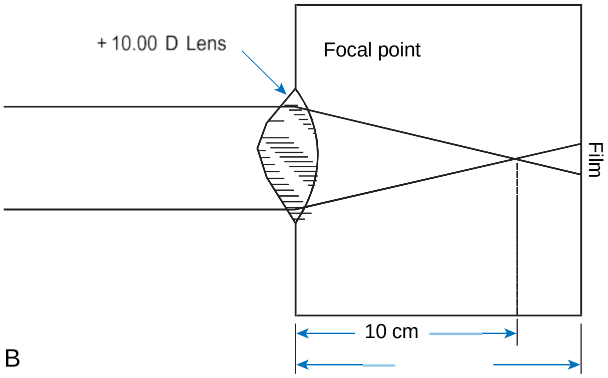
A

the point of focus, they have a vergence of 010.00 D. At a reference plane one centimeter closer, the same rays now have a vergence of:

$\frac{1}{0.09\text{m}}$ or +11.11 D

Still another centimeter closer and the vergence will be:

$\frac{1}{0.08\text{m}}$ or 0 12.50 D



B

To help in understanding effective power, suppose a 010.00 D lens is to be replaced by a different lens positioned 2 cm to the right of the original 010.00 D lens. Remember, the same focal point must be maintained. Therefore to have the same effective power as the 010.00 D lens, the replacement lens must be a

012.50 D lens.

As a second example, suppose a 010.00 D is to be replaced by a different lens positioned 5 cm to the right. To have the same effective power as the 010.00 D, but at a position 5 cm to the right, a 020.00 D lens would be required (Figure 14-4).

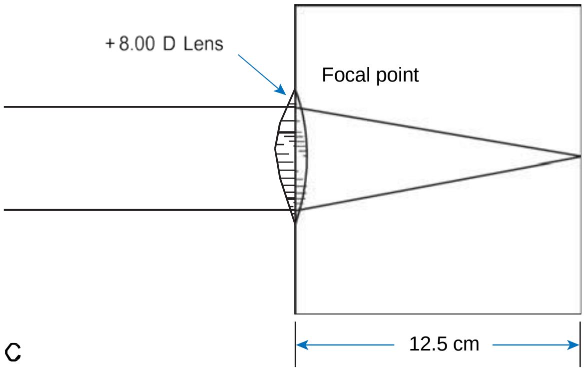


Figure 14-1. The relationship between lens power and desired focal plane may be illustrated using the example of a camera. In **(A)** the 010.00 D lens is correct for the camera's 10-cm depth. Placing that same lens in a deeper camera **(B)** however, results in a blurred image. The lens is farther from the film, and the image falls short. Choosing a lens of longer focal length **(C)** resolves the problem.

The vergence power a lens produces at a position other than that occupied by the lens itself is known as the *effective power* of the lens for that particular reference plane. The effective power of a given lens in air may be obtained by taking the reciprocal of the distance in air from the new reference plane to the focal point of the lens (Figure 14-3).

For example, if light rays are converging towards a given point in air, when these rays are 10 cm away from

Effective Power as Related To Vertex Distance Changes

The distance from the back surface of the spectacle lens to the front surface of the wearer's eye is known as the *vertex distance*. Traditionally, for purposes of calculation, a distance of 13.5 mm was considered average. In actual practice, vertex distances vary considerably. Positioning the glasses at a vertex distance other than that used during the refraction means that the effective power at the refracting distance is now different from that originally intended. For a low-powered lens whose focal length is long in comparison with the vertex distance, there is very little difference. But for higher powered lenses, a small change in vertex distance can make a considerable change in effective power.

3. A person is refracted at a 12.0-mm vertex distance and found to need a 08.50 D lens. A frame selection is made and the lenses fitted at a 17-mm vertex distance. (Incidentally, this is *not* a good frame selection for this prescription.) What power lens must be used at 17 mm to give the same effective power recorded for the refracting distance?

Solution

A 08.50 D lens has a focal length of 011.765 cm. If the newlens has a vertex distance of 17 mm, this is 5 mm to the left of the original position. To achieve the same refractiveeffect for the wearer, the focal length of the lens dispensed must be 5 mm longer than for the refracting lens.

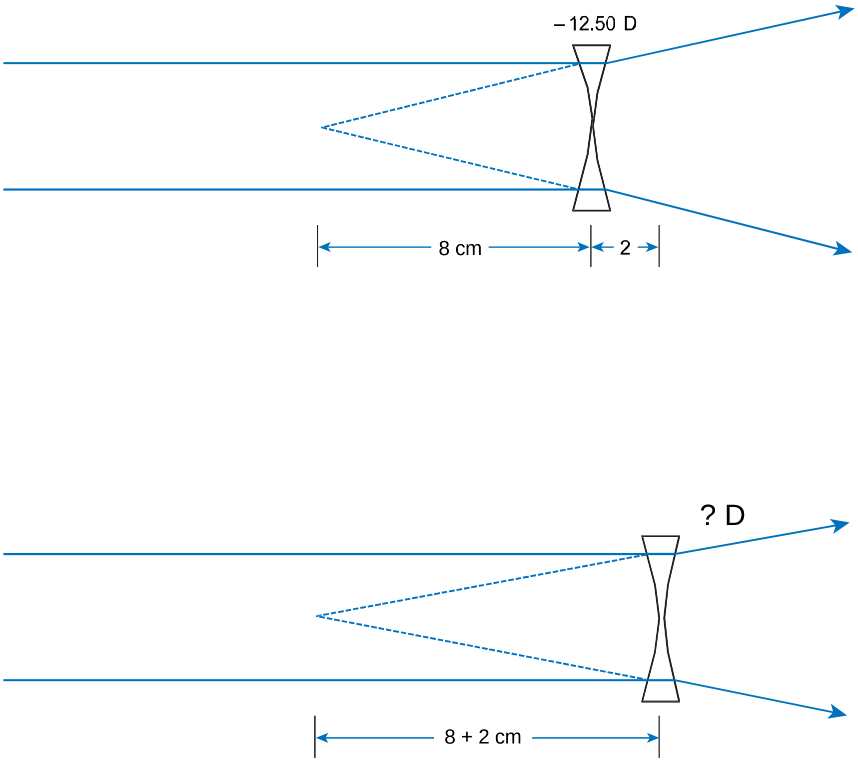


Figure 14-2. If the position of a lens changes, to maintain the same effect, a lens of a different power must be chosen.

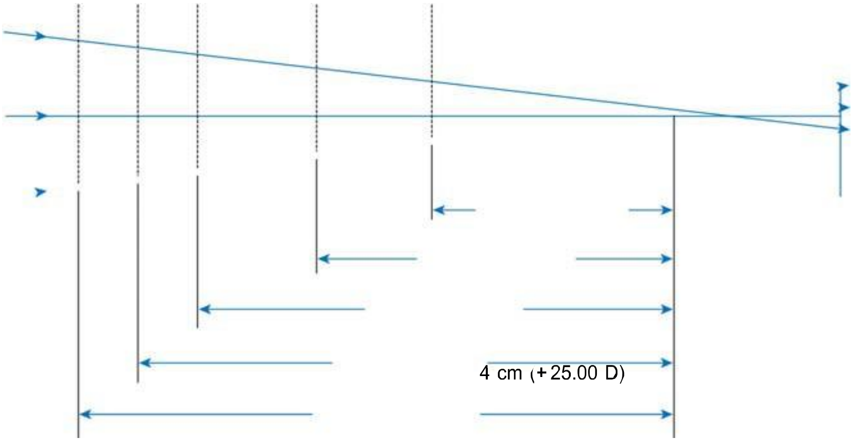


Figure 14-3. Vergence of light in air is the reciprocal of the distance from the reference plane to the point of focus.

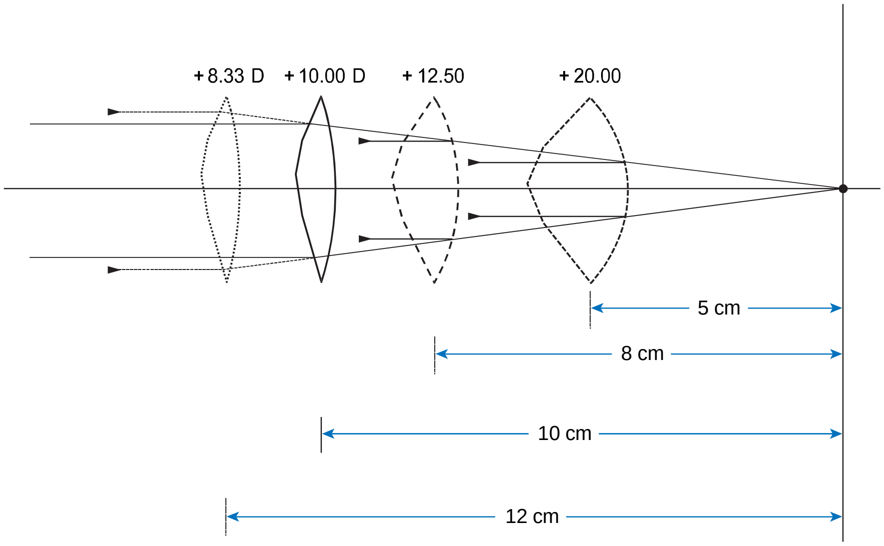


Figure 14-4. It can be seen that for different planes of reference, the effective power of

the original lens is different from the marked value. Thus the effective power of a 010.00 D lens at a point 2 cm to the left of where it actually stands is 08.33 D. In other words, the lens that would be used to replace a 010.00 D lens at a point 2 cm to the left of it would be a 08.33 D lens.

011.765 cm 0 0.5 cm 0 012.265 cm

If the new focal length must be 012.265 cm, the new lenspower must be:

ffective Power Written as a Formula

Effective power can be written as a formula. As a formula, effective power is as follows:

$$\frac{1}{00.12265\ \text{m}}\ 0\ 08.15\ \text{D}$$

F_{eff}

$0\ \ \underline{1}$

$\underline{1}\ 0\ d$

F_V0

Effective Power of a Spherocylinder Lens

When calculating the new power needed for a spherocylinder lens at an altered vertex distance, the power in each major meridian must be considered separately.

4. If a 014.00 03.00 0 090 lens is prescribed at 12-mm vertex distance and the frame selected is positioned at 15 mm, what will the new prescription be?

Solution

The major meridians are:

$$F_{180}\ 0\ 011.00\ \text{D}$$
$$F_{90}\ 0\ 014.00\ \text{D}$$

The new effective power for the 180-degree meridian is calculated by first finding the focal length:

$$f0_{180}\ \ 0\ \frac{1}{011.00}\ 0\ 09.09\ \text{cm}$$

The new lens will be 15 0 12 or 3 mm farther from the linefoci of the lens. Therefore since the lens is plus, the focal lengths will be 3 mm longer.

$$\text{New}\ f0_{180}\ 0\ 09.09\ \text{cm}\ 0\ 0.3\ \text{cm}\ 0\ 09.39\ \text{cm}$$

where F_{eff} is the effective power, F_v0 is the back vertex power of the lens, and d is the distance in meters from the original position of the lens to the new position of the lens. It is not advisable to memorize the formula instead of trying to understand the concept of effective power.

5. A lens has the following dimensions:

Figure 14-6. When light enters a lens from the front, the focal length, and consequently the measured focal power, can be different from when light enters a lens from the back. **A** and **B** show the difference between front vertex and back vertex focal lengths (f_v and f_v0). These focal lengths will directly determine front and back vertex focal powers (F_v and F_v0). (**B,** drawn with the lens backward to allow better visual comparison between the front and back vertex focal lengths.) **C,** The conventional manner of representing front and back vertex focal lengths diagrammatically. (*F* 0 first principal focal point; *F*0 0 second principal focal point; f_V 0 front vertex focal length; f_V0 0 second vertex focal length.)

Solution

Light entering the lens must be from an object at infinity to determine back vertex lens power. The rays entering the front surface of the lens will then be parallel, having a vergence of zero (Figure 14-7). Since

F_1 0 08.00 D
F_2 0 02.00 D
t 0 5 mm
n 0 1.523

and

$L_1$0 0 F_1

L_1

0What is the back vertex power of the lens?

L_1 0 0.00 D

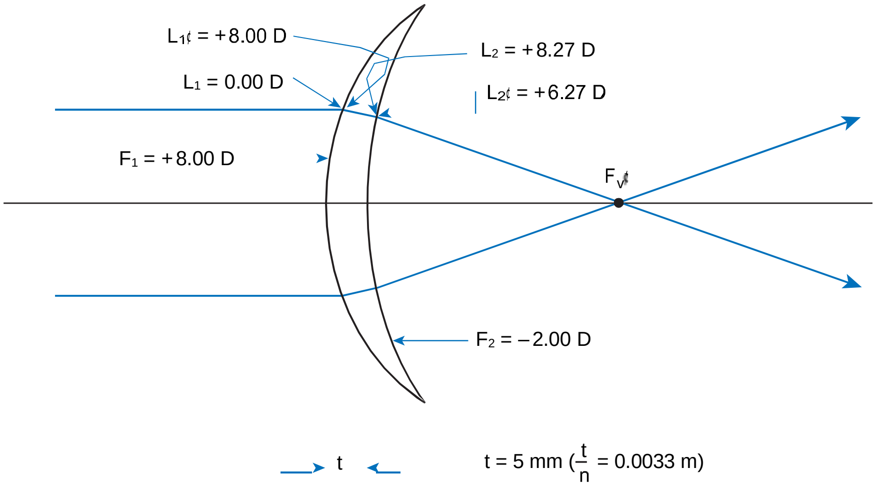
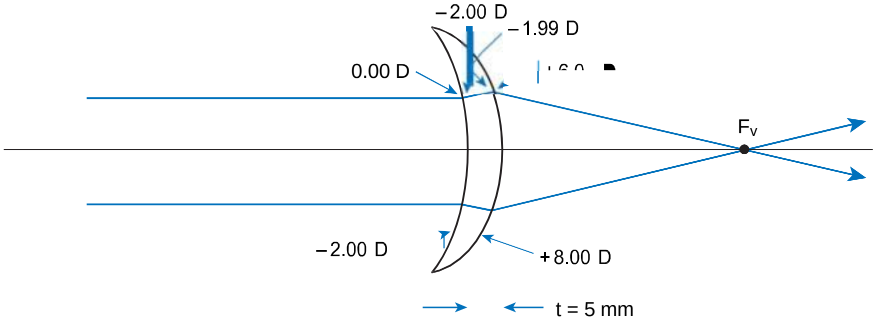


Figure 14-7. Lens curvature and thickness have a definite bearing on the final back vertex power of a lens.

Figure 14-8. Reversing a lens may change the position of the image. For some lenses, front and back vertex power may be quite different. Here, the lens shown in Figure 14-7 has been reversed to more easily use a vergence method of finding its vertex power.



then

$L_1$0 0 08.00 D 0 0.00 D

or

$L_1 0\ 0\ 08.00$ D

To find the vergence of light at F_2, the reduced thickness is subtracted from $l_1 0$.

$$l_2\ 0\ l_1{}^{0}\ 0\ \frac{t}{n}$$

$$0\quad \underline{1\ \ }0\ \underline{0.005\text{m}}$$

then in this case,

$L_2 0\ 0\ 02.00\ 0\ 8.22$
$0\ 06.22$

Since back vertex power is the vergence with which light from an object at infinity leaves a lens, the back vertex power ($F_v 0$) for this lens is 06.22 D. This is noticeably different from the nominal power of the lens, which equals 06.00 D.

Unit 5:

Optical Prism: Power and Base Direction

Learning Objective:

At the end of this chapter, students will be able to learn:

1. Relationship of prism with optical lenses.
2. Uses of ophthalmic prisms. Difference of ophthalmic, optometric and opticianry prisms.
3. Uses of prisms in spectacles, dispensing prisms.

A lens causes incoming light to change in its vergence by making that light converge or diverge.

A prism causes light to change direction without changing its vergence. The image of an object can be optically repositioned with a prism. People who have problems with how their eyes work together as a team can be helped by the use of prism. In this chapter we look at what a prism is and how it is used in eye care.

OPHTHALMIC PRISMS

A prism consists of two angled refracting surfaces. The simplest form of a prism is two flat surfaces that come together at an angle at the top. The point is called the *apex* of the prism; the wider bottom of the prism is called the *base*.

The Relationship Between Prism Apical Angleand Deviation of Light

Suppose a prism is oriented so that incoming light strikes the first surface perpendicularly. When light strikes the first surface it is going from a low refractive index material (air) into a higher refractive index material (the prism). However, it does not change direction because it enters the surface straight on. Light will continue to travel through the prism without being bent until it reaches the second surface (Figure 15-1). This ray of light then strikes the second surface at an angle. *Because the light has not been bent by the first surface, the angle at which it strikes the second surface is equal to the apical angle of the prism* (Figure 15-2). As this ray of light approaches the second surface of the prism, it is traveling from the denser (high refractive index) medium of the prism to a less dense medium (air) and will be bent away from the normal* to the surface. Light is always bent toward the base of a prism.

What is the relationship between the apical angle of a prism and the amount of deviation of the light produced by that prism?

Remember, “normal” to the surface means perpendicular to the surface.

Simplifying for Thin Prisms

In an effort to simplify, there is a shortcut for finding the angle of deviation that may be applied for thin prisms.

We know by looking at Figure 15-2 that:

The angle of incidence (i_2) equals the apical angle of the prism (*a*), or (i_2 D *a*)

The angle of refraction (i_2D) is the sum of the apical angle

(*a*) plus the angle of deviation (*d*), or

(i_2D D *a* D *d*)

Angle of refraction

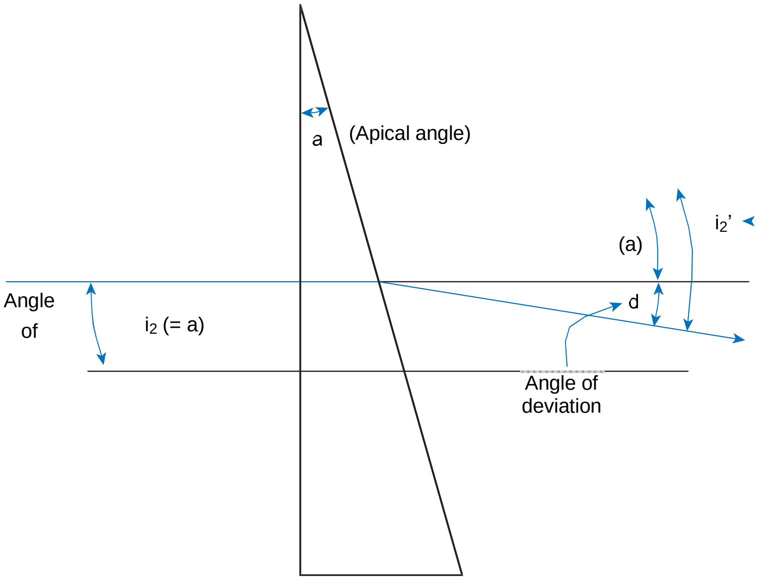


Figure 15-2. This prism is oriented with the first surface perpendicular to the incoming light ray. This means that the angle of incidence at the second surface (i_2) is equal to the apical angle of the prism. Note also that the angle of refraction (i_2D) equals the apical angle (*a*) plus the angle of deviation (*d*).

The Prism Diopter (D)

The power of a prism could be quantified in terms of apical angle. The problem is that prism power would vary depending upon the refractive index of the prism. So this does not work very well.

A prism could also be quantified in terms of the angle of deviation in degrees that it produces. This is better because it is independent of index. However, angle of deviation is not as easy to work with for ophthalmic purposes.

A third way of quantifying prism power is to express it in terms of how far it displaces light when measured on a flat screen. In other words, how far was light dis- placed from the point it would otherwise have struck at a given distance from the prism had it not first been bent by the prism. This type of unit is called the *prism diopter* and is abbreviated by the Greek delta symbol (D). The prism diopter is an angular measure derived by using the tangent of the angle of deviation. The prism diopter s the unit of angular measure whose tangent is 0.01 or

$\mathrm{D}\underline{1}\mathrm{D}$.

Finding Prism Displacement for Any Distance

If prism displacement can be written as:

$$\tan d \ \mathrm{D} \frac{P}{100}$$

We can also determine prism diopters if we know the amount of displacement of the ray for any given distance from the prism. If the displacement is *x* units on a flat plane that is located *y* units from the prism, then:

$$\tan d \ \mathrm{D} \frac{x}{y}$$

This means that:

$$\tan d \ \mathrm{D} \frac{P}{100} \ \mathrm{D} \frac{x}{y}$$

or

$$\frac{P}{100} \mathrm{D} \frac{x}{y}$$

$\mathrm{D}\,100\mathrm{D}$

Remember, in trigonometry the tangent of an angle

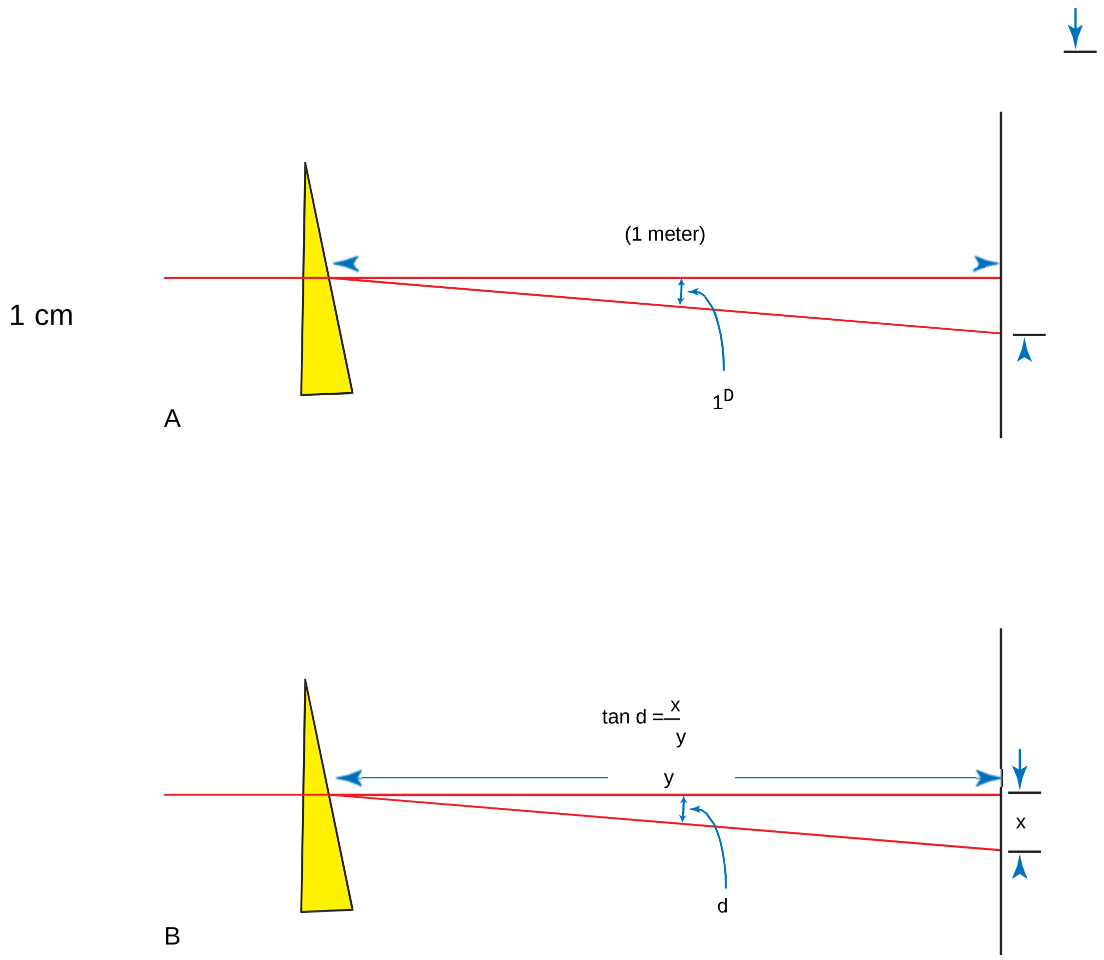
is the opposite over the adjacent $\tan d \ \mathrm{D} \ \mathrm{D} \ \frac{opp}{adj} \mathrm{D}\mathrm{D}\mathrm{D}$ (Figure

Notice that both *x* and *y* must be the same units of measure. If *x* is centimeters, then *y* must also be centi- meters (See Figure 15-4, *B*.)

15-3). This means that for a screen 100 cm away, if a prism displaces the image 1 cm, the prism has a power of 1 prism diopter. So from the geometry of Figure 15-4 we see that:

$$\tan d = \frac{P}{100}$$

where P is the number of centimeters that the image is displaced at a distance of 100 cm (1 m). By definition P will also be the number of prism diopters (D) of prism displacement power.



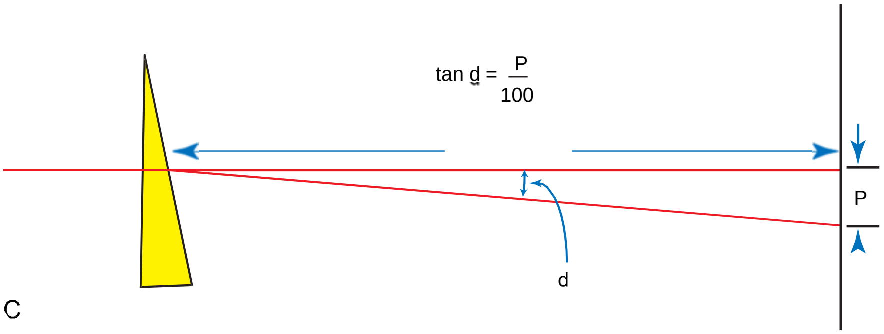


Figure 15-4. A, We see that, by definition, a prism having a power of one prism diopter (1D) will displace a ray 1 cm at a distance of 100 cm. **B,** We notice that the angle of deviation caused by the prism (*d*), and the amount of displacement (*x*) on a plane at a given distance (*y*) from the prism can be described by tan *d* D $\frac{x}{y}$. **C,** Knowing what we see in **B,** we can relate prism diopters to the angle of deviation with the relationship: tan *d* D $\frac{P}{100}$

and knowing that *x* D 9 cm and *y* D 300 cm, then:

$$\frac{P}{100} D \frac{9}{300}$$

So basically we used similar triangles to find that for a displacement of 3 cm at a distance of 100 cm, this prism has a power of 3D. This is because, by definition, a 3-cm raydisplacement at a distance of 100 cm is 3 prism diopters.

If we were to use the equation:

P D $\underline{\text{D9DD100D}}$
300

$\underline{P}$ D $\underline{x}$
3 cms
100 y

And change the units of measure for the distance from theprism to the screen into meters, then we would have:

$\underline{P}$ D $\underline{x\ \text{centimeters}}$

The Prism Centrad (A**)**

A seldom-used method of quantifying prism deviation isthe centrad (abbreviated A). A centrad is similar to a prism diopter in that a ray is displaced 1 cm at a distance of 1 m from the prism. The difference between the two is that a prism diopter is measured on a flat plane 1 m away, whereas the displacement of a centrad is measured

It is possible to convert back and forth from degrees of deviation to prism diopters using trigonometric functions as described earlier and shown in the equation:

tan d D P ——
100

*At this point, it should be mentioned that some manufacturing opticians refer to prism diopters by using the term degrees. Although sometimes used in the trade and understood to be the same thing as a prism diopter, this use of the term degrees is technically inaccurate and must not be confused with either degrees of deviation or apical angle as expressed in degrees.

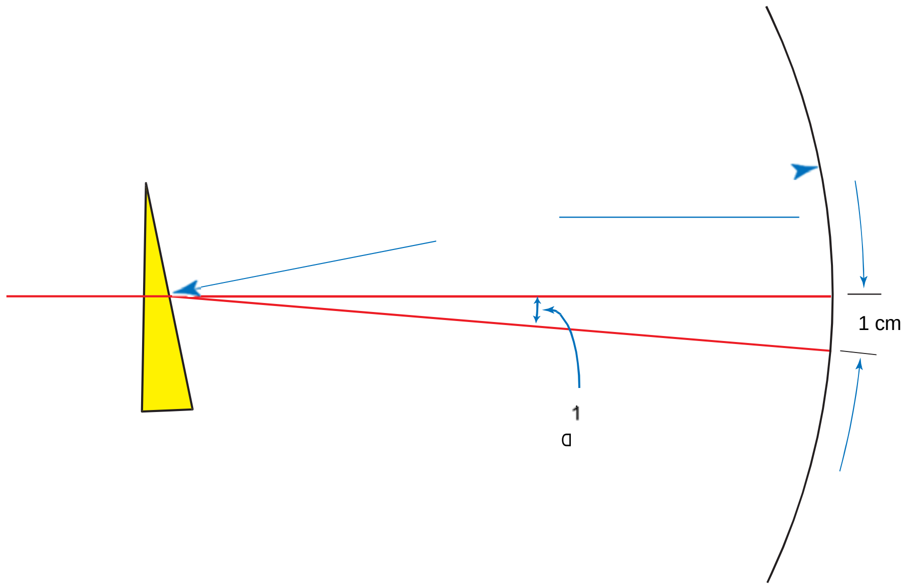


Figure 15-5. One (1) centrad equals one hundredth part of a radian. The one hundredth part is measured on the circular arc. If the radius equals 100 cm, then 1 centrad (A) is 1 cm mea- sured on the curved arc.

on the arc of a circle having a 1-m radius (Figure 15-5). The centrad is thus a more consistent unit of measurement, but it is not used clinically. For small angles of prism deviation, the centrad and the prism diopter are nearly equal. However, as the amount of prismatic deviation increases, the two become increasingly different.

Image Displacement

If a prism is placed before an eye, the deviated ray enters the eye. The eye itself has no way of knowing that the ray has been deviated. It simply appears to be coming from a different direction. Since this ray comes from a specific object, the object itself appears to be displaced. Since there is no actual displacement, what the eye sees is a displaced image of that object. The phenomenon is referred to as image displacement and is shown in Figure 15-6.

The amount of image displacement is predictable from the power of the prism and can be expressed in prism diopters. This corresponds exactly to the previous definition. As seen in Figure 15-7, if a ray of light is dis- placed 1 cm at a distance of 1 m from the prism, the image of an object in front of the prism will be correspondingly displaced 1 cm for each meter the object is from the prism.*

*For objects closer to the prism than infinity, the divergence of the rays striking the prism causes a ray displacement (and consequently an image displacement as well) that is slightly different than that manifested for an object at infinity. This is called "effective prism power" and is explained later in this same chapter. Rays from an object at infinity strike the prism with neither divergence nor convergence, but are parallel rays.

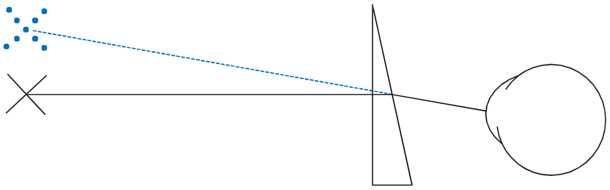


Figure 15-6. When looking through a prism, the image of an object appears to be displaced from its actual location.

Direction of Image Displacement

As previously seen, a single ray of light is deviated in the direction of the prism's base. From the point of view of an observer holding the prism before his or her eye, the prism causes the image of a viewed object to be displaced in the direction of the apex of the prism. To remember this easily, think of the prism as being an arrow with its apex pointing in the direction of the displaced image. *"The eye turns in the direction the prism points."*

Practical Application

Prism is used in a spectacle lens prescription to either cause or allow the eye to turn from the normal straight- ahead viewing direction. If one eye turns upward, a prism may be placed with its base down before that eye. This causes an object to appear as if it is farther up than it actually is. When this is done, the image the eye sees will correspond to the position where the deviant eye is looking so that both eyes may more easily work together as a team. In this simplified example, the direction of

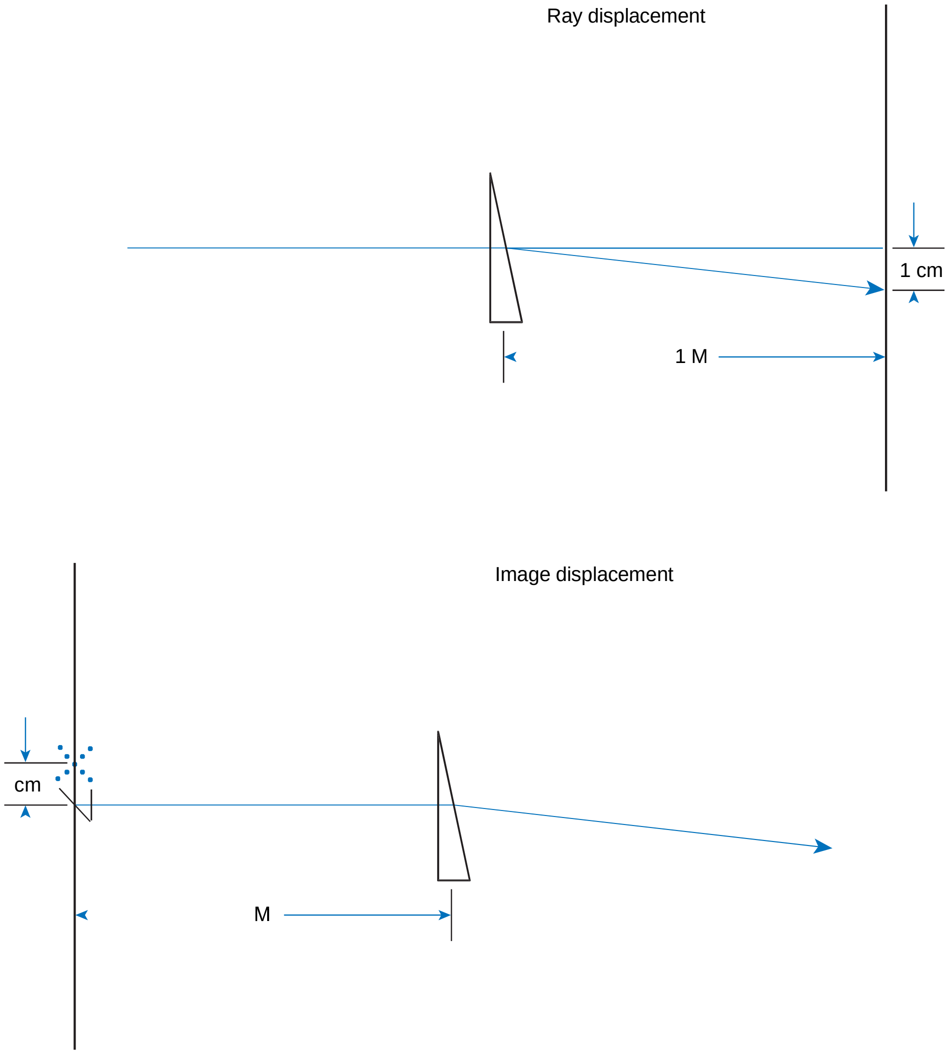


Figure 15-7. How prism diopters correspond for both displacement of rays or displacement of images.

prism orientation would depend on which way the eye tended to point.

How to Specify Prism Base Direction

There is more than one way of specifying prism base direction. Lens prescribers tend to use one method because it fits in more with how they measure the amount of prism needed. The optical surfacing laboratory uses another method because prism can only be ground in a certain manner.

The Prescriber’s Method

The person prescribing prism generally uses the wearer’s face to reference the prism direction. The top and bottom of the wearer’s face and the nose or sides of the head are used to specify base direction. If the prism is “right side up,” with the base pointing downward and the apex pointing upward, the prism is said to be a base-down prism. If it is “upside down,” the prism is said to be base up (Figure 15-8).

If the prism is on its side, so to speak, the base of the prism will be oriented either in the direction of the nose or outward away from the nose. Prism oriented with its base toward the nose is said to be base in (Figure 15-9). Prism turned with its base away from the nose is referred to as being base out (Figure 15-10). This is perfectly adequate for those doing the prescribing since vertical and horizontal prism elements are considered separately. If both horizontal and vertical prism corrections are required, then two prism elements are prescribed.

Unfortunately, this is somewhat limiting for the optical surfacing laboratory. First of all, if base-in or base-out prism is prescribed, it depends on which eye is being referenced as to which direction the base of the prism actually faces. For the right eye, base-in prism means that the base goes to the right, but for the left

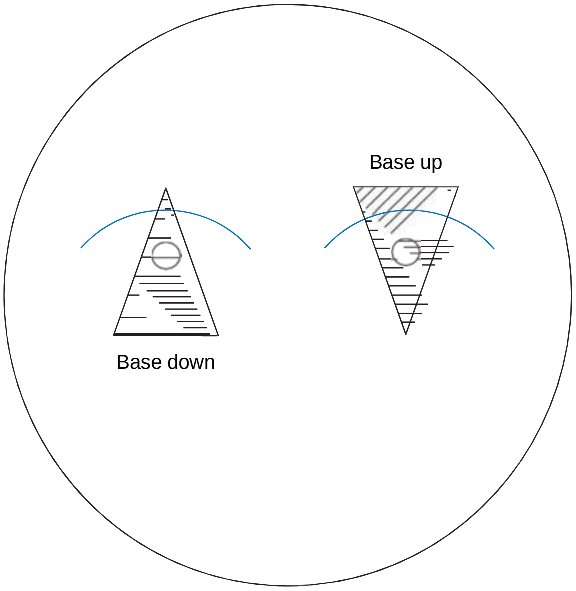


Figure 15-8. It is not necessary to know which eye a prism is on to be certain what “base down” or “base up” means. (However, base down before the right eye has the same effect for the wearer as base up before the left. They are *not* opposite effects.)

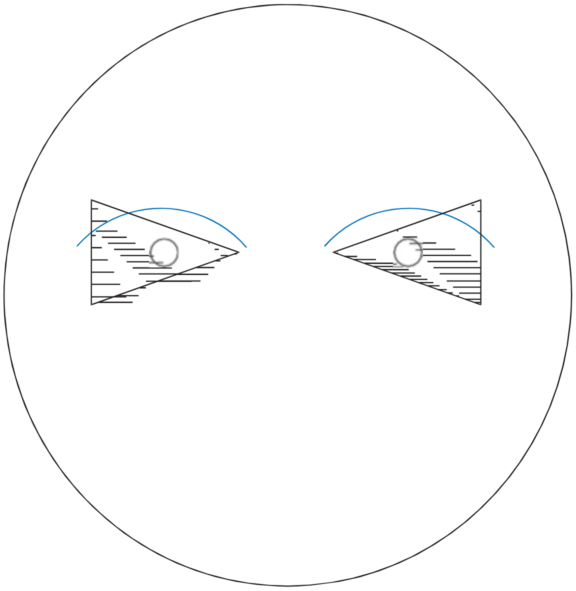


Figure 15-10. Even though the prism bases go in opposite directions, both are

classified as “base out.” It is not possible to know exactly which way a base-out prism is oriented until a right or left eye is specified.

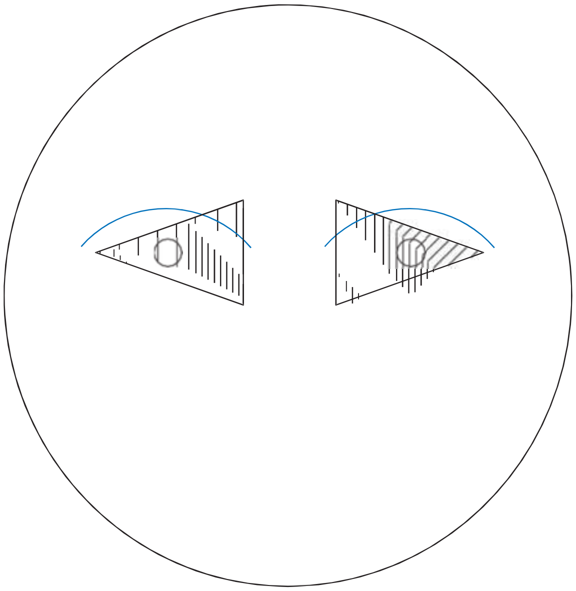


Figure 15-9. When horizontally oriented prism is prescribed for both eyes, it is almost always either base in for both eyes or base out for both eyes. Base-in prisms on both right and left eyes do not cancel each other, but rather augment the desired effect.

eye, a base-in prism means that the base goes to the left.

A 360-Degree Laboratory Reference System

Although the prescriber’s method of specifying prism is well suited for those examining eyes and those dispensing eyewear, it is not adequate for the optical laboratory. The optical laboratory uses either a 360-degree system or a 180-degree system of specifying prism base direction.

The 360-degree laboratory reference system uses the standard method of specifying direction in degrees, as shown in Figure 15-11. When a lens is viewed from the front (convex side facing the observer), the base direction is specified as follows: If the base is pointing to the right, it is specified as base 0 degrees. If the base is oriented in an upward direction, it is base 90 degrees. To the left is base 180 degrees, and straight down is base 270 degrees.

The prescriber’s method uses a rectangular coordinate system of horizontal and vertical measures. The laboratory method uses a polar coordinate system of degrees.

Converting the Prescriber's Method to the Laboratory System

Suppose a prescription calls for 2 diopters of base-down prism. What is that in the 360-degree laboratory reference system?

Base-down prism is below the 180-degree line. There- fore it must be greater than 180 degrees. Since there are only four directions in the prescriber's method, it must be either 0, 90, 180, or 270 degrees. The 270-degree direction is straight down. Therefore 2 diopters of base- down prism corresponds to base 270.

Converting from the Prescriber's Method When Two Prism Elements Are Involved

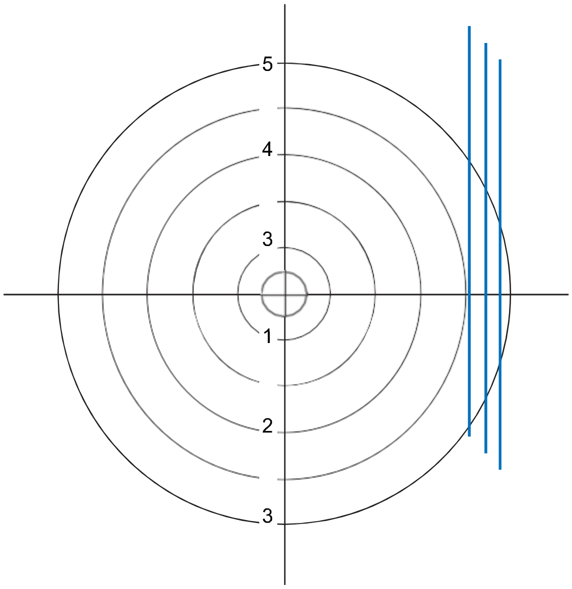
Sometimes a prescription calls for two amounts of prism in two different directions, both on the same eye. When lenses are ground, it is not possible to work with two prisms. Instead the two prisms are combined into one new prism. Fortunately the end result is the same.

Using one prism instead of two is like taking a short- cut across a field. Instead of walking 2 miles east and 2 miles north, it is possible to walk 2.83 miles northeast and arrive at exactly the same location. (Those familiar with geometry will recognize this as simply the sum of

indicate the amount of prism being measured. If the lensmeter is focused, the lines on the target cross at the location of the optical center of the lens. Normally the lens is moved until the target lines are superimposed on the center of the lensmeter reticle, as in Figure 15-13. If the target lines are not centered, the place on the lens where the lensmeter is measuring creates a prismatic effect. The amount of prism is indicated by the location of the intersection of the target lines.

For example, if the target lines intersect on the reticle ring marked "1," the lens shows 1 diopter of prism. If the target lines are on the "1" reticle ring exactly above the center of the reticle, as shown in Figure 15-14, the prism direction is base up. As would be expected, a base-in or base-out effect will be seen to the left or right, depending on which lens is being measured (Figure 15-15).

If a lens is placed in the lensmeter and the intersection of the target lines occurs at a location other than on the vertical or horizontal reticle line, then both vertical and horizontal prism are being manifested. The amount of each is found by drawing imaginary lines from the target center to the horizontal and vertical lines


5
4
3
1
2
3

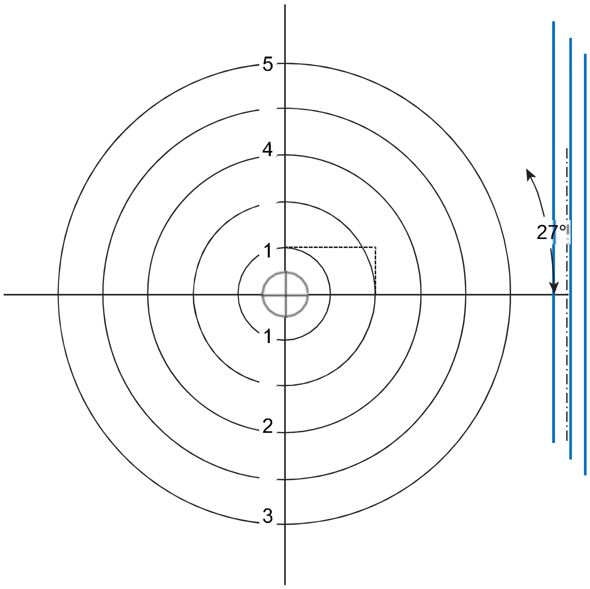

5
4
1
27°
1
2
3

Figure 15-14. If a lens shows this in the lensmeter, there is 1 prism diopter of base-up prism at the point on the lens being looked through. This is true regardless of whether it is a left or a right lens.

Figure 15-16. Assuming that this lens is for the right eye, the prismatic effect shown is 2D base in and 1D base up. The base direction of the resultant prism is 27 degrees. It should be noted that the tilt of the triple and single target lines do *not* tell base direction. Within the eyepiece is a hairline that is turned until it crosses the center of the target. This hairline indicates the correct number of degrees. (The interior degree scale is not shown.)

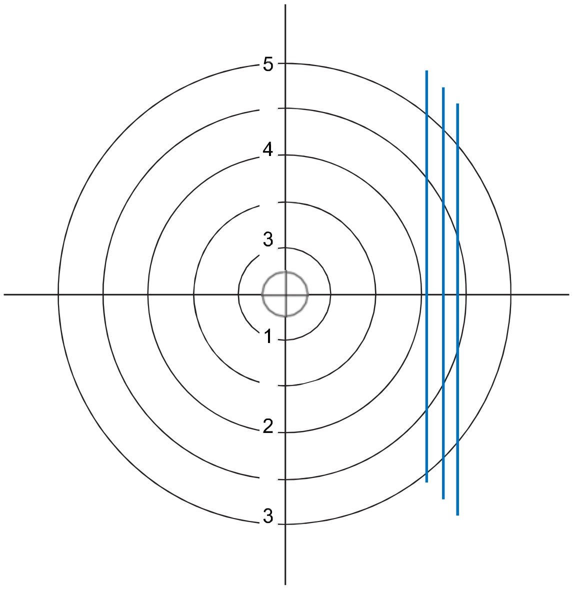


Figure 15-15. For this lens, the amount of prism is 1 prism diopter. However, since we do not know whether the lens is for the left or right eye, we do not know if the prism is base in or base out. If the lens is intended for the right eye, the base direction is base out.

In Figure 15-16, if the lens is a right lens, the amount of prism manifested is 2 prism diopters base in and 1 prism diopter base up. However, the location of the center of the target really shows only one prism. By looking at the figure it can be seen that the amount of

prism is really about 2.25 prism diopters. The base direction is approximately 27 degrees. (Most lensmeters have a degree scale within the reticle that can be used to measure the angle.) We now have a simple system for converting the prescriber’s method to the laboratory reference system of recording prism. Since looking into a lensmeter each time is somewhat inconvenient, an alternative is to use a device called a *resultant prism chart*. This chart is shown in Figure 15-17. Such a chart is used in the same manner, but without the lensmeter.

A Modified (180-Degree) Reference System

Since people in the optical industry are familiar with a 180-degree system when specifying cylinder axis, many prefer to use only 0 to 180 degrees when specifying prism base direction. With cylinder axis there is no difference between axis 90 and axis 270. The cylinder axis is one continuous line. This is not the case, however, with prism base direction. With prism a base 270 direction is exactly opposite a base 90 direction. Thus when using only 0 to 180 degrees, the number must be followed by either "up" or "down." Therefore "base 90" is "base 90 up," and base 270 is "base 90 down."

In practice if the base direction is between 0 and 180 degrees, the word "up" is dropped. But if the base direction corresponds to more than 180 degrees in the 360-degree system, 180 degrees is subtracted from the number, and the word "down" is always added. For example, in the 180-degree reference system, base 270 is (270 D 180), or base 90 DN (down).

Prism Base Direction for Paired Lenses

Prism is normally prescribed to compensate for difficulty the eyes have in working together (i.e., for the purposes of addressing a binocular vision problem). Because eyes work as a team, prism placed in front of one eye affects both eyes. Therefore the full prism correction may be placed before one eye, or the correction may be divided between the two eyes. Dividing the prism may be done as an even split or by placing an unequal portion before one eye and the remainder before the other.

Splitting Horizontal Prism

Very often horizontal prism is split evenly in front of both eyes. Both prisms will be base in, or both will be base out.

It is perfectly legitimate to split prism unevenly. For example, instead of splitting prism as:

R: 2D base out L: 2D base out

the prescriber may cause the same effect binocularly with

R: 3D base out L: 1D base out

or even

R: 0 prism
L: 4D base out

The net effect will be the same. One reason prism may be split unevenly may be because of eye dominance. In other instances, the choice of how to split prism may be made in an effort to either improve the cosmetic appearance of the lenses or equalize lens thicknesses.

Base-out prism in front of the right eye gives the same optical effect as base-out prism in front of the left eye. Base-in prism in front of the right eye gives the same optical effect as base-in prism in front of the left eye.

Splitting Vertical Prism

Vertical prism may also be split evenly or unevenly before the two eyes. An example of prism split evenly would be:

R: 2D base up
L: 2D base down

For example, the prescriber may cause the same effect binocularly with

R: 3D base up
L: 1D base down

or

R: 0 prism
L: 4D base down

With vertical prism, base up in front of one eye creates the same effect as prism base down in front of the other eye.

This concept is more easily understood by remembering that a prism allows the eye to turn in the direction of the prism apex. Therefore if the right eye turns up, a base-down prism before the right eye will allow the eye to turn upward (in the direction the prism apex points) and should help in preventing eyestrain or double vision.

To summarize:

Right eye	**Left eye**
Base out	Base out
Base in	Base in

is the same as

COMPOUNDING AND RESOLVING PRISM

As seen earlier, a prescription may require both horizontal and vertical prism in the same lens. In the manufacturing process, one simple prism may be calculated such that it produces exactly the same effect as the two specified prisms combined would have. When two prisms are combined in power and base orientation to form one prism that is the equivalent of both, the process is known as *compounding prism*.

The reverse of compounding prism is the process of taking a prism whose base orientation is oblique and expressing it as two prisms oriented perpendicularly to one another. The process of expressing a single oblique prism as two perpendicular components is known as *resolving prism*.

When using a lensmeter to analyze a prescription pair of glasses containing both horizontal and vertical com- ponents, the two components appear as one compounded prism with the base oriented obliquely. This prism may be resolved into horizontal and vertical components. This may be done easily when the compounding and resolving processes are understood.

Compounding

Compounding of two prisms into one is done by exactly the same process used for obtaining the sum of two vector. The two prisms are drawn to scale as vectors, the unit length of each corresponding to the units of prism power. The arrow points in the direction of prism base orientation.

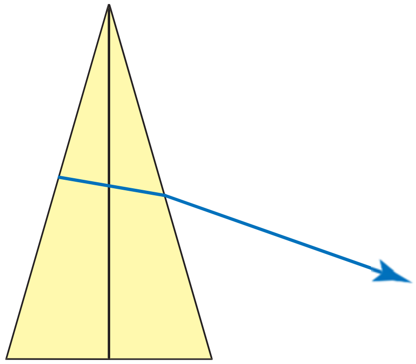
Combining Two Obliquely Crossed Prisms

At first glance, the problem of combining two oblique prisms into one single prism seems difficult. However, there are no new concepts here. In general terms, this can be done as follows:

1. Take each oblique prism and resolve it into its horizontal and vertical components.
2. Add the horizontal components from the two prisms together into one.
3. Add the vertical components from the two prisms together into one.
4. Combine the resultant vertical and horizontal components into a new, single prism.

ROTARY PRISMS

There is an application of obliquely crossed prisms that is used on a regular basis in ophthalmic practice. That application is called a *rotary* or *Risley's prism*. A rotary prism is a combination of two prisms. These prisms are placed one on top of the other. Initially, their base directions are exactly identical, but as the prisms are rotated, their bases move by equal extents in opposite directions.



A

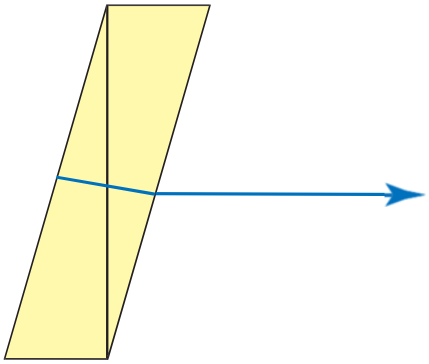


Figure 15-24. A, A Risley's or rotary prism is really two prisms, one on top of the other. When these equally powered prisms are placed base-to-base, their combined prism amount is at a maximum. **B,** When a Risley's or rotary prism has the two prism elements base-to-apex, the resultant amount is zero.

Now suppose we begin with both 10D prisms base down. Together they total 20D base down. Next we rotate one prism base 37 degrees clockwise and the other base 37 degrees counterclockwise. Now what prismatic effect is being manifested?

We plot each prism in vertical and horizontal components as seen in Figure 15-25. This shows that the horizontal components are equal and opposite. They cancel out. The vertical components are both 8D base down, which when added equal 16D base down.

As the prisms continue to be rotated in opposite directions, the horizontal components increase equally and continue to cancel out, and the vertical components decrease. This continues until both prisms are fully horizontal-one base left, the other base right. Now there is neither horizontal nor vertical prism. The prismatic effect is zero. If the two prisms continue to be rotated past the horizontal, base-up vertical prism begins to increase and continues to increase until both prisms are fully base up. As these prisms were being rotated, there was never anything but vertical prism being manifested.

The same thing may be done to produce varying amounts of only horizontal prism. To produce only horizontal prism, begin with both prisms base left. Rotate the base of one prism clockwise and the other counter-clockwise in equal amounts (Figure 15-26). Now horizontal prism varies, and vertical prism remains at zero. There are two common forms of the Risley's or rotating prism in ophthalmic practice. One, found on the phoropter, is used to measure phorias and ductions (Figure 15-27). The other is found on some lensmeters and is used to measure large amounts of prism in spectacle lenses.

HOW THE EFFECTIVE POWER OF A PRISM CHANGES FOR NEAR OBJECTS

A prism displaces a ray of light consistently. However, it will affect the eye somewhat differently when looking at a near object than it does when looking at a distant object. The eye will turn less when looking through a prism at a near object than it will when looking through that same prism at a distant object. Therefore the *effective* power of the prism, when measured as the angle that light enters the eye, will decrease as an object moves closer to the prism being worn. So although a prism displaces a ray of light consistently, the power of the prism, when measured by the angle that light enters the eye, will be less the closer the viewed object is to the prism.

For an object at infinity, a prism will cause that object to be displaced such that the angle of displacement, (d) equals the angle of rotation of the eye (d_e) (Figure 15-29). In other words, for distance vision, the prism causes the light to deviate or bend by the angle d. This is equal to the actual (effective) turn of the eye d_e.

Sample questions:

1. If a prism has an apical angle of 8 degrees and is made from CR-39 plastic with a refractive index of 1.498, how many degrees will the prism deviate the light ray from its original path?

Solution

When working through this example problem, refer to Figure 15-2. Notice that light entering the first surface is perpendicular to the surface and is not bent. It is bent at the second surface and, according to Snell's law,

n sin i D nD sin iD
where n D 1.498
nD D 1.0,
sin 8 D 0.1392

So by substituting,

(1.498) (0.1392) D (1.0) (sin iD)
sin iD D 0.2085

Next using a calculator we find the inverse sine (sin^{D1}) of 0.2085 to be:

iD D 12.03 degrees

The angle of refraction is the angle at which the light ray leaves the second surface. To find the angle of deviation (i.e., how many degrees the light is deviated from its original path), subtract the angle of incidence from the angle of refraction.

(angle of deviation) D (angle of refraction)
▯(angle of incidence)

d D iD D i
D 12.03 D 8.00
D 3.97 degrees

In this instance, the resulting angle of deviation is 3.97 degrees, or rounded off, 4.0 degrees.

2. A prism is made from polycarbonate material having an index of 1.586. It has an apical angle of 5 degrees. What is the angle of deviation that it produces in air?

Solution

Again using Snell's law,

n sin *i* D nD sin *i*D

We can substitute and find:

(1.586)(sin 8) D (1.0)(sin *i*D)

(1.586) (0.0872) D sin *i*D

sin *i*D D 0.1382

Next the inverse sine of 0.1382 is found.

*i*D D 7.95 degrees

The angle of deviation is:

d D *i*D D *i*

D 7.95 D 5

D 2.95 degrees

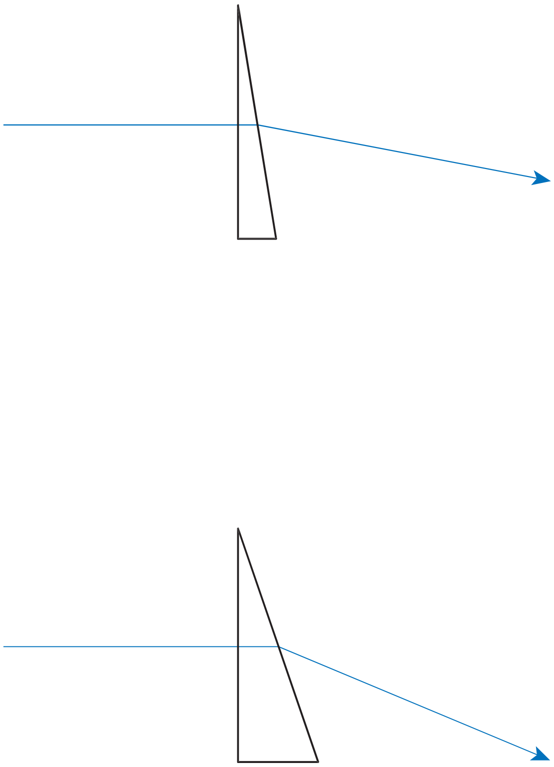


Figure 15-1. The more wedge shaped a prism is, the greater is its ability to divert light in another direction.

So the angle of deviation is 2.95 degrees.

3. A 5D base-in prism is prescribed for distance vision. The prism is worn at a vertex distance of 20 mm. What is the effective power of the prism for objects at 40 cm?

Solution

Before trying to solve by just using the equation, notice that vertex distance was given—not the distance to the center of rotation of the eye. If we use the effective prism power formula, we need to know the distance from the prism to the center of rotation of the eye. The unknown quantity is the distance from the front surface of the cornea to the center of rotation. This distance is usually assumed to be

13.5 mm. If we assume that the distance from the cornea to the center of rotation is 13.5 mm, then the distance from

and

100 D*l*

the prism to the center of rotation will be 20 mm D 13.5 mmor 33.5 mm.

Note that because of sign convention, the distance from

P_e D y

100 D*l* D *s*

the lens (prism) to the near object is a negative number (D400 mm). So when putting the numbers into the formula we have:

By transposing the first equation we get

y D *P*(D*l*)

100

And by transposition the second equation becomes

Effective Prism Power D 5

1 D 33.5

D400 mm

D 5 D 5

y D P_e DD*l* D*s*D

100

1 D DD0.084D 1.084

D 4.61D

Now we have two values for *y* that must be equal to one another. Therefore we can combine the two as:

P(D*l*) D P_e DD*l* D *s*D

100 100

This reduces to

p(D*l*) D p_e(D*l* D s)

and becomes

P D *P*(D*l*)

e DD*l* D *s*D

The effective power of a 5.00D base-in prism, when used toview an object at 40 cm, is 4.61D base in.

4. Suppose an object is at a distance of only D10 cm from a base-down prism having a power of 6. If the prism is worn at a distance of 25 mm from the center of rotation of theeye, what is the effective power of that prism?

Solution

Since *l* D D100 mm, *s* D 25 mm, and *P* D 6D, then

When transposed the result is what is referred to as the *effective prism power formula*:

$\underline{P}$

Pe D $\underline{s}$ $\underline{P}$

1 D

l

6

Pe D

1 D $\underline{s}$

l

D

D D100D

1 D D $\underline{25}$ D

So the effective power of the prism for near objects can be compared mathematically with the actual power of theprism for objects at infinity with the above formula.

D $\underline{6}$

1 D 0.25

D 4.8DNote: As an object approaches the plane of the prism, the effective power of the prism continues to drop, losing power rapidly until the object finally touches the front of the prism, and the effective power essentially drops to zero.

5. How many prism diopters are produced for each degree ofdeviation?

1 meter

or

y meters

Solution

For 1 degree of deviation, we begin by finding the tangent of1 degree.

6. How many degrees of deviation are produced by 1 prismdiopter?

Solution

This time we are going the other way.

How much prism power does a prism have if it displaces a ray of light 5 cm from a position it would otherwise strike ata distance of 5 m from the prism?

Unit 6:

Optical Prism:

Decentration and Thickness

Learning Objective:

At the end of this chapter, students will be able to learn:

1. Centration and decentration of lenses.
2. Rules and angles involved in prismatic prescriptions.
3. Level of thickness in different parts of the prisms.

The relationship between a normal plus or minus spectacle lens and optical prism can sometimes be difficult to understand. For example, when

the optical center of a lens is moved away from its expected position in front of the eye, that lens now causes a prismatic effect. The farther the lens is moved or decentered from its original position the greater the amount of resulting prism. This chapter explains how this happens and how prism is related to thickness differences across a lens. Grasping these concepts leads to a much greater understanding of prism and lens prescriptions.

DECENTRATION OF SPHERES

When light goes through the optical center (OC) of the lens, it goes straight through. It is not bent. When light goes through any other point on a lens, the ray of light is bent. The farther from the optical center that a light ray strikes a lens, the more that ray will have to bend to pass through the focal point of the lens. This lens characteristic may be used to advantage when pre- scribed prism is required in a prescription. However, it will also cause problems if the lens has not been properly centered before the eye.

A Centered Lens

At the exact OC of a lens, front and back lens surfaces What happens when the lens is moved so that the center of the lens is no longer in front of the center of the eye? To understand what happens, consider the shape of a plus lens. From the side (in cross section), it appears to look much like two prisms placed base to base (Figure 16-2). A minus lens gives the impression of being a com- bination of two prisms, but this time placed apex to apex (Figure 16-3). When the wearer looks right through the center of the lens, the object is not displaced from its actual location. But when a plus or minus lens is moved off-center in relationship to the location of the eye, the object appears displaced as shown in Figures 16-2 and 16-3. This means that a *decentered* lens causes a *prismatic effect*.

Prentice’s Rule

Remember that *prism power* is the amount light is dis- placed in centimeters at a distance 1 m away from the lens or prism.

The relationship between focal length (f) and decentration (c) is shown in Figure 16-4 using similar triangles. This relationship is the same as the definition of prism power: the displacement in centimeters over the distance in meters.

By similar triangles, as shown in Figure 16-4, *B* and *C,* we see that:

$$\underline{c\ \mathrm{DcmsD}}\ \mathrm{D}\ \text{image displacement in cm}$$

are parallel to each other. The line that passes through the OC of a lens is known as the *optical axis*. Light from

f DmetersD

1 meter

an object at infinity is focused somewhere on the optical axis. The exact location of the focal point depends on the power of the lens.

If the optic axis of a lens passes through the center of the pupil, the lens is centered in front of the eye. If the lens is moved so that it does *not* coincide with the line of sight of the eye (for our purposes at the center of the pupil), it is said to be *decentered*.

A Decentered Lens

Normally an individual wearing corrective lenses has each lens positioned with its optical center in front of the eye. In this position, when the wearer looks straight ahead there is no displacement of objects from their actual positions (Figure 16-1).

And we know from the definition of a prism diopter that

$$\mathrm{D}\ \mathrm{D}\ \frac{\text{image displacement in cm}}{\text{1 meter}}$$

Therefore, we can see that

$$\frac{c}{f}\ \mathrm{D}\ \mathrm{D}$$

So if we know lens decentration in centimeters (c) and lens focal length (f), the prismatic effect caused by the decentration may be calculated.

Figure 16-1. When a lens is positioned with its optical center directly in front of the eye, there is no prismatic effect.

Image is not displaced

Lens centered before eye

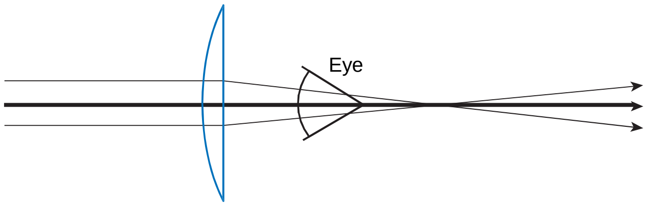


Figure 16-3. Moving the optical center of a minus lens downward will produce a base-up prismatic effect.

Image moves upward

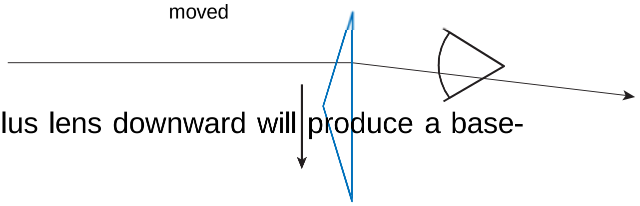
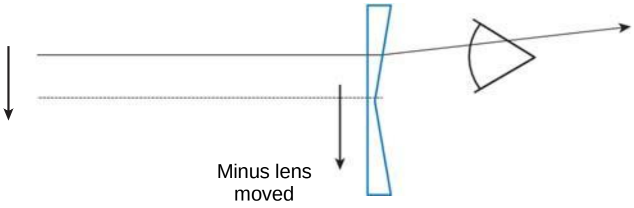


Figure 16-2. Moving the optical center of a plus lens downward will produce a base-down prismatic effect.

Image moves downward



Because

$$F\ \mathrm{D}\ \frac{1}{f}$$

Prism Base Direction With Decentration

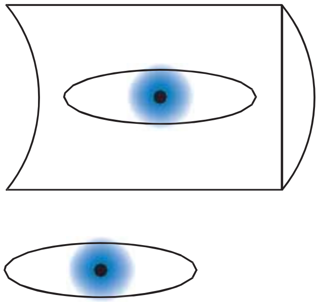
When a lens is decentered, a prismatic effect is created. With decentration, both prism power and prism base direction are manifested. The power of the prism depends on the amount of lens decentration and the refractive
the relationship further simplifies to

$$\mathrm{D}\ \mathrm{D}\ cF$$

The equation D D *cF* is commonly known as *Prentice's rule.*

DECENTRATION OF CYLINDERS

Cylinders produce varying prismatic effects when decentered. These prismatic effects depend not only on the



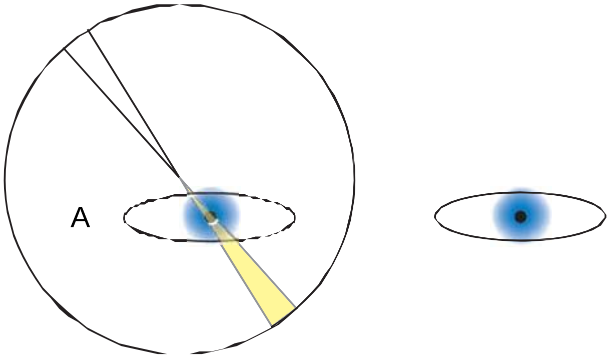
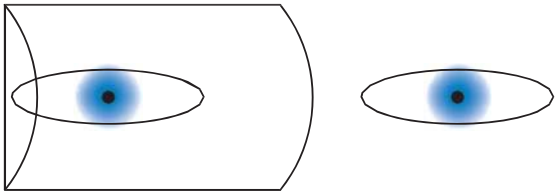


Figure 16-7. An oblique



decentration of a sphere lens produces prism in the same meridian as the meridian of decentration.

power of the cylinder but also on the orientation of the cylinder axis.

Decentration Along Major Meridians

If the axis of a plano cylinder is oriented in the direction of decentration, there will be no prismatic effect induced regardless of the amount of decentration. This is because there is no power in the axis meridian of a plano cylinder. If, however, the cylinder axis is at right angles to the direction of decentration, the amount of prism induced varies according to Prentice's rule.

Decentration of Cylinders Oriented Obliquely When decentering a plano plus cylinder or a plano minus cylinder, the resulting prismatic effect is always at right angles to the axis of the cylinder. In other words, if a plus cylinder with axis 90 is decentered, the resulting axis. This means that one base direction is 120 D 90, or210 degrees. The other is 120 D 90, or 30 degrees.

To solve a decentration problem for an oblique cylinder, one of the simplest procedures represents a combination of graphical and algebraic methods. It also helps to understand the concept of what is happening when an oblique cylinder is decentered. And understanding conceptually what is happening is the most important part.

Horizontal and Vertical Decentration of ObliqueCylinders

Prism induced by decentration of a cylinder lens both horizontally and vertically is found in exactly the same manner as just described. Once the decentered point is located, an axis line is drawn through it. Thereafter the procedure follows as previously described.

DECENTRATION OF SPHEROCYLINDERS

An accurate solution for prismatic effects induced by a spherocylinder lens may be found in several different ways:

1. Calculate for the sphere and cylinder separately and combine the results.
2. Transpose the prescription to crossed cylinder form. Each cylinder may then be worked independently and the results combined.
3. Use higher mathematical computations.[1]

Perhaps the easiest way is to simply calculate the sphere and cylinder independently. Then results from the sphere decentration and results from the cylinder decentration can be combined for the final answer.

Decentration of Spherocylinders Usingan Approximation

The optical laboratory needs to be able to move the optical center of a lens away from the boxing center of a frame and over to a location in front of the eye. The laboratory does this by grinding prism into the center of the lens. This moves the optical center to another location. The amount of prism needed for grinding will be the amount that should be found at the boxing center of the lens with the optical center in front of the eye. The laboratory calculates the prism that should be expected at the boxing center of the lens, then grinds that prism amount at the boxing center. The optical center ends up where it is supposed to be.

There is an approximation method for finding decentration prism that was used in the optical laboratory for years. It has now been largely replaced since decentration prism can be found more exactly with the aid of laboratory computers. It is still used in some other instances. The approximation method uses the concept of curvature in an oblique cylinder meridian.

Using the Sine-Squared Method to Approximate Prism for Decentration

To use the sine-squared method to approximate prism for decentration, the following steps are used[2]:

1. Find the needed decentration.
2. Find the “power” of the cylinder in the 180-degree meridian. This is done by using the formula.
3. Add this reduced cylinder value to the sphere power to find the total power in the 180-degree meridian.
4. Use the total power in the 180-degree meridian to find the prism needed to move the OC. This can be done using Prentice’s rule.

   D D *cF*

   where

   D D prism power
   c D decentration in centimenters
   F D the power of the lens in the 180 degree meridian

5. Find the base direction of the prism.

Pitfalls of the Sine-Squared Method

For grinding prism for decentration with single-vision lenses in a surfacing laboratory, the sine-squared method works well. There are two pitfalls, however, that prevent it from working every time with every type of lens.

The major pitfall is the failure of this method to take vertical prism into account. Finding a horizontal prism amount by using the “power” in the 180-degree meridian fails to account for the vertical component induced by an oblique cylinder. To see how this works, place a spherocylinder lens in a lensmeter at an oblique axis. Focus the lensmeter and position the lens so that the illuminated target passes through the center of the cross hairs in the lensmeter. Looking through the focused lensmeter, move the lens left and right. Not only will the illuminated target move left and right, but it will also move up and down. The vertical movement is a result of the vertical prism caused by the oblique cylinder. If this vertical prism is not factored into the surfacing process, the OC will be higher or lower on the lens than expected. This can present problems in multifocals.

The second pitfall of the sine-squared method is that the amount of horizontal prism calculated will not exactly duplicate the amount of horizontal prism found using one of the more accurate methods.

Ground-In Prism Versus Prism by Decentration As we have seen in the previous sections, prism may be created by the decentration of a powered lens. Prism may also be created by grinding the surface of the lens at an angle during the surfacing process.

There is no optical difference between prism created by decentration and prism that has been ground in. Neither is superior nor inferior to the other. It may be that it is possible to create a thinner prismatic lens by surfacing instead of by decentering a finished lens. That is an issue of lens blank thickness rather than prism quality, however.

PRISM THICKNESS

Thickness Differences Between Prism Base and Apex

A prism causes light to change direction. This is because light must pass through two surfaces that are not parallel with one another. Because the surfaces are at an angle to one another, the prism is thin at the top (apex) and thick at the bottom (base). Prismatic power is determined by the angle the front and back surfaces make with one another and by the refractive index of the material. Because lens surfaces of a prism are angled, adding pre- scribed prism to a lens will cause a change in lens thickness.

Knowing the thickness difference between the base and apex of a prism allows the amount of prism to be found using the formula:

$$P \mathrm{D} \frac{100g \mathrm{D} n \mathrm{D} 1 \mathrm{D}}{d}$$

where

P D the amount of prism
g D the difference in thickness between the apex and the base of the prism
n D the refractive index of the lens material, and

d D the distance between the apex and base of theprism

See Figure 16-15 and be sure to read the caption carefully.

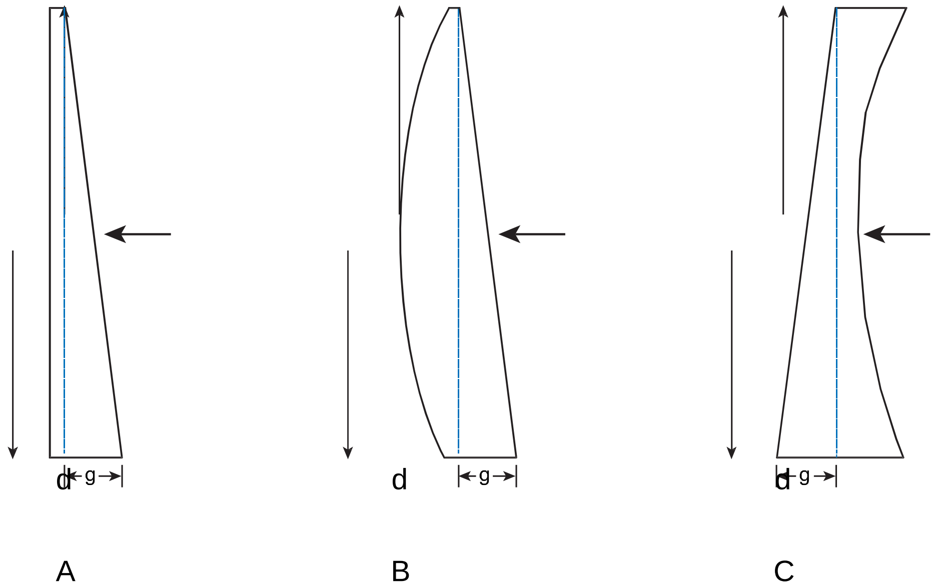


Figure 16-15. When using the prism edge-thickness formula:

$$P \; D \; \frac{100g \; Dn \; D1D}{d}$$

d is the distance between the two measured points, and *g* is the thickness difference between the points measured. The prismatic effect, *P*, is for that point halfway between the two points measured. Note that in **(A)** the dimension marked as g does not go the full width of the prism base. The *g* dimension is the width of the top of the prism subtracted from the width of the bottom of the prism (i.e., the thickness difference). For the plus lens **(B)** the prismatic effect at the halfway point (marked with an arrow) is the same as **(A)** even though the lens has a dioptric power. This is because the thickness difference, g, is the same. **C,** This lens is a minus lens. Even though the lens has minus power, the same thickness difference principle holds. The prismatic effect at the point halfway between the measured points is independent of the refractive power of the lens. In these figures, the measured points were the tops and bottoms of the lenses. They would not have to have been measured at the edges of the lenses, however. Thickness difference will determine the prismatic effect halfway in between the two measured points in the meridian of measurement, regardless of where the points are measured. *To summarize:* In **A** the prism amount is the same across the entire lens, because the prism has only prism power (D) and does not have refractive power (D). In **B** and **C** where the lenses have refractive power as well, the prismatic effect is calculated for the halfway point, but will vary at other points across the lens. The amount calculated is for the halfway-between point only.

How Prescribed Prism Affects Lens Thickness If prism is present in a lens, the lens center thickness will change. Most of the time it is assumed that a lens will be thicker by one half of the prism thickness difference,
or ½ *g* when prism is present, *regardless* of how the prism base direction is oriented. This simplifies the problem, but it is not always true. The base direction determines just how much the Rx (prescribed) prism will change the center or edge thickness. How this works is summarized in Box 16-1 and explained in the following sections.

D 3D

Notice in this particular circumstance, when the index is near 1.5 and the diameter is 50, that the thickness difference is a direct predictor of prism amount.

Plus Lenses

A plus lens is normally decentered inward because of the wearer's PD. After the lens is in the frame, the thicker portion of the lens edge will be found nasally and the thinner portion temporally (Figure 16-16, *A*). This means that if Rx prism is positioned *base inward,* the thickest portion of the lens will become even thicker (Figure 16-16, *B*). The thinner temporal portion though must retain the same minimum thickness. Therefore the center thickness of the lens will increase by an amount equal to almost half of the difference between base and apex thickness.

Base-Out Rx Prism If the Rx prism is *base out,* the thicker portion of the prism is turned outward. This corresponds to the thinnest part of an inwardly decentered plus lens. The net effect is a lens that is closer to the same thickness both nasally and temporally. If the lens has sufficient center and nasal edge thickness, it may be *thinned* by an amount up to the full prism thickness difference *g*. Therefore a nasally decentered plus lens with base-out Rx prism can be made thinner than it would be without Rx prism (Figure 16-17).

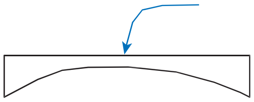
Base-Up or Base-Down Rx Prism Small amounts of base-up or base-down Rx prism will not affect the center thickness of the lens if the vertical (*B*) dimension of the frame is small compared with the *A* dimension. However, for prescriptions with larger amounts of prism or for frames with larger *B* dimensions, center thickness will be affected. The amount of center thickness increase

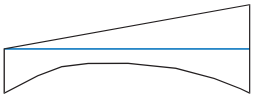
Minus Lenses

With minus lenses the amount of prism affects edge thickness. *Base-out* prism increases the thickness of the temporal edge by an amount equal to the base thickness of the prism.

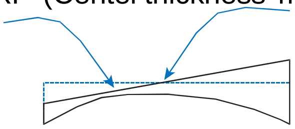
Center thickness will increase somewhat when *base- out* or *base-in* Rx prism appears in minus lenses. The thinnest point on the lens moves from the major reference point to the location of the displaced optical center, as shown in Figure 16-18.

Figure 16-18. A, Here is a finished but unedged lens with no decentration and no prism. The major reference point (MRP) and optical center (OC) are at the same location. **B,** This minus lens has prism. Simply adding extra thickness to a minus lens by an amount equal to one half the prism's apex-base thickness difference will cause the lens to be unnecessarily thick. **C,** Thinning a minus lens with significant prism back to a normal minimum thickness at the MRP will cause the minus lens to be excessively thin at the now displaced OC. The displaced OC will be at a location other than the MRP.





MRP (Center thickness maintained)



Sample Questions:

1. If a lens having a power of D3.00 D is decentered 5 mm away from the center of the eye, how much prismatic effect will this cause?

Solution

To find the prismatic effect, simply multiply the distance *in* power of the lens being decentered. The prism base orientation depends on the direction of decentration and whether the lens is positive or negative.

As noted before, a plus lens resembles two prisms placed base to base. Both bases are at the center of the lens. Therefore for a plus lens, the base direction created by decentration will correspond to the direction of the decentration. A plus lens decentered down will result in prism with the base down (see Figure 16-2).

A minus lens resembles two prisms placed apex to apex. Both apices are together at the center of the lens. Thus if a minus lens is decentered down, the result will be prism with the base up, opposite to the direction of decentration (see Figure 16-3).

centimeters that the lens has been displaced by the power of the lens. Since 5 mm equals 0.5 cm,

Prism diopters D 0.5 D 3.00
DD1.5

2. If a D4.00 D spherical lens is decentered 5 mm upward, how much of a prismatic effect is induced, and what is the base orientation?

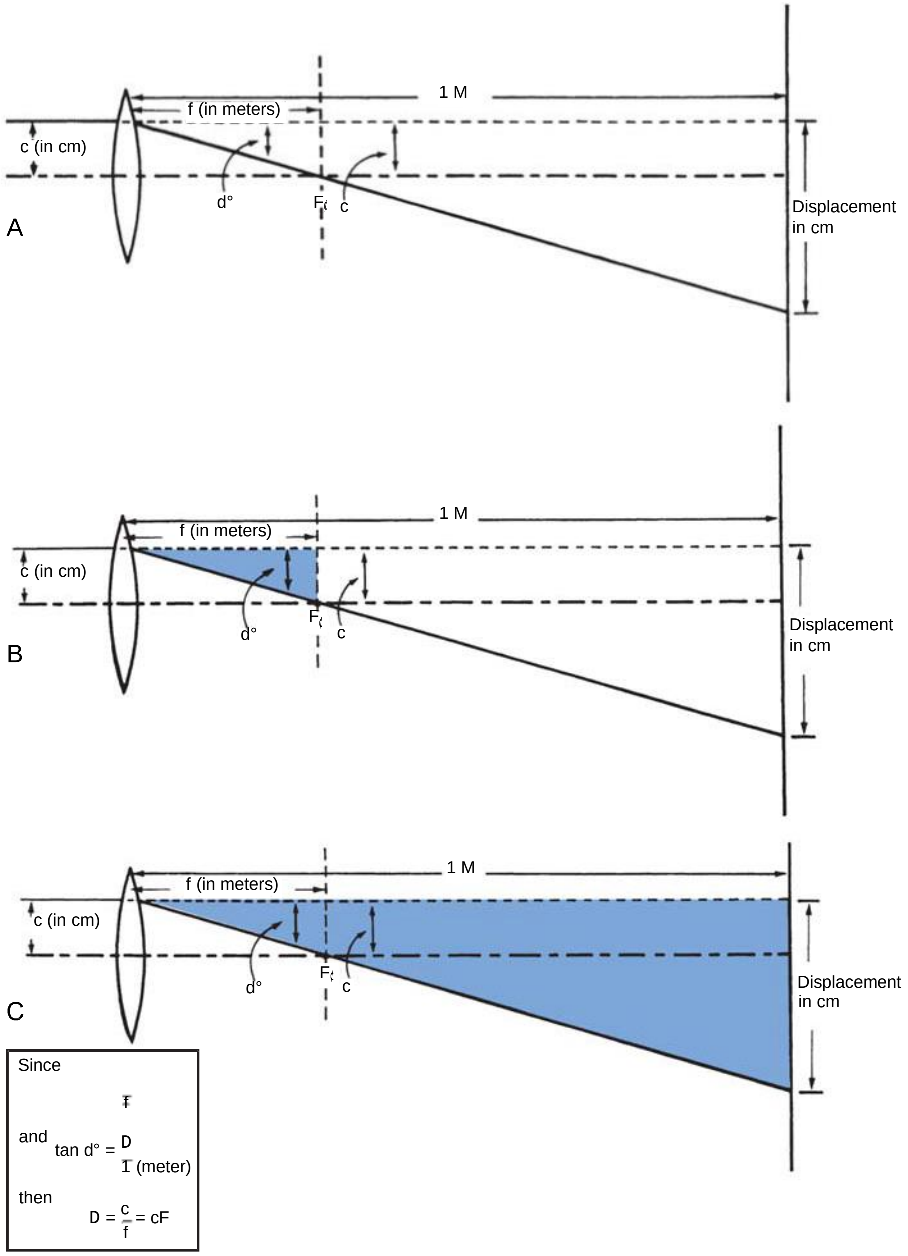


Figure 16-4. A, When a lens is decentered, the geometry of the displaced ray as it travels through the lens focal point may be illustrated as shown. **B,**

Because the deviated ray passes through the focal point, degrees of deviation (d) may be found from the two known parameters (f and c) by using the relationship:

$$\tan dD \; D \; \frac{c}{f}$$

C, Once a value for d is known, it can be seen from the figure how prism value expressed in prism diopters may be established. From this relationship, Prentice’s rule may be derived as shown in the boxed equation at the bottom left of the figure.

Solution

Prentice's rule is used to find the prismatic effect.

D D *cF*

In this instance

D D (0.5)(4.00) D 2.00

(Normally when using Prentice's rule, the absolute value ofthe lens power is used. Plus and minus signs are ignored.) The decentration induces 2.00D of prism. Since the lens is minus in power, the base direction is opposite to that of thedecentration. Therefore the complete answer is 2.00D basedown.

3. A D6.50 D lens before the right eye is decentered 3 mm nasalward. What amount of prism is induced, and what is the base orientation?

Solution

Prentice's rule is again applied as follows:

D D cF
D D (0.3)(6.50) D 1.95.

The lens is plus so the base direction corresponds to the direction of decentration. Since nasalward is inward, the base direction is in. This gives a final answer of 1.95D base in.

4. A D4.00 D sphere lens is ordered for the right eye. The pre-scription also calls for 2D of prism base out before the righteye. How should the lens be decentered to obtain the correctamount of prism?

Solution

This time the missing parameters are the amount and direc- tion of decentration. Amount is found by a simple algebraictransformation of Prentice's rule.

D D *cF*

D

An exceptionally large frame is chosen. The frame is so large that it will not allow the correct interpupillary distance (PD) unless an extra large lens blank is used. Using conventional lens blanks will not allow enough decentration. A gap is created temporally where there is not enough lens material to fill the frame. If the blanks were to be used anyway, the situation would require an incorrect placement of the lenses at a PD of 64 mm. How much prism would be induced and in what direction if this wrong PD is used?

Solution

The problem is shown diagrammatically in Figure 16-5. If the lenses have their OCs 64 mm apart, each lens is erroneously decentered 2 mm outward from the line of sight. It can be seen from the figure that the induced prism is base in (oppo- site the direction of decentration).

Prentice's rule shows that:

D D (0.2)(5.00)
D 1D

The incorrect lens placement was done in order to avoid using large lens blanks. However doing so would cause 1D base in of unwanted prism before each of the two eyes.

Horizontal and Vertical Decentration of Spheres When a sphere lens is decentered both horizontally and vertically, the most straightforward solution for finding the prismatic effect is to consider each component by itself.

5. If a D3.50 D sphere is decentered 4 mm in and 5 mm down, what is the resulting prismatic effect?

Solution

In this situation, the two decentrations may be handled independently.

The horizontal decentration results in:

D D (0.4)(3.50) D 1.40
or 1.40D base in

The vertical decentration gives:

c D
F 2
c D ——
4.00
D 0.5 cm

D D (0.5)(3.50) D 1.75

Because the lens is plus, decentration must also be outward. The lens must be decentered 5 mm out.

6. The following Rx is ordered:

OD: D5.00 D sphere OS: D5.00 D sphere PD D 60 mm

or 1.75D base down

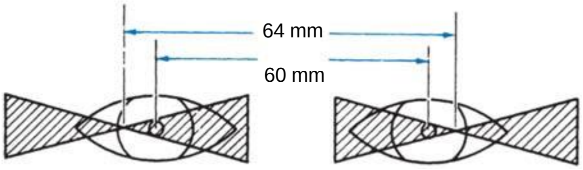
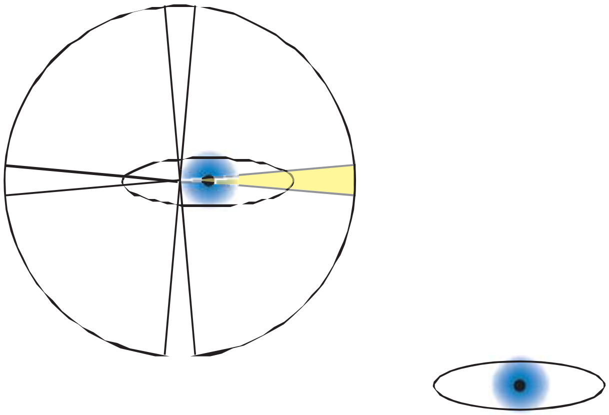


Figure 16-5. For a minus lens, a cross-sectional view suggests two prisms apex to apex. By visualizing the movement of these two prisms before the eyes in decentration, solving for base direction is considerably simplified.

In most cases these results may be left as is. If a single compounded prism is desired,”



7. A right lens of power D7.00 D sphere is decentered 3 mm out and 4 mm up. What are the resulting horizontal and vertical prismatic effects?

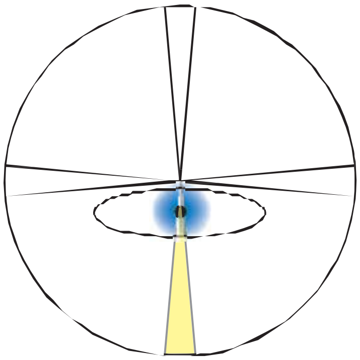
Solution

The horizontal component is:

A

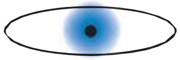
D D (0.3)(7.00) D 2.10

or 2.10D base in



This is shown in Figure 16-6, *A*. The vertical component is:

D D (0.4)(7.00) D 2.80
or 2.80D base down



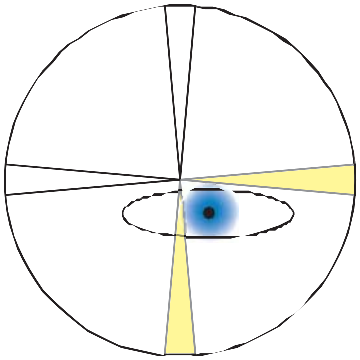
Which is shown in Figure 16-6,

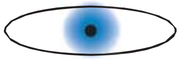
B. The combined decentra-tion is shown in Figure 16-6, *C*.

Oblique Decentration of Spheres

When a sphere lens is decentered in an oblique direction, the resulting prismatic effect and base direction will also be along the same meridian of decentration.

B





8. A right lens of power D7.00 D sphere is decentered 5 mm up and out along the 127-degree meridian. What is the resulting prismatic effect and base direction?

Solution

The prismatic effect for this lens decentration is:

D D (0.5)(7.00) D 3.50 prism diopters

The base direction for a minus lens is exactly opposite the direction of decentration. Therefore the base direction is:

(127) D (180) D 307 degrees

So the resulting prismatic effect and base direction is 3.50D base 307 (Figure 16-7). A 307-degree base direction is base down and in for a right eye.

Notice that the previous two examples are really identical. Decentering a lens 3 mm out and 4 mm up is the same thing as decentering that same lens 5 mm up and out along the 127-degree meridian. If we split 3.50D base 307 into its vertical and horizontal components, we would find it to be 2.10D base in and 2.80D base down. This is because a decentration of 3 mm out and 4 mm

C

Figure 16-6. A, The D7.00 D sphere lens has been decentered 3 mm out, resulting in base-in prism. **B,** The D7.00 D sphere lens has been decentered 4 mm up, producing a base-down prismatic effect. **C,** The combined up and out movements have produced prism base down and in. It may be expressed as two prismatic effects or these two prismatic effects may be combined into one single prism. up is the same decentration as 5 mm up and out along the 127-degree meridian.

Unit 7:

Fresnel Prisms and Lenses

Learning Objective:

At the end of this chapter, students will be able to learn:

1. Different types of prisms.
2. How to use different types and amount of prisms in different prescriptions.
3. What are Fresnel prisms, their uses and advantages over other prisms.

Normal lenses and prisms vary in thickness depending upon the power of the lens or prism and upon the size of the lens or prism. This is not the case with Fresnel lenses and prisms, since they are constructed differently. Though not a replacement for normal lenses, Fresnel lenses and prisms are highly versatile and are very useful in certain specific circumstances.

WHAT IS A FRESNEL PRISM?

A traditional prism has two flat, nonparallel surfaces. Parallel light entering the prism is bent toward the base of the prism and leaves the back surface at an angle. A prism is thicker at the base than at the apex. The larger the prism, the thicker the base of the prism will be.

A *Fresnel prism* attempts to circumvent thickness by building a “tower” of small, wide prisms. To understand how a Fresnel prism works, imagine cutting off the tops of a large number of equally powered prisms and gluing them, one above the other, onto a thin piece of plastic (Figure 17-1). Although a Fresnel prism is molded into one flexible piece, its construction duplicates this imaginary example (Figure 17-2). A Fresnel prism is only 1 mm thick.

What Are the Advantages of a Fresnel Prism? There are several advantages of a Fresnel prism. First, it is very *thin and extremely lightweight*. It is *flexible* and can be applied to an existing spectacle lens, making it *possible to apply the lens in-house,* without an in-house optical laboratory.

Because the lens is made from a soft, flexible material, it *can be cut to any shape* with scissors or a razor blade. This means that it can be cut and applied to one sector of a lens. (Practical applications are explained later.)

Because conventional prisms have a large increase in thickness from apex to base, a high-powered prism is troubled by magnification differences and changes in power across the lens. Although Fresnel lenses do not eliminate this problem, they do *reduce magnification differences* considerably.

What Are the Disadvantages ofa Fresnel Prism?

Fresnel prisms *look different* than conventional lenses. They are different enough that they may be noticed by others. Because Fresnels have a number of small ledges, they are *harder to clean* than conventional lenses.

High-powered prisms will cause a slight decrease in visual acuity. Most of this is due to the chromatic aberration and distortion associated with prisms. This decreased acuity occurs in both conventional and Fresnel prisms. Fresnel prisms also cause a *slight loss of visual acuity caused by reflections* at the prism facets, especially under certain sources of illumination. The minimal acuity decrease through Fresnel prisms may be slightly less than a line on a Snellen chart at a 90% contrast level compared with acuity through conventional prisms.[1]

WHEN ARE FRESNEL PRISMS USED?

There are a variety of clinical applications for Fresnel prism. The following six sections discuss major applications.

High Amounts of Prism

Because of its thickness advantage, Fresnel prism is especially useful for high amounts of prism.

Use and Reuse

Fresnel prism lenses are easy to apply and remove. They may be used and reused. This is helpful when determining how a given prism amount will work long term or for use during visual training.

Sectorial Application

A partially paralyzed extraocular muscle may result in a different amount of prism needed for different directions of gaze. A Fresnel lens can be cut to fit that particular lens area. Prism is present only where it is needed.

For Vertical Imbalance Correction

When a person may require a correction for vertical imbalance, Fresnel prism can be applied to existing lenses to see if a vertical imbalance correction of a certain amount will be helpful before it is actually ordered.

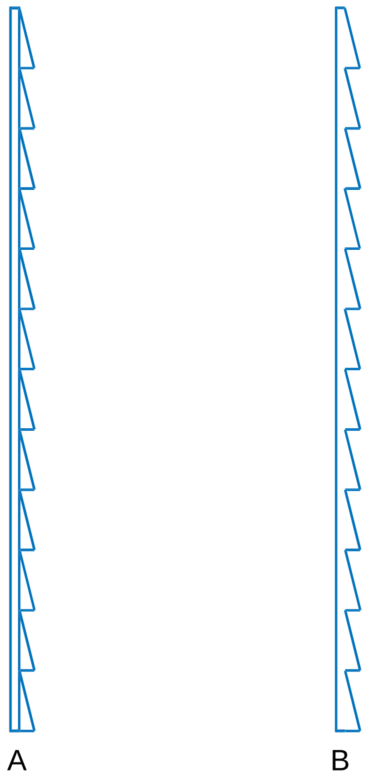


Figure 17-1. A, Fresnel prism is thin because it is really a series of prisms stacked one on top of the other. The concept of individual prisms attached to a thin piece of plastic is shown. **B,** In actuality, the Fresnel prism in molded from one piece of material.

For Horizontal Prism at Near

For a prescription with horizontal prism for near only, it is feasible to use Fresnel prism applied to the lower portion of the lenses only. (For more on horizontal prism at near, see Chapter 19.)

Visual Field Defects

With visual field defects, prism may be applied in one section of the lens with the base direction in the direc- tion of the defect and the edge of the prism close to the central visual area. This way the eye travels only a short distance before it picks up the image through the prism. The image appears closer to the center and can be seen without moving the head.

A person may have a visual field defect where the right half of the visual field is blind for both right and left eyes. The defect is call homonymous hemianopia. Fresnel lenses can be applied to the right side of both lenses. In this instance, prism base direction would be base right. With prism in place, the wearer looks to the right, but does not have to turn the eyes as far to see an object in the right-hand field of view.

If the defect is a constricted visual field down to 5 to 15 degrees of viewing area, prism from 20 to 30 prism diopters could be placed base out on the temporal sides of the lenses and base in on the nasal sides.[2]

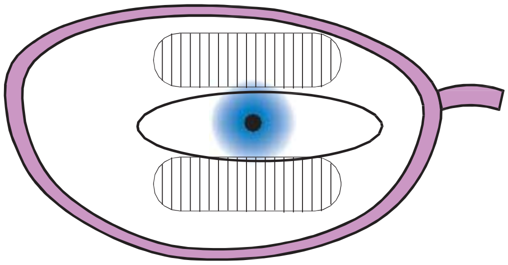
Homonymous Hemianopia Application

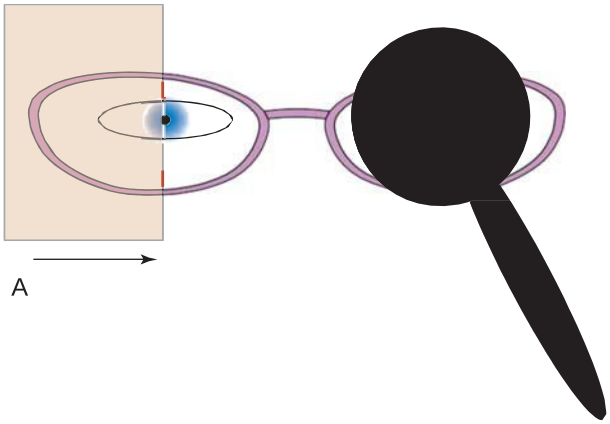
To measure for correct placement of a prism on one half of the spectacle lens in the case of homonymous hemi- anopia, the spectacles, properly adjusted, should be on the subject's face. The subject looks into the viewing eye of the practitioner. The eye with the visual field loss nasally is occluded, usually with a cover paddle. A near- point card or other straight edge is brought in from the temporal, nonseeing side. When the subject first reports seeing the card, the location of the card is marked on the lens with a vertical line (Figure 17-3, A). The edge of the prism is placed 3 to 5 mm temporalward from this position (Figure 17-3, B).[3] The amount of prism may vary. Though others have used Fresnel prism, Lee and Perez used 12 prism diopters of sectorial prism,* but not Fresnel prism, maintaining that Fresnel prism reduced acuity too much.

In the past sectorially applied prism for homonymous hemianopia has been placed on each eye in the blind area. Many practitioners are using only a single sectorially applied prism on the eye with the temporal field defect.

Figure 17-2. A Fresnel lens has a series of slightly visible lines on the surface. These lines are really ledges that indicate the location of the base of the prism. The base direction is at right angles to the direction of the visible lines.

*Slab-off prism may be ground vertically instead of horizontally as is normally done for the correction of vertical imbalance. There are other types of low-vision prism options available.





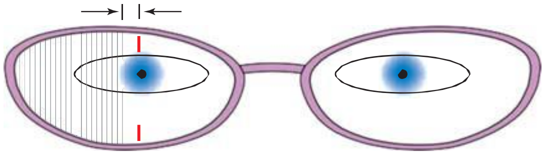


Figure 17-3. A, To position a Fresnel prism for homonymous hemianopia, occlude the eye with the nasal field loss. On the eye with the temporal field loss, move the card from the temporal side until the person first sees the card. Mark the posi- tion of the card. (Marks are shown in red.) **B,** Measure back 3 to 5 mm from this point to find the location of the apical edge of the prism and apply the prism to the temporal portion of the lens.

Eli Peli's High-Powered Prism Segment

Another method of sectorial application of prism for helping the person with homonymous hemianopia places high-powered (30 to 40 D) prism in certain segment areas of the lens Two prism segment areas, with their base-apex axis in the horizontal position, are placed on the lens prescribed for the eye with the visual field loss. The upper one is placed above the pupil in alignment with the upper limbus and the lower one below the pupil in alignment with the lower limbus (Figure 17-4). These prisms are placed base out and create diplopia in that eye. Objects seen through the segment areas are shifted from the nonseeing to the seeing part of the visual field. With adaptation the individual is able to visualize the parts of the objects viewed through the prism in the areas where they would normally be located, expanding the visual field area by up to 20 degrees.

Such prisms may be constructed as a prism segment within the carrier spectacle lenses. The first trials are done with Fresnel prisms cut to the expected dimensions of the finished prism segment areas.

Slowing of Nystagmus

Nystagmus is a condition characterized by a constant back and forth movement of the eyes. Such movement is involuntary and reduces vision. In some cases nystagmus may slow when the person looks to one side or the other. For example, if the examiner sees that movement slows when the person looks to the right, equal amounts of prism may be applied to both lenses. The correct base direction would be base left. Because the eyes turn toward the apex, prism base left will keep the head pointed straight while the eyes turn to the right. Since the eyes are turned to the right, nystagmus slows. For a summary of Fresnel prism uses, see Table 17-1.

WHAT IS A FRESNEL LENS?

Chapter 12 explained how a lens works. Figure 12-20 presented the concept of how a plus lens is like a series of prisms, each more powerful than the one before. The front and back surfaces at the optical center (OC) of a lens are flat. But as the distance from the OC increases, the lens surface becomes more angled.

A Fresnel lens is similar to a series of concentric prisms, each with a slightly higher prismatic effect (Figure 17-5). When the concentric surfaces are angled correctly, a plus or minus sphere of any desired power may be created. Advantages and disadvantages of Fresnel lenses parallel those of Fresnel prisms.

When Are Fresnel Lenses Used?

Nonspectacle Uses

Fresnel lenses are not just used for spectacles. A common application may be found when looking through the writing surface of an overhead projector. (Adjust the focus to be slightly off and see the concentric rings of the lens projected on the screen.)

Large minus Fresnel lenses are sometimes applied to a window to create a wider field of view, or are used for the warning beams of seaside lighthouses so that the illumination projected from the source within the building is increased

Use	**Comments**
High prism amounts	Keeps lens thin
Temporary prism	The practitioner can get an idea of how the prism will work before ordering It is possible to change prism amount without remaking glasses
Sectorial application of prism for palsied muscle	Can apply to half the lens or to any portion of the lens
Visual field defects such as homonymous hemianopia	Place the sectorially applied prism in the blind area Orient the prism base toward the blind area
Prism in bifocal portion only	Can be horizontal and/or vertical prism
Cosmetic improvement of blind, turning eye	Use inverse prism (e.g., if the eye turns out, give base out prism)
Treatment of nystagmus	Used yoked prism to reduce eye movement (e.g., both base left or both base right)
For those who cannot sit up in bed	Use yoked base-down prism of 15D30D (Note: There are also “recumbent spectacles” that are specially made for these purposes)
Use as a partial occluder	Place prescribed prism over the nonamblyopic eye as Fresnel prism to slightly decrease acuity

Figure 17-5. The Fresnel lens shown here is in the original container, but has been turned around so that the rings will be more readily apparent. When worn, the rings will be much less visible than their appearance in the photograph because they will be on the back surface of the Fresnel lens, and the Fresnel lens will be on the back surface of the carrier spectacle lens.

Short-Term Wear

Clinically, Fresnel lenses are useful on a temporary basis, such as during vision training or frequent changes in refraction that may result from unstabilized diabetes or certain postsurgical situations.

Creating Adds

Fresnel lenses can also be applied to one portion of the spectacle lens. High add powers can be created for low-vision or occupational purposes.

Fresnel lenses are available as precut flat-top bifocal segments in powers ranging from D1.00 D to D6.00 D. These segments will also work well in the dispensary to give a realistic simulation of bifocal heights (see Chapter 5, Figure 5-22).

Fresnel lenses or lens segments can be used to create special occupational lenses. For example, if a person has a need for a double D occupational lens, the current bifocal or progressive add lens can be converted to an occupational lens using an upside-down Fresnel bifocal segment at the top. If Fresnel segments are placed on a pair of single-vision sunglasses, it changes them into prescription bifocals.

For a summary of Fresnel lens uses, see Table 17-2.

Use	Comments
To create a thin lens	Fresnel lenses are always thin, regardless of lens power
Temporary lenses	Fresnel lenses can be especially handy during visual training or for unstabilized diabetes when lens powers may need to be changed frequently
Underwater diving masks, swimming goggles, etc.	Application to optical surfaces is easy
Sectorial applications	Plus lenses of normal or high powers can be used as a multifocal add; this add can be used temporarily or permanently for certain unusual occupational needs or for low-vision needs
Trial bifocals	Available in powers from D1.00 to D6.00 D Used for accurate determination of bifocal height, for temporary wear, or for making prescription sunglasses into multifocals

Sample Questions:

1. **How can nystagmus be slow down with the help of special lenses?**

Nystagmus is a condition characterized by a constant back and forth movement of the eyes. Such movement is involuntary and reduces vision. In some cases nystagmus may slow when the person looks to one side or the other. For example, if the examiner sees that movement slows when the person looks to the right, equal amounts of prism may be applied to both lenses. The correct base direction would be base left. Because the eyes turn toward the apex, prism base left will keep the head pointed straight while the eyes turn to the right. Since the eyes are turned to the right, nystagmus slows. For a summary of Fresnel prism uses, see Table 17-1.

2. **When Are Fresnel Lenses Used?**

Nonspectacle Uses

Fresnel lenses are not just used for spectacles. A common application may be found when looking through the writing surface of an overhead projector. (Adjust the focus to be slightly off and see the concentric rings of the lens projected on the screen.)

Large minus Fresnel lenses are sometimes applied to a window to create a wider field of view, or are used for the warning beams of seaside lighthouses so that the illumination projected from the source within the building is increased.

3. How to Apply a Fresnel Lens or Prism to a Spectacle Lens?

Fresnel prisms and lenses are applied using the following steps:

1. For lenses, mark the desired position of the lens OC on the *front* of the carrier lens. (The carrier lens is the spectacle lens already in the eyeglass frame.)

   For prisms determine correct base direction. (In the presence of horizontal and vertical prism, determine what single prism amount and base direction will result from the combination of the two prisms.)
2. Take the carrier lens out of the spectacle frame.
3. Place the Fresnel lens or prism on the *back* of the carrier lens with its smooth side against the carrier. Be sure the OC or base direction is properly oriented.
4. With a razor blade, trim the Fresnel lens or prism flush with the beveled edge of the carrier lens. (It is also possible to use sharp, high-quality scissors.)
5. Remove the Fresnel lens or prism and reinsert the carrier lens into the frame.
6. Wash both carrier and Fresnel lens with a weak solution of lotion-free, liquid detergent.
7. In a bowl of warm water, or under a stream of warm water, apply the smooth side of the Fresnel to the carrier. Work out any air bubbles that may be trapped between the two surfaces.
8. Give the lenses to the wearer, but instruct the wearer to handle with care for 24 hours until drying is complete.

It is possible to substitute rubbing alcohol for water when applying Fresnel lenses and prisms. The lens is said to adhere faster, the bubbles slide out easier, evaporation is faster, and the lens can be dispensed sooner without fear that the Fresnel prism will slide out of place.[5]

Unit 8:

Lens design

Learning Objective:

At the end of this chapter, students will be able to learn:

1. What are different types of lens design.
2. Relationship of lens design with aberrations.
3. Lens designs for high plus lenses and high minus lenses.

A well-designed lens has excellent optics both through the center and the periphery of the lens.

In addition, the lens should be as attractive as possible and easy to wear. This chapter attempts to bring understanding in what to look for in a lens and how to make an appropriate choice of lens design.

A SHORT HISTORY OF LENS DEVELOPMENT

Lenses have gone through several stages of development. To quickly summarize, here are some general categories and time lines.[1] These describe not the theoretical development of the lens, but when these lenses were introduced and available.

1. *"Flat" lenses* (1200 to 1800): Actually the word "flat" is deceiving, since neither side of the lens was flat. Instead the lens was bean shaped, like a lentil—the bean that resembles the shape of a lens. The lenses worked well for central vision, but vision was poor through the edges.
2. *Periscopic lenses* (1800s): An improvement in peripheral vision occurred when a D1.25 D back surface was used.
3. *Six-base meniscus lenses* (Beginning in the 1890s): These lenses improved vision in several ways. The quality of peripheral vision increased markedly. The lenses could also be fit closer to the eye because the vault of the lens cleared the lashes. Six-base lenses were still used up until the 1960s. During the 1950s and 1960s, the use of six-base lenses moved almost entirely to places that were known for low- end pricing. Eventually, companies simply stopped producing these types of lenses.[2]
4. *Corrected curve lenses* (early 1900s): In 1908 the Carl Zeiss Company introduced Punktal lenses that corrected for oblique astigmatism found in the lens periphery. These lenses required a very large number of base curves and became available in the United States in 1913. In 1919 American Optical introduced a corrected curve series of lenses that also corrected for oblique astigmatism, but, unlike the earlier Punktal lenses with a large number of required base curves, the AO lenses were designed with base curves that changed in 1 or 2 diopter

intervals. This made stocking semifinished lenses much more practical. In the 1960s there was a transition time while single vision lenses were being converted from plus cylinder form (with the toric surface on the front) to minus cylinder form to match the back surface torics that were already being used for multifocals.

5. *Aspherics*: Aspherics have been available for very high plus “cataract” style corrections beginning in the early part of the twentieth century. They have been available in lower powered plus and minus single vision lens form during the latter part of the twentieth century, but only began to enjoy more widespread use as higher index plastic lens materials became available.
6. *Atorics*: Atorics are rapidly replacing aspheric lens series for new lines of single vision finished lenses. However, atorics are generally not available in multifocal lenses. The exceptions to this are those progressive lenses that are individually designed and custom produced by free-form generating techniques.

LENS ABERRATIONS

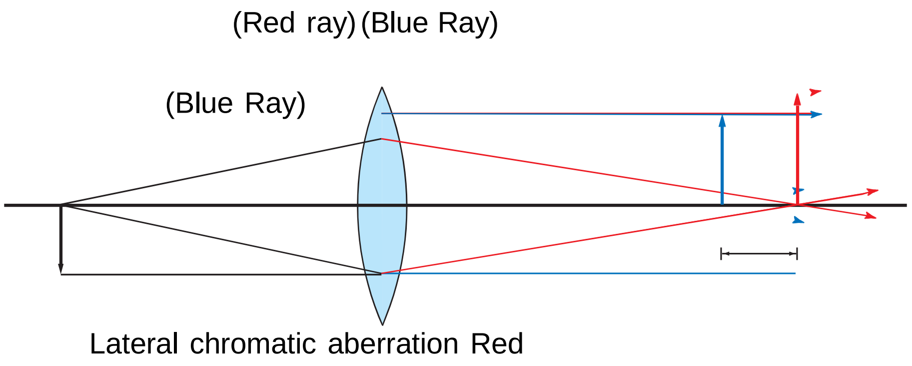
To understand the developments and characteristics of these lens designs, it is necessary to understand what problems the designer is attempting to prevent. Such problems, which cause lenses to deliver less than a perfect image, are known as *aberrations*.

When light from a point source goes through a correctly powered spectacle lens yet fails to create a perfect image, the cause is lens aberration. There are several types of lens aberrations that can contribute to an imperfect image. These aberrations can be grouped into two major types: *chromatic aberration* and *monochromatic aberration*.

Chromatic aberration is color related. It causes an image to have a colored fringe. Monochromatic aberration occurs when the light source contains only one wavelength (one color).

Chromatic Aberration

There are two manifestations of chromatic aberration. One is called *longitudinal chromatic aberration*.



image

Longitudinal chromatic aberration

Figure 18-1. Chromatic aberration has two aspects. One is longitudinal chromatic aberration. This means that light of different wavelengths will focus at different focal distances from the lens. The other aspect is lateral chromatic aberration. Lateral chromatic aberration is shown here and in Figure 18-2.

Longitudinal chromatic aberration occurs when a point light source that is composed of several wavelengths (e.g., white light) forms a series of point images along the optical axis. Each of these images is of a different color, and each has a slightly different focal length.

The second manifestation of chromatic aberration is called *lateral chromatic aberration*. This type of chromatic aberration will produce images of slightly different sizes at the focal length of the lens, depending on the color of the light.

Longitudinal (Axial) Chromatic Aberration

Since each color or wavelength undergoes a slightly different degree of refraction at the same surface curvature, longitudinal chromatic aberration results in a series of foci spread out along the optic axis (Figure 18-1). Thus longitudinal chromatic aberration can be expressed as the dioptric difference between two extremes—blue light (F_F) and red light (F_C). Written as a formula, longitudinal chromatic aberration is:

longitudinal chromatic aberration D F_F D F_C

Longitudinal chromatic aberration is not directly related to prismatic effect. Therefore plano prisms do not have longitudinal chromatic aberration.

Normally, we think of glass or plastic lens material as having one specific index of refraction (n). In actuality lens material has a slightly different index of refraction for each wavelength. The index of refraction we memorize for a given lens material is really the index of refraction for yellow light. Lens materials that are relatively free of chromatic aberration have indices of refraction that are nearly the same for each wavelength. Materials that have a lot of chromatic aberration, such as the glass for crystal chandeliers, have indices of refraction that

Where
F D the power of the lens,
n D the refractive index of the lens (for yellow light), and
R D the curvature of the lens.

(NOTE: R D R_1 D R_2, where R_1 D the curvature of thefirst lens surface and R_2 D the curvature of the second lens surface.)

This means that since:

longitudinal chromatic aberration D F_F D F_C

Refractive Abbé

TABLE 18-1

Abbé Values for Some Representative Lens Materials

Lens Material	Index	Value
Crown Glass	1.523	58
CR–39 Plastic	1.498	58
Corning Photogray Extra (Glass)	1.523	57
Trivex (plastic)	1.532	43-45
Spectralite (plastic)	1.537	47
Corning 1.6 index PGX (glass)	1.600	
Essilor Thin-n-Lite (plastic)	1.74	33
Essilor Stylis (plastic)	1.67	32
Schott High-Lite Glass	1.701	31
Polycarbonate	1.586	30

longitudinal chromatic aberration D $\frac{n_F \ \mathrm{D}\ n_C}{D} F$

The quantity

$\underline{n_F\ \mathrm{D} n_C}$

n_D D 1

n_D D 1

is useful for quantifying chromatic aberration of a given material. It is called the *dispersive power*. Dispersive power is abbreviated as the Greek letter omega, or D. This means that longitudinal chromatic aberration can be written as:

longitudinal chromatic aberration D F_D

The Abbé Value

Because the value for dispersive power ends up as a decimal value, working with it can be unwieldy. It is the longitudinal chromatic aberration for this lens in both crown glass and polycarbonate.

Lateral (or Transverse) Chromatic Aberration and "Chromatic Power"

Lateral chromatic aberration is expressed either as differences in image magnification or differences in prismatic effect.

Magnification Differences With refractive lenses, lateral chromatic aberration is thought of in terms of *magnification differences*. A magnification difference is the difference in size between the images formed by two different wavelengths, such as red and blue (see Figure 18-1).

Differences in Prismatic Effect When quantified by prismatic effect, the lateral chromatic aberration of a prism is the difference in prismatic effect for light of two different wavelengths (Figure 18-2). As a formula this would be expressed:

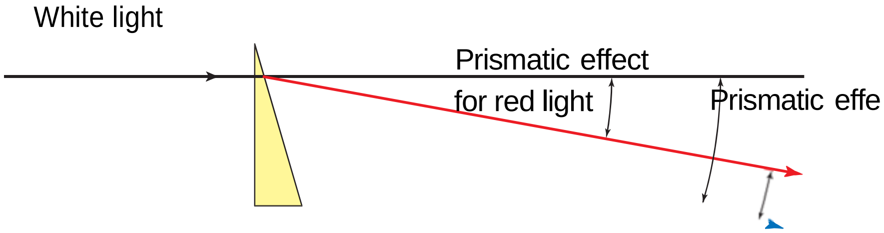


Figure 18-2. Lateral chromatic aberration occurs when a prism bends light of two different wavelengths by different amounts.

lateral chromatic aberration D (prismatic effect

F D F D $\underline{F}$

for blue light) D (prismatic effect for red light)

Solution

For a prism, lateral chromatic aberration is the prism amount (D) divided by the Abbé value (D).

$$\text{lateral chromatic aberration D}\ \frac{\text{D}}{\text{D}}$$

For a certain point on a lens, to find the lateral chromatic aberration, we need to know the prismatic affect at that particular point. For a lens with power, the prismatic effect is the power of the lens times the distance of the decentered point from the optical center, or D D *dF*. This makes the lateral chromatic aberration equal to:

$$\text{lateral chromatic aberration D}\ \frac{dF}{\text{D}}$$

For a point 8 mm from the center of a polycarbonate lens, the lateral chromatic aberration is:

$$\text{lateral chromatic aberration D}\frac{\text{D0.8DD6D}}{(\quad)\text{polycarb}_{30}}$$

D 0.16D

For the same point on a crown glass lens, the lateral chro- matic aberration is:

When Does Chromatic Aberration Reduce Visual Acuity? Suppose a person is wearing a pair of prescrip- tion spectacle lenses and is looking at an object directly through the OCs. When the wearer looks through the OCs, there is no prismatic effect and thus no chromatic power.

As the wearer looks to the right or left, the pris- matic effect of the lenses increases. So does the chromatic power. The more the chromatic power (lateral chromatic aberration) increases, the more the image blurs. There is more prismatic effect in the periph- ery of a high-powered lens than in the periphery of a low-powered one. So peripheral visual acuity drops off faster for high-powered lenses than it does for low- powered ones.

The higher the chromatic aberration, the lower the Abbé value. The lower the Abbé value, the faster the reduction in relative visual acuity peripherally. (This is shown in Figure 18-3.)[3]

Fortunately, the peripheral areas of a lens are seldom used for intensive viewing during normal spec- tacle lens wear. Instead, if something needs to be seen clearly, the head is turned. Otherwise, lens materials with low Abbé values would not be as well tolerated as they are.

lateral chromatic aberrationDcrown glassD

$$D\ \frac{D0.8DD6D}{58}$$

D 0.08D

To reduce the possibility of chromatic aberration becoming troublesome, the dispensing factors shown in Box 18-1 should be considered.

BOX 18-1

Important Dispensing Factors for Lenses With Low Abbé Values (Polycarbonate and Some High-Index Materials)

1. Use monocular interpupillary distances.
2. Measure major reference point heights, considering pantoscopic angle (see Chapter 5).
3. Use shorter vertex distances.
4. Have sufficient pantoscopic angle, but not more than 10 degrees for high lens powers.
5. Give attention to comparative edge thicknesses (OCs that are too high above the horizontal midline of the edged lens will cause large differences in top and bottom edge thicknesses).

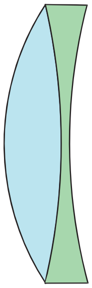


Figure 18-4. An achromatic lens is constructed from two different materials, each with a different refractive index chosen to counteract the effects of chromatic aberration. Achromatic lenses are not used in normal spectacle lenses.

The Monochromatic Aberrations

Aberrations can occur in a lens even when the light entering the lens is only one color. These aberrations, called *monochromatic aberrations* may be more troublesome for cameras or optical systems than for prescription ophthalmic lenses, but are still of definite concern when designing a spectacle lens and evaluating visual performance.

Seidel Aberrations

When rays of light pass through a lens, we expect them to focus at one predictable location. When those rays are paraxial (or central) rays, we can predict the location of focus using the fundamental paraxial equation:*

$$F \text{ D } L\text{D} - L$$

which, written another way is:

$$L\text{D D } L \text{ D } F$$

The fundamental paraxial equation is derived from Snell's law on the basis of an assumption. The assumption is that for small angles (measured in radians instead of degrees) sinD D D. However, a still more accu- rate approximation for sinD is a polynomial series expan- sion given as:

$$D^3 \quad D^5 \quad D^7$$

— — —

of approximation. This third order approximation is used as a basis of comparison when determining the quality of how well a given wave front of light is able to come to a proper focus after passing through a lens, a lens surface or a lens system. In the process of passing through a lens, the wave front may lose some of its spherical shape. This reveals aberration and a resulting imperfect focus.

Using third order terms, Seidel classified aberrations into 5 categories. The 5 are interrelated. Making a lens change to reduce the amount of one aberration can affect the magnitude of other aberrations. These 5 aberrations have become known as the *Seidel or 3rd order aberrations*. (There are other aberrations that will occur when using higher order approximations such as 5th or 7th order.) The 5 Seidel aberrations are *spherical aberration, coma, oblique (radial or marginal) astigmatism, curvature of field (power error)*, and *distortion*. These will be described shortly.

One of the drawbacks of expressing aberration as Seidel aberrations is that all lens surfaces are assumed to be spherical. To better describe aberration for surfaces that may not be spherical, such as the refracting surfaces of the eye, a different system works better.

Classifying Aberrations Using Zernike Polynomials There are other systems for classifying how a given wave front deviates from a perfect sphere when leaving a refracting surface, a lens, or a refracting system. One system that describes aberrations of the human eye uses Zernike polynomials. The use of Zernike polynomials is a more complete representation of the aberrations that could be present in a lens or eye. Furthermore it does not assume spherical surfaces, which Seidel aberrations do. The Zernike system has gained visibility because of an ever increasing interest in aberrations within the human eye. This interest is driven by several factors, including

1. A desire to see into the eye clearly to detect disease-driven changes. The aberrations of the eye degrade the view of retinal elements within the eye. Correcting these aberrations will allow earlier diagnosis of ocular disease.
2. The challenge of refractive surgery. Unfortunately aberrations of the eye are often increased because of

sinD D D D D DD...

3! 5! 7!

The first term represents the paraxial approximation sin D D D. If we use both the 1st and 2nd terms of this equation we are using third order terms for sin D. In other words, instead of saying sin D D D, we say that sin D D D D D^3 (again measured in radians instead of

3!

degrees). This substitution gives us the next higher order

*See the section in Chapter 14 called “Reduced Thickness and Refractive Index.”

refractive surgery. Ideally one would want to not only correct sphere and cylinder refractive errors, but also reduce other aberrations so as to enhance visual performance.

3. A desire to measure ocular aberrations so that they might be corrected. If ocular aberrations can be measured, the next logical step is to figure out a way to correct them. Options will include not only refractive surgery, but also contact lenses or other methods.

As stated earlier, the use of Zernike polynomials has become a popular system to describe and measure ocular monochromatic aberrations. Zernike polynomials use a

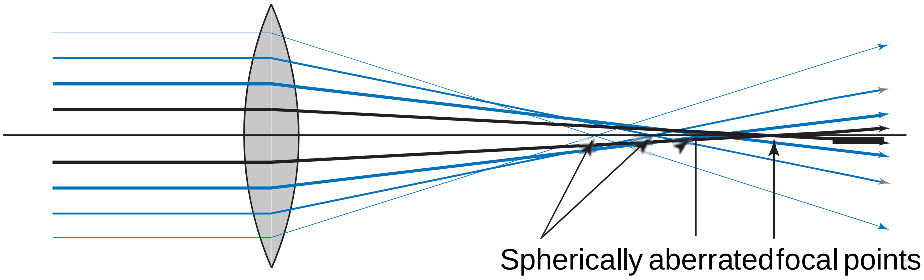


Figure 18-5. This exaggerated depiction shows that when spherical aberration is present, the closer to the edge of the lens the rays are, the shorter their focal length will be. The peripheral rays have an increasingly shorter focal length than the central (paraxial) rays. (This particular form of spherical aberration is positive spherical aberration. There is a form of spherical aberration called negative spherical aberration where the peripheral rays have a longer focal length than the central rays.)

numbered term that describes a geometric shape for the aberration. These terms are grouped into orders. (These orders are not the same as those described in the previous section on Seidel aberrations, although some Zernike terms are similar to certain Seidel terms.) Here are how the Zernike orders describe some of the commonly known aberrations related to the eye.[10]

Order	***Aberration***
1st	Prism
2nd	Defocus and astigmatism (Defocus includes spherical refractive error such as myopia and hyperopia)
3rd	Coma and trefoil
4th	Spherical aberration and other modes
5th to 10th	Higher order irregular aberrations

According to the orders within this classification, second order aberrations are errors which are corrected by the written ophthalmic eyeglass prescription. These “aberrations” of the human eye are corrected using sphere and cylinder lenses. Those aberrations classified as 3rd order and up are referred to as *higher order aberrations*.

The Five Seidel Aberrations

Spherical Aberration

Spherical aberration is a Seidel aberration that occurs when parallel light from an object enters a large area of a spherical lens surface (Figure 18-5). When spherical aberration is present, peripheral rays focus at different points on the optic axis than do paraxial rays. (Peripheral rays are those that enter the lens nearer the edge than the center. Paraxial rays are those that pass through the central area of the lens.)

Spherical aberration occurs when the object point is on the optical axis of the system. All of the other Seidel aberrations occur when the object point is off the optic axis.

Because the pupil of the eye limits the number of rays entering the eye for any given direction of gaze, spherical aberration is not a large problem in ophthalmic lenses.

Coma

The second Seidel aberration is coma. When the object point is off the axis of the lens, there is a difference in magnification for rays passing through different zones of the lens. (Zones could be considered to be imaginary doughnut-shaped rings on the lens, each having a longer radius.) The focal areas of the peripheral "zones" lie in a different location than those of the more central rays. Instead of forming a single point image off the optic axis, the image appears comet or ice cream cone shaped. The point of the cone points toward the optic axis. This aber-ration is known as coma (Figure 18-6).

Oblique Astigmatism

Oblique astigmatism is another Seidel aberration that occurs when rays from an off-axis point pass through the spectacle lens. When a small bundle of light strikes the spherical surface of a lens from an angle, oblique astig- matism causes the light to focus as two line images, known as the tangential and sagittal images, instead of a single point (Figure 18-7). It is as if the light were passing through an astigmatic lens, rather than a spherical lens.

The distance between the two line foci that occurs in oblique astigmatism is called the *astigmatic difference*. When expressed in diopters, this difference is called the *oblique astigmatic error*. Oblique astigmatic error is a measure of oblique astigmatism.

Oblique astigmatism is troublesome for the spectacle lens wearer and must be taken into consideration when designing spectacle lenses. Oblique astigmatism may be reduced by finding the optimum base curve for a given lens power. There is a graph that shows the best lens form(s) for eliminating oblique astigmatism at a particu- lar off-axis viewing angle. This graph is in the shape of an ellipse and is called *Tscherning's ellipse* (Figure 18-8). The size of the ellipse may vary, depending on the viewing distance and angle the lens designer uses when trying to reduce oblique astigmatism.

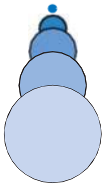


Figure 18-6. Coma is an aberration that causes light from peripheral areas of the lens to be focused farther from the true image point than it should be. Because light farther in the periphery is displaced increasingly farther from the point focus, the image is distorted in cometlike fashion as shown. The drawing is simplified to show the way the image is created. In actuality there are unlimited "circles" of blur that blend together in a flared appearance like the tail of a comet.

There are two synonyms for oblique astigmatism. These are *radial astigmatism* and *marginal astigmatism*.

The Effects of Tilting Lenses

Oblique astigmatism is also manifested when lenses are tilted in front of the eye. This happens because the optic axis of the lens tilts with the lens. The object of regard, which used to be on the optic axis of the lens, now becomes an off-axis object or point. Because the lens is angled in reference to the object of regard, oblique astigmatism will affect the image of that point. Before the tilt, the object, located on the optic axis, formed a single-point image based on the actual spherical power of the lens. With tilt the image is now formed as if it were refracted through a new sphere and cylinder.

The new sphere and cylinder powers manifested through the "old" tilted lens can be determined by first finding the effective powers in the sagittal and tangential meridians of the lens.[4] It turns out that the sagittal

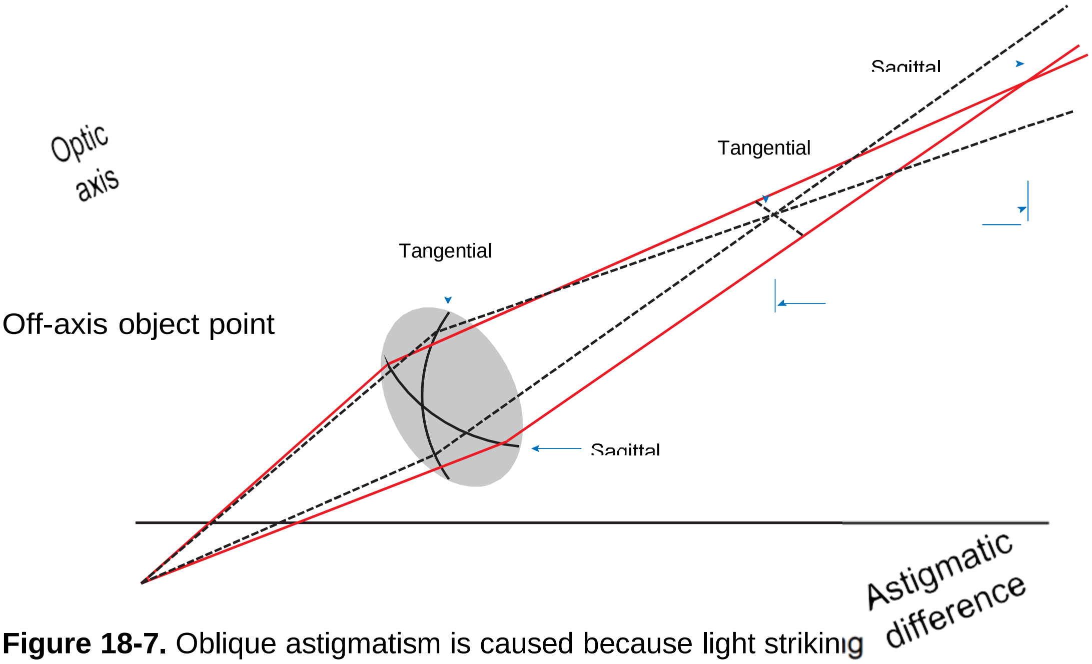


Figure 18-7. Oblique astigmatism is caused because light striking the lens in the tangential plane focuses at one line focus, whereas light striking the lens in the sagittal plane focuses at another line focus. (The tangential plane of the lens is the plane that intersects the optic axis and the off-axis object point. The sagittal plane is 90 degrees away from the tangential plane.)

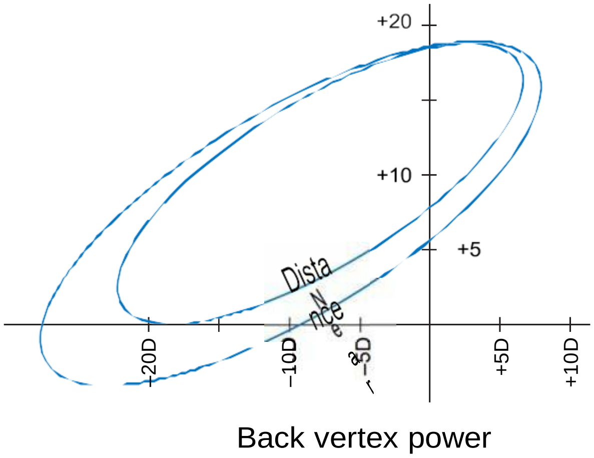


Figure 18-8. A Tscherning's ellipse graphically shows the base curves needed to correct for oblique astigmatism. There is a different ellipse for each viewing distance. (From Keating MP: Geometric, physical and visual optics. Boston, 1988, Butterworth-Heinemann.)

meridian coincides with the axis of lens tilt. For a pantoscopic tilt, the axis of tilt is along the horizontal or 180-degree meridian, and so the horizontal meridian is the sagittal meridian. For a face-form tilt, the axis of tilt is along the vertical or 90-degree meridian, and so the vertical meridian is the sagittal meridian. (The tangen- tial meridian is perpendicular to the sagittal meridian, as shown in Figure 18-7.)

The effective power in the sagittal meridian is:

$$D \quad \sin^2 D\, D$$

where

F D the power of the lens being tilted (i.e., the "old" lens) and
D D the angle of tilt.

The sign (D or D) of the induced cylinder is the same as the sign of the tilted lens. The axis of the induced cylinder is the same as the axis of tilt. Finding the induced cylinder with this equation is not as accurate as finding the difference between tangential and sagittal powers.

Wrap-Around Prescription Lenses Wrap-around prescription eyewear presents unique optical problems that can require compensating power changes in lens powers to keep the optical effect of the prescription as intended. Here are some examples of what can happen optically to a prescription placed in a wrap-around frame.

Tilting of Spherocylinders When tilted, a spherocy- lindrical lens also has induced power changes. For either pantoscopic or face-form tilt of a spherocylinder lens with axis 90 or 180, the tilted spherocylindrical lens acts similar to a spherocylinder with a new sphere power and a new cylinder power. The principal meridians of the “old” (or untilted) lens are horizontal and vertical. The lens power chosen to calculate the effective sagittal power (F_S) is the power of the spherocylinder in the sagittal meridian. The lens power chosen to calculate the effective tangential power (F_T) is the power of the spherocylinder in the tangential meridian.

After calculating the new powers, one can then put them on a horizontal and vertical power cross and from it determine the new (or effective) spherocylindrical parameters (sphere, cylinder, *and* axis) in the usual manner.

For pantoscopic or face-form tilt of a spherocylindri- cal lens with an oblique axis, there is an effective change in cylinder axis and an effective change in the sphere and cylinder powers. Here the computations are more com- plicated and require resultant calculations combining obliquely crossed cylinders. It is also feasible to work backwards as we did above to find what prescription must be placed in a wrap-around frame to prevent unwanted

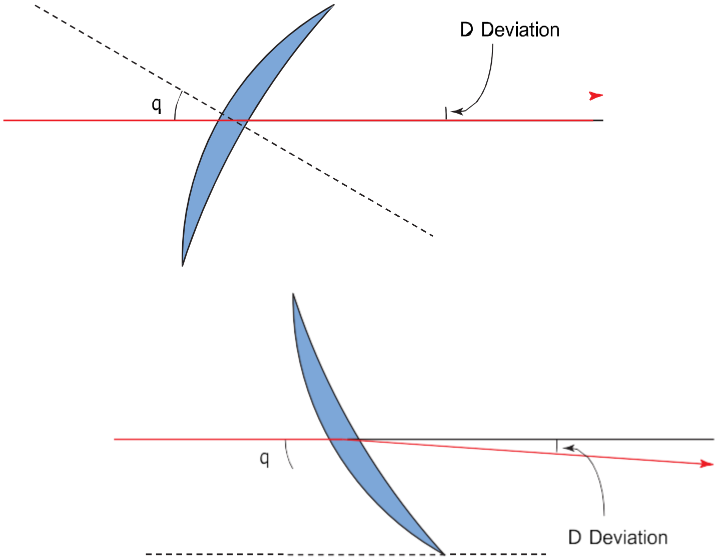


Figure 18-9. Lens tilt will cause a slight amount of prismatic effect. The amount of prism deviation is equal to

$D\ D\ 100\ \tan D\ \frac{t}{}F$.

power changes. For an explanation of how this may be done, see Keating MP: Geometric, Physical, and Visual Optics.

$n\ 1$

Induced Prism with Wrap-Around Eyewear There are also induced prismatic effects associated with tilting lenses. To see how this works, take a lens prescription and center the optics in a lensmeter with the prescription correctly neutralized. Then tilt the prescription to simulate a wrap-around effect. The prism that appears is a result of that lens tilt.

This prismatic effect depends on the angle of tilt, the steepness of the base curve, the index of the material, and the thickness of the lens. It is predictable using the equation

$$D\ D\ 100\ \tan D\ \frac{t}{}F$$

$$n\ 1$$

Where

D D the prism induced
D D the angle of tilt
t D the thickness of the lens at the reference pointin meters
n D lens refractive index
F_1 D the front curve of the lens

Notice that the refractive power of the lens does not enter into this equation for prismatic effect, only front curve lens power.

The base direction of the prism induced is deter- mined by the angle at which the light enters the lens. If

In this figure D is the angle between the optic axis and the incoming central ray.the light enters the lens from above the optic axis, the orientation of the prism will be base down. If the light enters the lens from the left of the lens, then the base of the induced prism is to the right.

For lenses with pantoscopic tilt, the bottom of the lens is tilted in toward the face. Light coming from straight ahead strikes the lens as if it were entering from above. Therefore the prism induced is base down. Since the induced prism is base down for both right and left lenses, there is a net prismatic effect of zero. Both lenses cause the image to move up by basically the same amount so no compensation would be required.

For wrap-around lenses, the right lens is tilted such that light coming into the lens from in front of the wearer is striking the lens as if it were coming from the left (Figure 18-9). Therefore the prism base direction is base right. For the right eye, base right is the same as base out. For the left eye, the base direction will be base left, which is also base out. With both eyes having base out prism, the eyes must turn slightly inward to retain a single image of the object viewed. To compensate for induced base out prism, base-in prism would need to be used. This is true even for wrap-around lenses that have no power when made with a curved lens. However, if the front of the lens is flat, then the prismatic effect drops to zero.

Intentionally Tilting a Lens to Prevent Problems Earlier lens tilt examples present situations where the wearer's interpupillary distance and the frame A D DBL dimensions are the same. In other words, there is no necessity for decentration. Yet most prescriptions do require at least a small amount of decentration inward since the wearer's PD is generally smaller than the frame's A D DBL measurements.

If a prescription *does* require some decentration inward, then the frame front *should* have a certain amount of face form. A lens with decentration inward and no face form will end up having tilt at the optical center. This is explained in more detail in Chapter 5. (Note especially Figures 5-2, 5-3, and 5-4.) Decentration that is compensated for with a certain amount of face form will actually *prevent* the decentered lens from being tilted at the OC. However, adding more face form than the needed amount will end up causing those unintended sphere and cylinder power errors that have been just described.

Curvature of Field (Power Error)

If a designer makes a lens that is completely free of oblique astigmatism, there will still be another aberration the wearer encounters when looking through the periphery of the lens. This fourth of Seidel's five aberrations is called *curvature of field* or *power error*. Power

sphere is curved because the eye turns to see objects toward the periphery of the lens.) Instead it focuses on the Petzval surface. The Petzval surface is formed when oblique astigmatism is corrected. Another name for the Petzval surface is the image sphere.

error is the most descriptive term because this aberration causes the spherical component of the lens to have the effect of being off-power in the periphery when worn (Figure 18-10). (The dioptric difference between the place where the image actually focuses and where it should focus is called the *image shell error*.)

It is important to use the manufacturer's recommended base curve for each given lens power. The optimum base curve will ensure that oblique astigmatism and power error are held to a minimum. When using the wrong base curve, the wearer will not be able to see as well through the periphery of the lens.

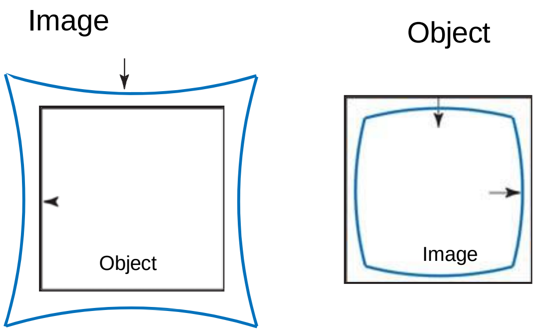
Distortion

The last of the five Seidel aberrations is distortion. *Distortion* occurs because there is a different magnification at different areas of the periphery of the lens in pro- portion to the distance of those areas from the OC of the lens. For plus lenses, magnification increases pro- portionately toward the periphery, whereas in minus lenses, the magnification decreases proportionately. When looking at the center of a square window through a high plus lens, the corners of the window are farther away from the center of the lens than the middle of the sides (or the middle of the top and bottom). This means the corners will be magnified more, making the window look like a pincushion (Figure 18-11). This is known as *pincushion distortion*.

For minus lenses, the corners would receive less mag- nification than the middle of the sides, causing *barrel distortion*.

Spectacle Lens Design

As noted previously, some aberrations are more im- portant than others when designing spectacle lenses. To summarize:



the only practical variables left to work with are front and back surface powers.

The Importance of Using the Correct Base Curve for Surfaced Lenses

When a laboratory receives a single vision series of finished lenses, the base curve of the lens is set. When the lens is removed from the package, the only choices left are related to lens edging. When a lens has to be surfaced, however, the laboratory looks at the desired

Pincushion distortion (Usually occurs with plus lenses)

Barrel distortion (Usually occurs with minus lenses)

lens power and chooses a lens blank with a front (base) curve appropriate for that particular power. Lens design- ers have already recommended certain base curves for

Figure 18-11. Magnification occurs with plus lenses and minification with minus lenses. However, the magnification is not even across the lens. This results in the types of distortion of the magnified or minified images shown here.

- Chromatic aberration is important when considering possible high-index materials to use for spectacle lenses or when choosing the fused multifocal segment of a glass spectacle lens.
- Because of pupil size, the Seidel aberrations of spherical aberration and coma are less problematic.
- The three Seidel aberrations proving to be most troublesome in ophthalmic lenses are oblique astigmatism, power error, and distortion.

Looking at design possibilities simplistically, there are three possibilities:

1. A lens designer can correct the oblique astigmatism completely, leaving the power error uncorrected. A lens designed in this fashion is referred to as a *point focal lens*.
2. A designer can concentrate on eliminating power error, but choose to leave residual astigmatism uncorrected. This type of lens is referred to as a *Percival form lens*.
3. A designer can design a lens referred to as a *minimum tangential error form* that is a compromise between the first two choices. At this point in time, designing a lens that is strictly a “point focal” or a “Percival” form lens is not likely. A lens which compromises between the two forms is common practice.

It should be noted that all three of the above choices are referred to either as *corrected curve* or *best form* lenses.

Four Variables of Lens Design

There are four variables the designer can use to arrive at the best form for an individual lens of a specific power. These four are:

1. Vertex distance
2. Lens thickness
3. Refractive index
4. Front and back lens surface powers

For a single vision series of lenses, the first three variables must be decided for the whole series. Therefore

specific lens powers so the laboratory usually tries to remain within those guidelines.

Failure to select the correct base curve for a given lens power will not affect the quality of vision a person has through the center of the lens. It will reduce the quality of vision through the periphery of the lens, however.

By using the correct base curve, the most troublesome monochromatic aberrations can be reduced. By looking at Tscherning’s ellipse (see Figure 18-8), we see that it is possible to completely correct for oblique astigmatism* for sphere powers ranging from approximately D7.00 D to D23.00 D. For powers outside of this range, there is no spherical base curve that will eliminate oblique astigmatism. There is another option, however. That option is to use an aspheric lens.

The Tscherning's ellipse also shows that there are really two base curves that correct for oblique astigmatism. The lower half of the ellipse corresponds to the lenses that are customarily used today.

APPROPRIATE BASE CURVES

It is possible to create the same power using an almost infinite variety of lens forms. A lens with a front curve of D2.00 D and a back curve of D6.00 D will produce virtually the same power that a lens with a D3.00 D front curve and a D7.00 D back curve will produce. If many lens forms produce the same power, is there a particular front curve that should be chosen for a given lens power?

Although there is a range of possible lens forms that will prove acceptable, there are limits beyond which the overall results will be poor. If an incorrect base curve is selected, the quality of vision is acceptable while looking straight ahead. But vision will be degraded when turning the eyes to view an object off to the side. This effect is due to lens aberrations brought about by an incorrect lens form.

*The phrase "completely correct for oblique astigmatism" means that for one viewing distance at one oblique viewing angle, oblique astigmatism can be eliminated. At other viewing angles and distances, oblique astigmatism will be considerably reduced, but not entirely eliminated.

Manufacturers' Recommendations

Lens manufacturers recommend specific base curves for each lens power. These recommendations list the range of powers and tell which base should be used for those powers.

A General Guideline

The power of a lens determines its shape.

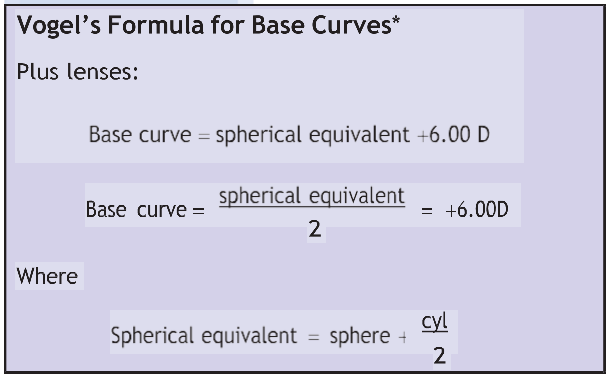
- Plano lens powers usually have back surface curves close to D6.00 D.
- As lens power becomes more minus, the back surface steepens, and the front surface flattens.
- As plus lens power increases, the back surface becomes progressively flatter, while the front curve becomes steeper.

From the front, minus lenses look flatter, and plus lenses look steeper.

Base Curve Formulas

One method for estimating the range in which an appropriate base curve might be found is to use a simplified formula derived from precalculated base curves. Such a formula is not a replacement for manufacturers' recommendations. One such formula is *Vogel's formula,*[7] which states that, for plus lenses, the base curve of the lens equals the spherical equivalent of the lens power plus 6 diopters. Written as a formula this is:

BOX 18-2



Vogel's Formula for Base Curves*

Plus lenses:

$$\text{Base curve} = \text{spherical equivalent} + 6.00\text{ D}$$

$$\text{Base curve} = \frac{\text{spherical equivalent}}{2} = +6.00\text{D}$$

Where

$$\text{Spherical equivalent} = \text{sphere} + \frac{\text{cyl}}{2}$$

*Note: These base curves are estimates for glass and low index plastic lenses and will estimate a somewhat higher base curve for plus lenses. They are for general reference purposes and should not be used for actual lens production.

Considering Right and Left Lenses As a Pair

Up to this point, we have only been choosing the base curve on the basis of the power of one individual lens. This works fine as long as both left and right lenses have exactly the same power. But if the powers are different in the left and right eyes, one lens might call for one base curve, whereas the other lens requires a different curve. This could be problematic in certain instances.

Consider for instance, the situation where one lens in a pair has a power that is only 0.50 D stronger than that of the other. Yet when looking at manufacturer's recom- mendations for each lens, the right and left base curve powers straddle two available base curves. (Lens blanks come in power jumps, such as 2, 4, 6, etc.) One lens calls for a D6.00 base, whereas the other calls for a D8.00. If the lenses were chosen with two different base curves, there would be both a visible difference in the appear- ance of the two lenses and a difference in magnification created between the images seen by the right and left eyes. Therefore a decision needs to be made to modify the base curve(s).

Because an error in base curve selection is worse for high-powered lenses than for lenses closer to zero power, from an *optical* standpoint, the higher powered lens would drive the choice.

This would mean that:

1. In instances *where both lenses are plus,* the steeper base curve (higher numerical base curve) of the two would be the correct optical choice. From a cosmetic standpoint, this choice may not always be followed.
2. *If both lenses are minus,* the flatter base curve of the two should be chosen.
3. *If one lens is plus and one lens is minus,* again, from an optical standpoint the base curve for the lens with the highest numerical value should be chosen.

It is usually advisable to maintain individual lens base curve choices when the difference between the right and left base curves is greater than 2 diopters. A correctly chosen base curve will produce clear vision, regardless of whether the wearer is looking through the center or off toward the edges. If the recommended base curve is changed too much, vision in the periphery of the lens will be poor. (Aniseikonia considerations may also influence base curve choice. For more on Aniseikonia and base curve, see Chapter 21.)

Other Factors That Modify Base Curve Choice Most *metal frame* eyewires are curved to best accept a lens with a six-base curve since this is the most common base curve. For this reason, prescriptions that would normally have steeper base curves may have those curves flattened somewhat so that the lenses will stay in the frame better. (Instead of flattening the lens, a better choice would be to use an aspheric lens. Aspherics can be made on a flatter base curve without degrading optical quality.)

Plastic frame styles that have a poor lens retention record may retain their lenses better if the lenses have flatter base curves.

Prescriptions with *large amounts of prism* end up being thicker. Lens thickness increases lens magnification and makes the eye look larger. This is especially true for plus lenses. Much of this magnification comes from a steep front curve. This means that magnification may be reduced by using a flatter base curve. As an added benefit, large prisms are easier to work with when produced on a somewhat lower base curve.

ASPHERICS

What Is an Aspheric Lens?

The term *aspheric* means “not spherical.” The degree of curvature of a spheric lens is continuously uniform with a consistent radius of curvature throughout its entire surface, like that of a ball or sphere. An aspheric lens surface changes shape. It does not have the same radius of curvature over the entire surface. Aspherics are, generally speaking, based on a surface curvature that comes from a conic section. A conic section is a slice through a cone. There are 4 basic types of conic sections (Figure 18-12). These are:

1. *A circle:* A circle is the shape formed by a horizontal plane, or slice through an upright cone.
2. *An ellipse:* An ellipse is a shape formed by an angled plane through a cone that does not intersect the base of the cone.
3. *A parabola:* A parabola is a curve that is formed by the intersection of a cone with a plane having one side parallel to the side of the cone.
4. *A hyperbola:* A hyperbola is a shape formed when a cone is intersected by a plane that makes a greater angle with the base of the cone than the side of the cone makes with its base.

When these shapes are used as the shape for the front of a lens, they compare as shown in Figure 18-13.

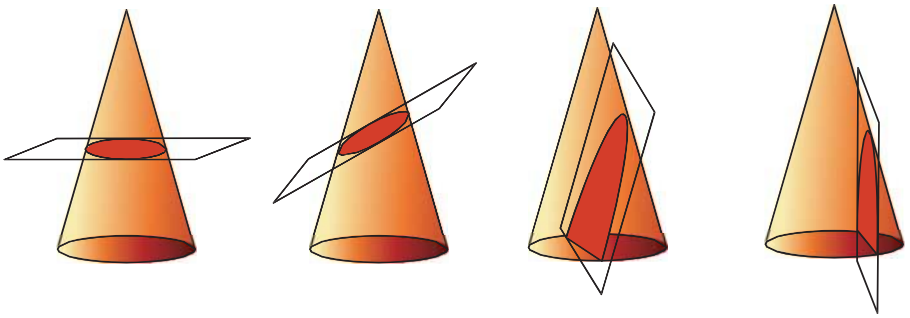
The type of asphericity used on a lens surface is often classified by “*p*-values.”

P-values refer to the value p in the equation[8]:

$$y^2 \text{ D } 2r_O x \text{ D } px^2$$

This equation describes the conic sections referred to previously. The r_o value is the radius of curvature at the vertex of the conic section. Knowing the *p* value will differentiate the conic sections from each other, as shown in Box 18-3.

These were shown in Figure 18-13. Thus knowing the “p-value” of an aspheric surface helps to under- stand which type of asphericity is being used and how far the surface departs from a circular or spherical shape. For example, a surface having a p-value of D3.0 is a hyperbolic surface. This surface departs further from a spherical shape than one having a value of D0.5.



Circle Ellipse Parabola Hyperbola

Figure 18-12. Conic sections create the curves that are often used for lens surfaces. The circle is used for spherically based lenses. The ellipse, parabola, and hyperbola are used for aspheric surfaces.

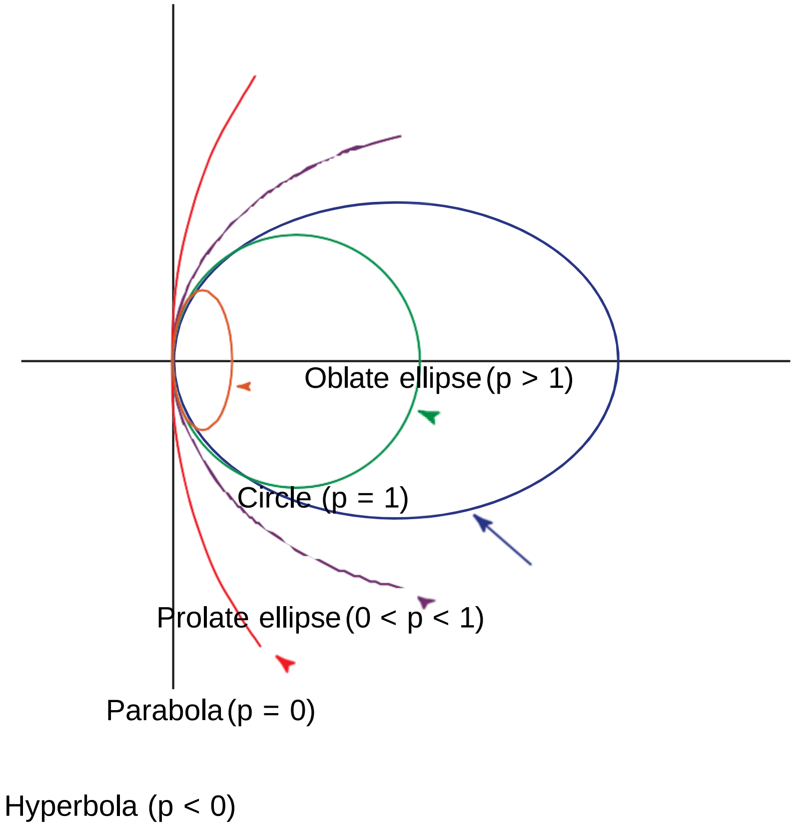


Figure 18-13. This figure shows how geometric conic sections could be used on front or back lens surfaces to produce different types of asphericity. The type of asphericity used on a surface may be classified by “*p*-values.” *P*-values refer to the value p in the equation and describe the varying shaped conic sections referred to in Figure 18D12. Using a different approach it is also possible to classify asphericity by “Q-values,” with Q being a measure of conicoid asphericity. Using Q-values, a circle has a value of zero compared with this system in which a circle is classified with a p-value of 1. (From Jalie M: Ophthalmic lenses & dispensing, ed 2, Boston, 2003, Butterworth-Heinemann.)

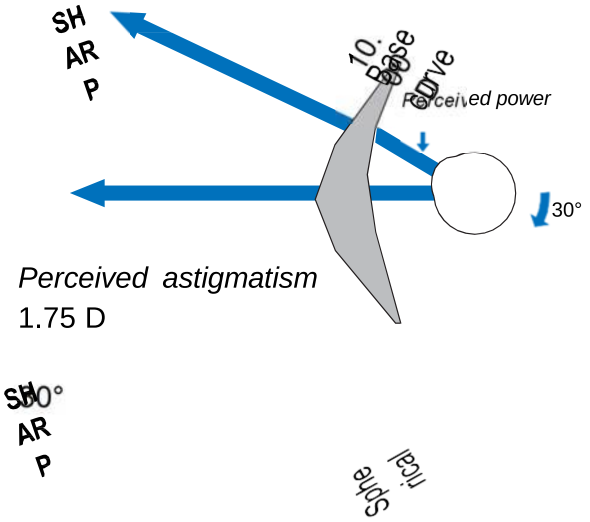
BOX 18-3

p-Values for Aspheric Surface Shapes

If the p-value is:		Then the type of aspheric surface will be:
p > 1	(p is greater than 1)	Oblate ellipse (The long axis of the ellipse is vertical)
		Circle
p = 1	(p is equal to 1)	Prolate ellipse (The long axis of the ellipse is horizontal)
p = 0		

One having a p-value of D0.50 is a prolate elliptical surface.

Aspheric surfaces have a changing radius of curvature and thus a varying amount of surface astigmatism everywhere except at the center of the lens surface. This means that it is possible to select a specific type of aspheric surface that will neutralize unwanted oblique astigmatism. For example, suppose we want to use a lens that has a considerably flatter base curve than normal. Just flattening the base curve on a spherically based lens will mean increased oblique astigmatism resulting in poor peripheral optics. Yet this flatter base can be used successfully if a type of aspheric surface that has a matching



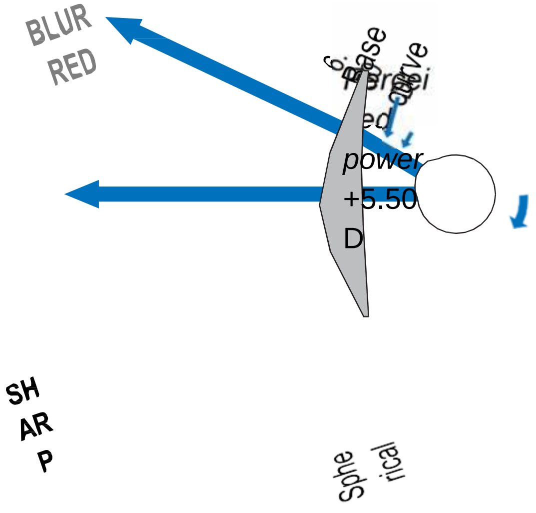


Figure 18-14. The normal base curve for a plano lens is D6.00 D. The D10.00 D front surface of this D5.00 D lens looks considerably steeper and causes more magnification. However, this spherical corrected curve lens will give sharp vision both centrally and peripherally. (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word!, Oldsmar, Fla, November, 1993, Varilux Press. Figure 1A. Courtesy Varilux Corp.)

Figure 18-15. Flattening a D5.00 D lens from a D10.00 D spherical base curve lens back to a D6.50 makes it look more like a low-powered plus lens. With this flat curve, it is no longer optically sound. Even though the center may produce 20/20 vision, the periphery suffers from both power error and oblique astigmatism. (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word!, Oldsmar, Fla, November, 1993, Varilux Press. Figure 1B. Courtesy Varilux Corp.)

but counterbalancing amount of surface astigmatism is chosen.

Purposes for Using an Aspheric Design

There are at least five good reasons for producing a lens that has an aspheric surface.

1. The first reason is to be able to optically correct lens aberrations.
2. The second reason is to allow the lens to be made flatter, thereby reducing magnification and making it more attractive.
3. The third reason is to produce a thinner, lighter weight lens.
4. A fourth reason may be to ensure a good, tight fit in the frame.
5. The fifth reason is to make a lens with progressive optics.

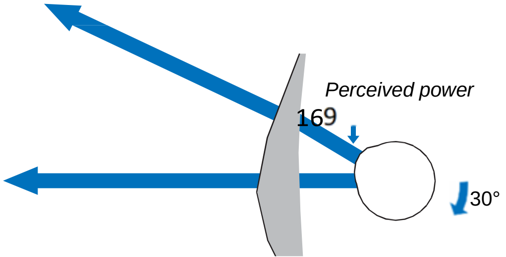
Asphericity for Optical Purposes

As stated earlier, for most powers, it is possible to produce a lens that is optically sound using regular, spherical surfaces. Once lens powers go beyond the D7.00 D to D23.00 D range, however, it is necessary to use an aspheric design.

In the middle, an aspheric lens surface starts out as any other spherical surface. Then at a certain distance from the OC, the lens surface gradually changes its curvature at a rate calculated to offset peripheral aberrations. (This concept will be discussed in greater depth in the section on high plus lenses later in the chapter.)

Asphericity for Flattening Purposes

For lenses with spherical base curves, higher plus power always results in steeper base curves (Figure 18-14). Unfortunately, for high plus lenses the steeper the base curve, the worse the lenses look. Choosing a flatter base



Asp
heri
c

Figure 18-16. Properly using aspherics, it is possible to flatten a lens and still overcome peripheral aberrations. Here, this D5.00 D lens has been flattened to have a D6.50 front curve, yet because the front curve is aspheric, vision remains clear in the periphery. (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word! Oldsmar, Fla, November 1993, Varilux Press. Figure 1C. Courtesy Varilux Corp.)

curve will make the lens look less bulbous and also reduce magnification. Cosmetically the lens looks much better. It even looks considerably thinner than before, although in reality it is only slightly thinner. Because flat base curves reduce magnification, the wearer's eyes do not look as big.

Unfortunately, just flattening a regular lens results in bad optics. In the periphery, the sphere power will be off (because of power error), and there will be unwanted cylinder (because of oblique astigmatism) (Figure 18-15).

If the flattened lens surface is aspheric, it is possible to get both good cosmetics and good optics (Figure 18- 16). Such a lens may even change the degree of aspheric- ity when approaching the edge of the lens to further flatten the lens.

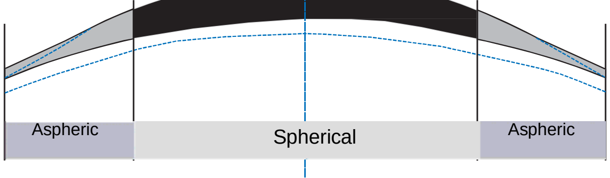
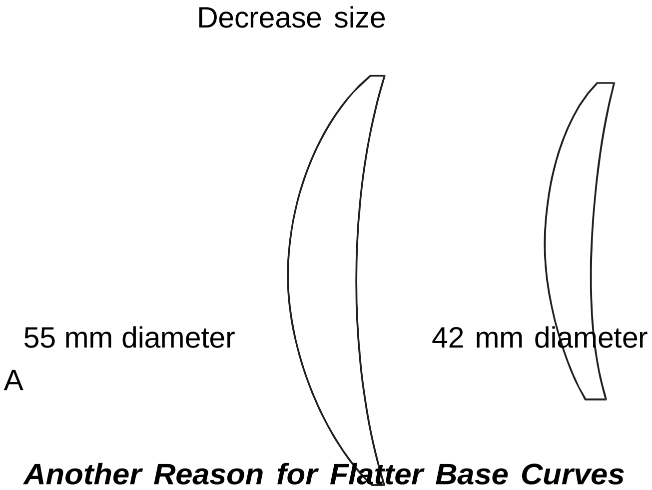


Figure 18-17. When using asphericity for the purpose of thinning a plus lens, the front surface is flattened to give the edge more thickness. For a plus lens, center thickness is limited by edge thickness. If edge thickness can be added with asphericity, then the whole lens can be thinned, and center thickness will be reduced. (Dotted lines show the shape of the unthinned, spherical lens.) (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word! Oldsmar, Fla, November 1993, Varilux Press. Figure 2A. Courtesy Varilux Corp.)



Another Reason for Flatter Base Curves

The steeper the base curve, the easier it is to dislodge the lens from a metal frame. So it is not unusual for a laboratory to flatten a base curve to make it fit more securely in the frame. Yet rather than flattening a regular lens, a better option is to use a flatter, aspherically designed lens.

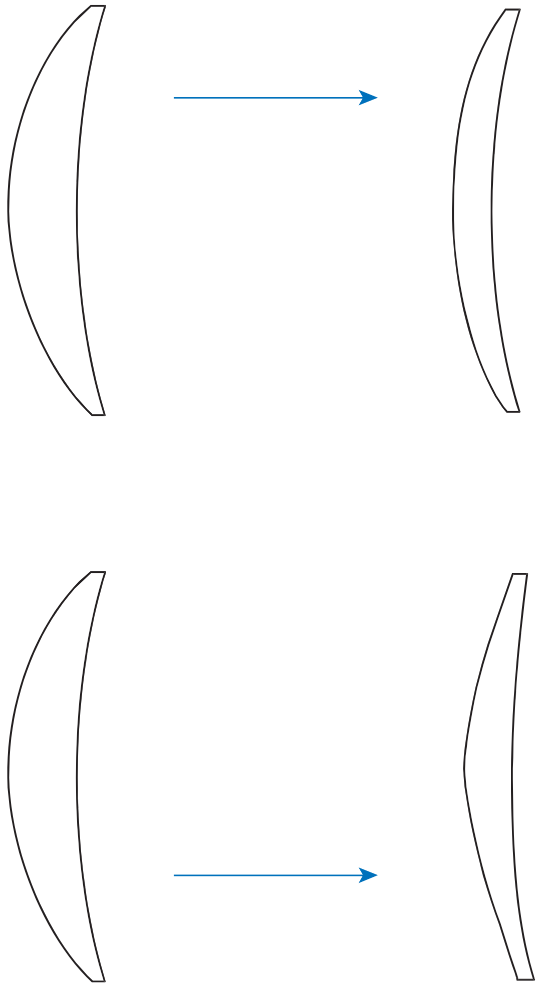
Asphericity for Thinning Purposes (Geometric Asphericity)

Asphericity can be engineered with the express purpose of making the lens thinner. To do this for plus lenses, the lens front and back surface are flattened quite a bit toward the edge. Flattening the periphery makes it pos- sible to grind the whole lens thinner (Figure 18-17). Of course there are several aspects for thinning lenses, often combined with one another. Figure 18-18 shows how lens thickness responds to a decrease in lens diam- eter, an increase in lens index, and a change to an aspheric design.

To thin minus lenses, either the peripheral portion of the lens front surface is steepened, or the peripheral portion of the back surface is flattened toward the periphery, or both. This reduces edge thickness (Figure 18-19).

To Ensure a Good, Tight Fit in the Frame

Most frames are made to best hold a lens with around a 6 D base curve. Using ordinary methods for edging lenses, the steeper the base curve is, the harder it is to keep the lens tight in the frame. Since a lens can be made closer to a 6 D base curve in an aspheric design without



Increase index

1.5 index 1.7 index

B

Change to aspheric

compromising peripheral vision, an aspheric design will help in ensuring that the lens stays in the frame.

1.5 index

spherically based

C

1.5 index

aspheric

Asphericity for Producing Progressive Power Changes By definition, any lens surface that is not spheric is aspheric. Progressive addition lenses achieve their add

Figure 18-18. A plus lens may be thinned by decreasing the overall diameter of the lens **(A)**, increasing the refractive index of the lens **(B)**, and changing from a spherical surface to an aspheric surface **(C)**.

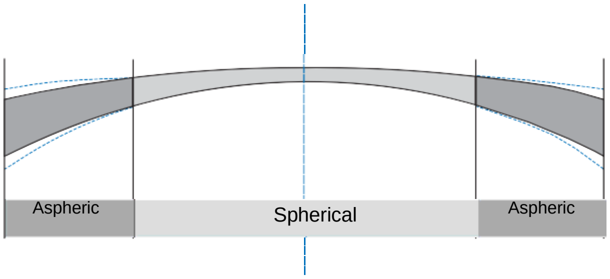


Figure 18-19. Asphericity can be used to thin the edge of a high minus lens. This is done by steepening the periphery of the front and/or flattening the periphery of the back curve. (From Meslin D: Varilux practice report no. 6: asphericity: what a confusing word! Oldsmar, Fla, November 1993, Varilux Press. Figure 2B. Courtesy Varilux Corp.)

power gain from a progressively steepening surface curvature. So progressive addition lenses are also aspheric lenses.

Most progressive addition lens designs continue to follow the same rules as spheric base curve lens designs. In other words, their distance portion will have the same base curve as one would expect for spherically based corrected curve lenses.

A progressive lens can also be made with a flatter base curve for the distance portion. To prevent unwanted aberrations, the front surface should be aspherically

different rates for each of the two meridians means that each rate of change can be optimized for the power in that meridian. When each meridian is optimized on a toric lens, the design is called an *atoric* lens. For a lens having cylinder power, an atoric design is able to expand the peripheral range of clearer vision beyond what is found for either a well-designed (best form) spherically based lens or an aspheric lens (Figure 18-20).

Atoric lenses should be recommended for all cylinder powers above 2.00 D, even when the spherical compo- nent of the prescription is low. They may also prove advantageous for anyone with cylinder power beyond
1.25 D. Fortunately, many of the newer high-index single vision series of lenses being marketed are now being made as an atoric series and not just aspheric.

Comparing the Construction of SphericallyBased Lenses, Aspherics, and Atorics

Here is a quick and general comparison of the way single vision lenses are constructed for spherically based, aspheric, and atoric lenses.

Spherically based lenses

- For simple spheres (no cylinder), the front surface is spherical, and the back surface is also spherical.
- For spherocylinders, the front surface is spherical, and the back surface is toric.

Aspheric lenses

- In most cases, for simple spheres (no cylinder), the

compensated as in any other nonprogressive aspheric lens. (As would be expected, the combined asphericities will become considerably more complex to design.)

ATORIC LENSES

A spherically based lens using a properly chosen base curve to create a corrected curve design can do a very good job of minimizing peripheral lens aberrations. So can an aspheric lens. In fact an aspheric lens is able to create a lens that has a flatter base curve and is often thinner and lighter while still maintaining corrected curve quality for reduction of aberrations.

Yet like the spherically based lens, the base curve and/or asphericity combination of an aspheric lens is designed for one specific lens power. The problem is when a lens corrects for astigmatism and introduces a cylinder component into the prescription, the lens has two powers. A lens with two curves on the same surface is called a *toric* lens. Which power will be used to deter- mine the correct amount of asphericity? Choosing to correct one power means that correction for peripheral aberrations for the other power will be less than ideal. Usually a compromise power somewhere in between the two is chosen, with neither being optimum.

An aspheric lens changes the curvature of the surface in all directions equally. With two lens powers, the rate of change in surface curvature would have to be different for each power meridian. Changing the curvature at

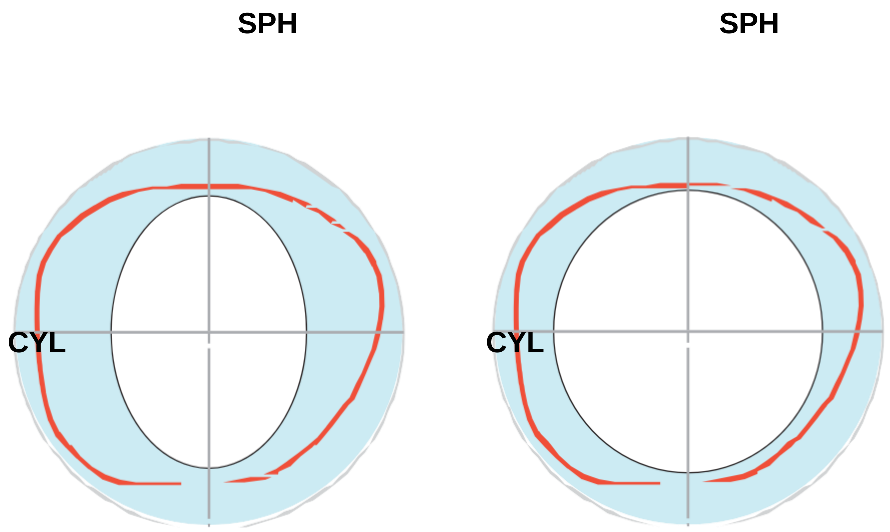
front surface is aspheric, and the back surface is spherical.

- For spherocylinders, the front surface is aspheric. The back is toric. It is not possible to correct both of the major meridians of a cylinder lens for aberrations when a lens is designed this way.

Atoric lenses

- There are both spheres and spherocylinders in a given lens series that use an atoric design. This means that in the case of spheres, the lens is really an aspheric. Technically it cannot be an atoric because it has no cylinder power.
- There are several ways atoric lenses can be made. It can be anticipated that the number of these possibilities will expand.
  1. A finished single vision lens with the front surface spherical and the back surface atoric.
  2. A semi-finished single vision lens with the front surface having the gradual changes in power associated with the lens atoricity. The back surface is the normal toric surface correcting for cylinder power. So the back surface takes care of the refractive power of the cylinder, whereas the front surface makes atoric changes for peripheral aberrations.
  3. A third category is an atoric design in conjunction with a progressive addition lens.

In the past, atorics had only been available in single vision lenses. Atorics had been out of the question with

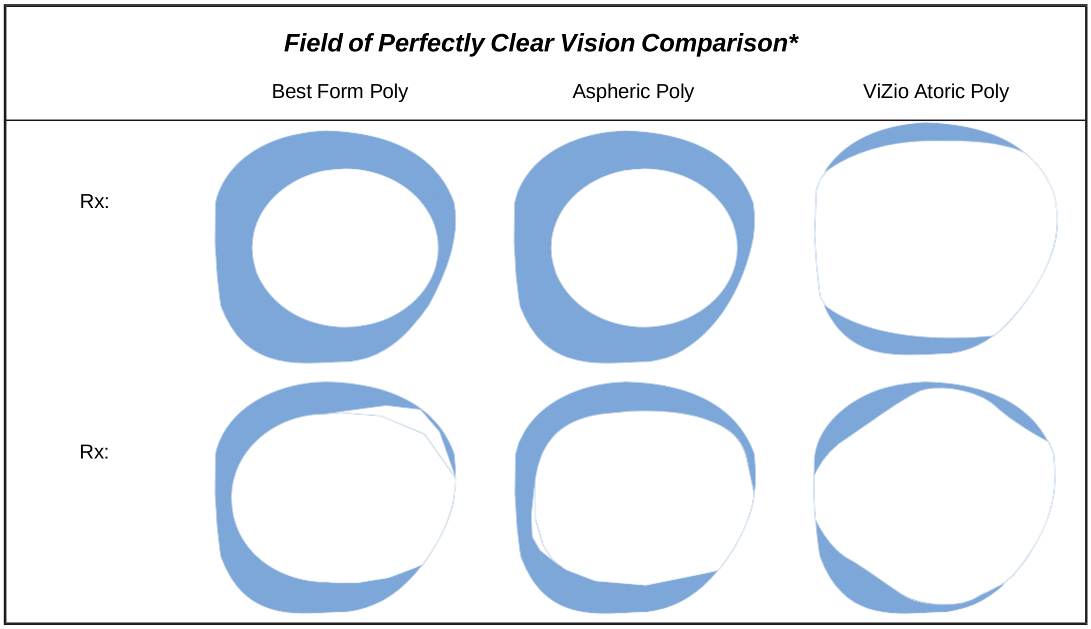


Best Form and Aspheric Designs

A

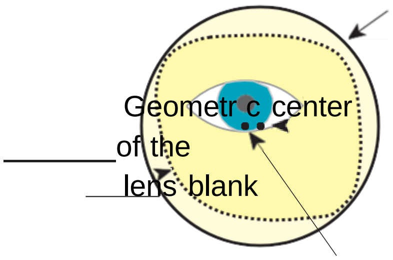
B

Atoric Design



C

Figure 18-20. A, This is conceptual drawing showing the zone of optimum vision for a best form spheric or an aspheric spherocylinder lens when the design is opti- mized for the sphere power meridian. The cylinder power represented in this drawing is fairly high. Here the wider area produced by the sphere meridian happens to fall in the narrower vertical meridian because of cylinder axis orientation. **B,** In B an atoric lens allows the design to be optimized for both sphere and cylinder power meridians, resulting is a larger area of better vision. (Illustrations **A** and **B** courtesy of Darryl Meister, Carl Zeiss Vision.) **C,** Here is a comparison of the size of sharp, clear vision for three polycarbonate lenses in best form, aspheric, and atoric forms for two specific spherocylinder lens powers. There is little difference in peripheral lens clarity between the best form (corrected curve) spherically based lens and the aspheric design, assuming that both lenses are fit correctly. Because an atoric lens can correct peripheral aberrations for both astigmatic meridians independently, the atoric design is able to widen the peripheral area of sharp, clear vision. (From Meister D: ViZio the next generation of aspheric lenses, Sola optical publication #000D0139D10460, 10/98.)



ing laboratory so that the correct amount of prism will be found at the center of the aspheric zone. A finished single vision lens cannot simply be decentered to create a prismatic effect as is done with normal spherically based lenses. Decentering a stock aspheric lens to create prism will mean that the wearer will no longer be looking through the middle of the aspheric zone.

Identifying a Lens As an Aspheric or Atoric Lens

Figure 18-21. When the unsurfaced, unedged lens blank is small or the frame is large, it may be necessary for the laboratory to move the OC away from the center of the lens blank. This is done by grinding prism in the center of the lens blank so that the OC will be properly placed after the lens has been edged.

multifocals and progressives. The segment or progressive zone of the lenses requires that the lenses be surfaced to prescription to correctly place the cylinder axis direction. The segment or progressive zone is already on the front of the lens. Since there was no practical way to grind and polish atoric optics onto the back side of the lens, atorics were only made in single vision lenses. Now “free-form” generating and polishing is making atorics available for an increasing number of newer custom progressive lens designs.

WORKING WITH ASPHERICS AND ATORICS

An Aspheric Design Prohibits Grinding Prismfor Decentration

When a conventional (nonaspheric) single vision lens is surfaced, the laboratory can move the OC to any loca- tion on the lens. This is done by grinding prism for decentration and is especially helpful when using large frames. Grinding prism for decentration moves the OC away from the center of the lens blank. On a spherically based lens, the OC may be moved without creating any new optical problems (Figure 18-21). Decentration prism is helpful when the lens blank would otherwise be too small for the frame size.

But what will happen if the OC is moved away from the geometric center of an *aspheric* lens blank? If the OC of an aspheric lens is moved, the asphericity will be mis- placed relative to the position of the eye (Figure 18-22). When the eye looks one way, it reaches the aspheric portion too soon. When it looks the other way, the aspheric area is not reached soon enough. In short the OC of an aspheric lens must remain locked to one position on the lens blank.

Rx Prism Still Works With Aspherics

Just because aspherics do not allow prism for decentra- tion does not mean that aspherics cannot be used for prism prescriptions. They can be used with Rx prism. The prism must be ground in prism done in the surfac-

When someone comes into the office already wearing glasses, it is helpful to know if the lenses being worn are aspheric lenses. It is not always easy to tell. Here are some possibilities for identifying an aspheric lens.

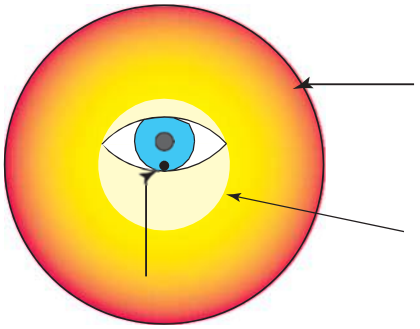
- *Use a lens clock:* By placing the three pins of a lens clock on the front surface of a lens and moving the lens clock sideways, it may be possible to identify some aspherics. If front surface lens power changes, the lens is aspheric. However, if the lens is edged and in the frame, it is not possible to move the lens clock very far. Therefore many, if not most aspherics may be missed.
- *Use a grid pattern:* View a grid pattern through a higher plus lens. Not seeing distortion of the grid may identify certain types of aspherics, but not all types.
- *Notice lens curvature:* Notice the flatness of the front (and back) curve compared with other lenses of equal powers. Of these first three suggestions for identifying the possibility of having an aspheric lens, this may be the best.
- *Look for identifying markings:* Fortunately, some manufacturers are putting identifying markings on the front surface of their lenses. This will allow the identification of a lens as being a specific brand of aspheric, much like the system used for identifying progressive addition lenses. Remember, however, that whereas progressive lens marks will appear along the 180-degree line, aspheric lens markings may appear in any lens meridian because of the lens being rotated during edging.

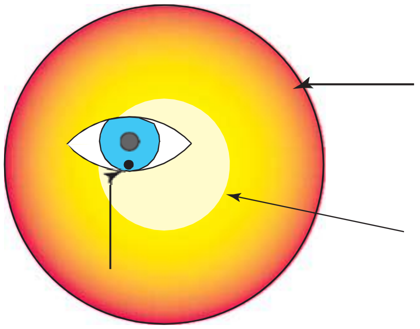
Why Dispensing Rules Take on Special Importance for Aspherics

A well-designed aspheric lens can produce excellent optical and cosmetic results. There is one thing that must be kept in mind, however. Aspheric lenses are not as forgiving of dispensing errors as regular lenses. If a regular lens is fit without adhering to all the proper fitting rules, vision may still be acceptable enough to produce a happy wearer. But if an aspheric lens is fit improperly, the lens can end up being optically worse than a regular spheric-based lens would have been.

Fitting Guidelines for Aspherics

Fitting rules for aspherics are really no different than careful fitting rules for any other lens. Remember to





Incorrectly ground optical center (lens has ground-in prism for decentration)

B

Central spheric zone of the lens

Figure 18-22. A, An aspheric lens should always have the OC in the middle of the central, spheric portion of the lens. This way as the eye looks left and right, the lens is used as intended. If an aspheric lens is ground with prism for decentration as shown in **B,** the eye will run into aspheric changes too quickly in one direction and not quick enough in the other direction. (The eye is slightly above the OC to allow for pantoscopic tilt and reading.) NOTE: Do not confuse prism for decentration with prescribed (Rx) prism. Prism ground onto an aspheric lens as Rx prism is always acceptable.

always use monocular PDs, measure for MRP height, and use the correct amount of pantoscopic tilt.

Use Monocular Interpupillary Distances

The eye must be horizontally centered in the "concentric aspheric rings" of the lens. Taking monocular interpupillary distances will ensure that this happens.

Measure Major Reference Point Heights and Compensate for Pantoscopic Angle

First, measure MRP heights in the conventional manner (see Chapter 5). Then use the rule of thumb for tilt compensation (i.e., subtract 1 mm of MRP height for each 2 mm of pantoscopic tilt). Aspheric areas concentrically surround the lens OC. Therefore do not move the MRP more than 5 mm below the pupil, even if the rule of thumb for tilt calls for more than 5 mm. Moving the MRP too far downward can cause the peripheral aspheric area to interfere with normal distance vision. Because the MRP should not be dropped more than 5 mm below the pupil, it is not advisable to use more than 10 degrees

of pantoscopic tilt with high-powered aspheric prescriptions.

Alternative Method for Determining Major Reference Point Height: Tilt the Head and Measure An alternative method for finding MRP height is to first tilt the wearer's head back until the frame front is perpendicular to the floor. Next measure MRP height with the subject's head tilted back. (If the frame has a large amount of pantoscopic tilt, remeasure height without tilting the head. The difference in measurement should not exceed 5 mm.) This head-tilt method should give the same results as compensating for pantoscopic tilt and is certainly easier. (See Chapter 5 for more details regarding MRP height.)

Caution: Some laboratories assume that the MRP height specified on the order form places the MRP in front of the eye. Since this is incorrect in the presence of pantoscopic tilt, some laboratories drop the MRP below the ordered amount to compensate for tilt. You will need to know how your laboratory is treating so-called MRP heights.

BOX 18-4

Fitting Guidelines for Aspherics

1. Use monocular interpupillary distances.
2. Measure major reference point heights in the conventional manner. Then subtract 1 mm for each 2 mm of pantoscopic tilt. (The OC should not be more than 5 mm below the pupil.)
   Alternative method for finding major reference point height: First tilt the wearer's head back until the frame front is perpendicular to the floor. Next measure the major reference point height in this position. This alternative method should give the same results as compensating for pantoscopic tilt will give.
3. Remember that the laboratory cannot grind prism for decentration with aspheric lenses. Moving the OC away from the center of the aspheric zone will

The guidelines for fitting aspherics are summarized in Box 18-4.

Full Versus Nonfull Aspherics

When thinking of aspherics, we generally think of the lens surface radius of curvature changes as beginning nearly at the optical center of the lens. The changes start gradually and increase more rapidly as distance increases from the center of the lens. This type of aspheric lens is referred to as a *full aspheric* lens. Because changes start almost centrally, it is important to follow recommended fitting guidelines. If the eye in not correctly located in the aspheric configuration, this poor fitting can produce results worse than would be experienced if spherically based lenses were poorly fit.

To help reduce poor fitting problems, some aspheric lenses are designed with a spherical central area or *cap* that may vary in size depending upon who makes the lens. In this central area, the lens behaves like a spherically based lens. If the eye is not properly centered, the consequences are not supposed to be as noticeable. Such a lens is referred to as a *nonfull aspheric*.[9] Another advantage is that the lens may be able to be decentered for smaller amounts of prism without having as many adverse affects.

When to Recommend Aspherics and Atorics

For Plus Lens Wearers

For plus lenses, an aspheric may easily be recommended when the power goes above D3.00 D. However, opinions vary on when to recommend aspherics with beginning points ranging from D2.00 D to D4.00 D or even lower. Remember that as frame size increases, the amount of plus power needed before recommending an aspheric lens decreases. The larger the lens, the lower the power will be when aspheric lenses are recommended.

For Minus Lens Wearers

For a minus lens wearer, an aspheric may be recom- mended for powers above D3.00 D. The "minimum" lens power that is recommended continues to drop. Again differences as to what the lowest power is for recom- mending a minus aspheric will differ, depending upon frame size and wearer concerns. (Note: If a high-index aspheric is being used primarily to thin the lens, it is counterproductive to place such a lens in a frame with a small eye size and narrow vertical dimension if that frame is a nylon-cord frame. Nylon-cord frames need a minimum edge thickness to allow for grooving the edge. Such high-index lenses may have to be made thicker because of the frame.)

Aspherics Are Recommended for Anisometropia When a person has a difference in power between the left and right eyes that is greater than 2.00 D, there will also be differences in magnification. Aspherics are nor- mally flatter, thinner, and closer to the eyes and reduce magnification differences.

Other Possibilities for Using Aspherics

Aspherics can also be recommended for

- Children who are sensitive about how their glasses look;
- Contact lens wearers so they will not overwear their contacts to avoid wearing thick, ugly spectacle lenses; and
- Older wearers to decrease lens weight.

Adapting to Aspherics and Atorics

Changing base curve and lessening the amount of distortion a person experiences when switching from a spherically based lens to an aspheric or atoric would seem like a good thing. And it is. However, the person who has been wearing lenses that cause straight lines to appear curved has already made some adaptations. They have mentally been able to correct the distortions caused by the lens. Their mind straightens the optically dis- torted (curved) line and sees it as straight. Now when a new correcting lens no longer curves straight lines, the mind tries to compensate as before, and the world takes on an unfamiliar appearance. Until readaptation takes place, nothing looks right. Those being changed from conventional spherically based lenses into aspheric or atoric lenses should be warned about the adaptation time that will be necessary. Once a person is used to wearing aspherics and atorics, they find them much to their liking. (This is assuming that the lens has been carefully measured and fit.)

HIGH PLUS LENS DESIGNS

Before the advent of intraocular lens implants following cataract surgery, high plus lenses were common, and a number of high plus spectacle lens options were

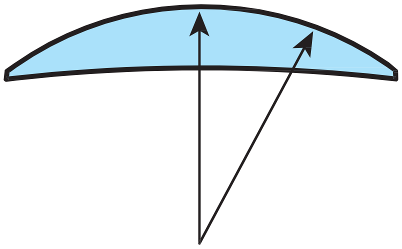


Figure 18-23. This lens has the same radius of curvature over the entire front surface of the lens. A “full-field” lens is one that is optically useable over the entire viewing area. There- fore technically, even this regular spherically based lens could be called a full-field lens.

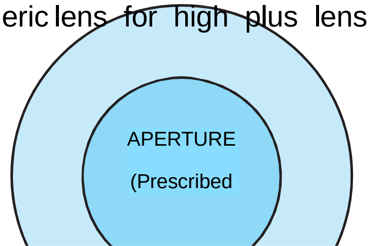
developed. Many of these options are still available. Because high plus options are often thought of simply as “cataract lenses,” they may not be used to full advantage. People who need a high plus correction and have never had cataract surgery are still candidates for these special lens designs.

Regular Spheric Lenses

It is possible to use a regular, spherically based lens for a high plus wearer, even though the optics are not as good. Sometimes these lenses are called “full-field lenses” to make them sound better. Actually, any lens that has the prescribed lens power over the whole viewing surface could be described as a full-field lens (Figure 18-23).

High-Index Aspheric

Whenever possible, it is best to use a high-index aspheric lens for high plus lens



wearers. High index aspherics may not be available in some of the very highest plus powers. Unfortunately, many of the specialty high plus lenses described in the next sections are only available in regular 1.498-index CR-39 lens material because these lenses were designed when CR-39 was the preponderant material.

Lenticulars

A lenticular lens is one that has a central area with the prescribed lens power surrounded by an outside area of little or no power. The central area is called the *aperture*, and the outer area is called the carrier (Figure 18-24). The lenticular style was developed for the purpose of thinning the lens. It is like a small, plus lens that is attached to a thin plano lens (Figure 18-25).

Lenticular lenses are available as either spheric or aspheric lenticulars. *Spheric lenticulars* look just like the lens shown in Figure 18-25. *Aspheric lenticulars* have an aspheric aperture. An aspheric lenticular can be thought of as a small, aspherically designed plus lens that has been placed on a near-plano carrier (Figure 18-26). Of the two lenticular designs, the aspheric lenticular is the better choice.

Figure 18-24. When a lenticular lens is viewed from the front, the optically useable central aperture is seen in the center of the outer carrier portion.

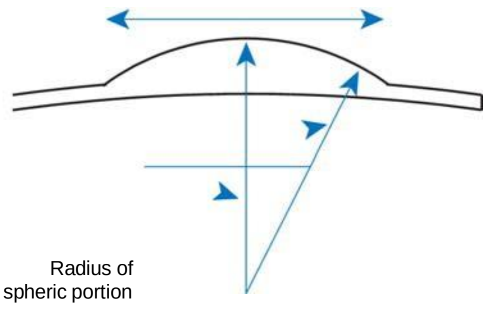


Figure 18-25. The cross section of a spheric lenticular lens shows that the optically useable central portion has the same radius of curvature across its entire surface. The outer carrier portion is considerably flatter.

Advantages of a Lenticular Design

The main advantages of the lenticular design are weight reduction, thickness reduction, and, for aspheric lenticulars, good optics.

Disadvantages of a Lenticular Design

The main drawback to the lenticular design is looks. Even for small eye sizes, the edge of the aperture is usually visible. If the frame eye size is too large, the lens looks like the yolk of a fried egg.

The Development of High Plus Multidrop Lenses The *Welsh 4-Drop* lens was developed in an effort to overcome the cosmetic negatives of the lenticular design while maintaining a thin lens. The Welsh 4-Drop had a back surface curve that was almost flat. The front surface of the lens had a 24-mm spherically based central area. Outside of that central area, the lens surface became aspheric and dropped in power, 1 diopter at a time, for a total of 4 diopters (Figure 18-27). For example, if the lens had a central base curve of D14.00, there were four outer concentric areas with powers of D13.00 D, D12.00 D, D11.00 D and D10.00 D. Each area blended into the other so that the changes in power were not visible.

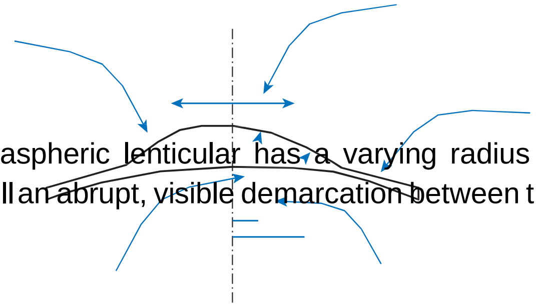


Figure 18-26. The cross section on an aspheric lenticular has a varying radius of curvature across the aperture. There is still an abrupt, visible demarcation between the central aperture and the carrier.

Increasing radius of aspheric portion

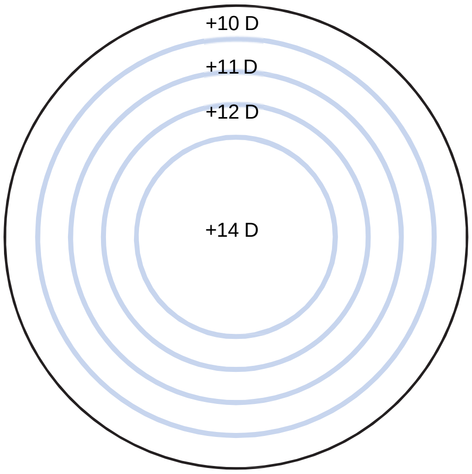
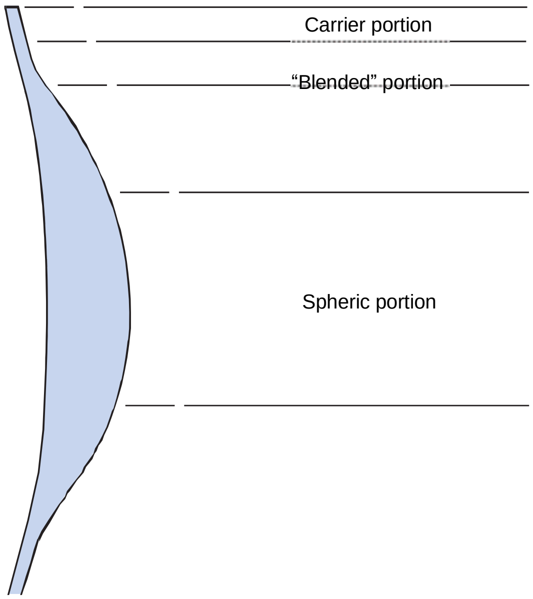


Figure 18-27. The original Welsh 4-Drop lens had a front surface that dropped 4 D from center to edge.



The Welsh 4-Drop was a radical change over previous plus lens designs. The optics were less than ideal, but the lens was thin and better looking. The concept was picked up by competing lens companies and modified.

In the competing products, the concentric areas no longer changed as abruptly. The amount of aspheric drop was no longer limited to 4 D, regardless of base curve. The general category of lenses that emerged became known as *multidrop* lenses.

In the early stages of multidrop development, the issue of using aspherics to correct for aberrations instead of just for cosmetic and weight purposes had not yet been substantially addressed. Eventually, multidrop lenses were developed that more effectively took into account both peripheral aberrations and cosmetics. The central portion of the newer multidrop lens has an area that resembles the optics of an aspheric lenticular. Once outside of this more traditionally designed central area, the front surface suddenly flattens. The outer zone of the lens functions more like a carrier. In essence the lens resembles a large, blended aspheric lenticular (Figure 18-28).

Figure 18-28. A multidrop lens can incorporate the advan- tages of optically sound aspherics for near-peripheral viewing, plus a fast-changing aspheric drop toward the edge resulting in what could almost be considered a blended aspheric lenticular.

HIGH MINUS LENS DESIGNS

Perhaps the greatest lens problem facing the high minus wearer is thick edges. This can be substantially addressed through appropriate frame selection. (For a review of frame selection for high minus wearers, see Chapter 4.)

Many of the options for high minus lenses discussed in the following sections may not be needed if the dispenser first applies traditional dispensing principles, such as small effective diameter sizes, high-index lenses, roll and polish, and antireflection coating. Yet if lens power is high enough, these measures may still prove insufficient. If this happens, a special high minus lens design is in order.

Lenticular Minus Designs

A lenticular design for a high minus lens uses the same idea as the lenticular design for high plus lenses. The

Same lens powers

Same bowl sizes

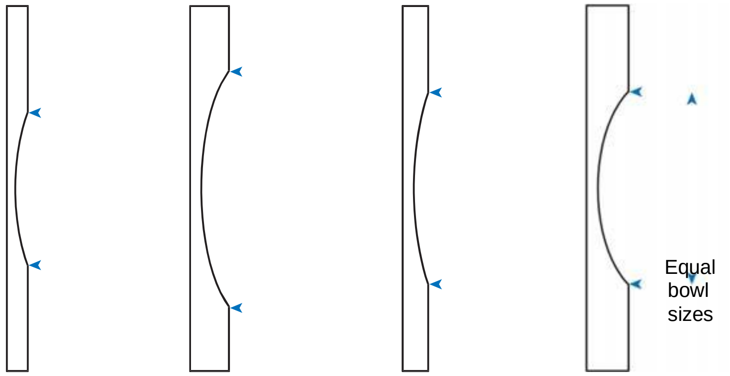


Figure 18-29. For a myodisc lens (having a plano carrier), edge thickness increases with both lens power and bowl size.

Smaller bowl size

Larger bowl size

Lower lens power

Higher lens power

central area of the lens contains the prescribed refractive power of the lens. The peripheral (carrier) area serves only to extend the physical size of the lens without increasing its thickness.

Lenticular minus lenses can be found in several forms; one of which is the myodisc. It is important to remember that minus lenticular lens designs are not limited to one type of lens material and can be made of higher index material.

The Myodisc

According to the traditional definition, the myodisc design has a front surface that is either flat or almost flat. The front usually contains the cylinder component of the prescription. A myodisc also has a plano back carrier area. There is a high minus “bowl” in the middle of the back surface. (Originally, these lenses, made from glass, had a small 20- or 30-mm bowl size. Myodisc was a trade name.)

In a myodisc type of lens, the carrier is near plano. Therefore the thickness of the carrier portion is con- stant. The larger the bowl area is, the thicker the carrier will be. For lenses with the same-sized bowl areas, increases in lens power will mean an increase in carrier thickness (Figure 18-29).

Because the myodisc carrier is plano, as bowl size and/or lens power increases, edge thickness can become significant. It is conceivable to reduce edge thickness by using a different form of a minus lenticular design.

Minus Lenticular

A high minus lens with a lenticular design can be made so that the carrier is not plano. Several examples of minus lenticular lenses are shown in Figure 18-30.

If the back side of the carrier is made positive, as shown in Figure 18-31, *B* and *D*, the outer edge will thin down considerably. Often the laboratory makes this type

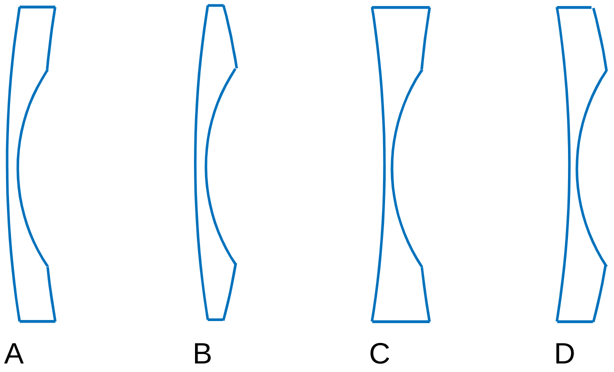


Figure 18-30. Minus lenticular lenses may be made in a variety of forms. Here are some examples. All have a high minus power in the central bowl area. The

numbers are for illustration purposes only. **A,** A minus lenticular with a D2.00 D back carrier curve and a D2.00 D front curve. **B,** A minus lenticular with a D6.00 D back carrier curve and a D2.00 D front curve. The plus 6 back carrier helps to thin the lens edge. **C,** A minus lenticular with a D2.00 D back carrier curve and a D2.00 D front curve. The minus front curve increases the total minus power without having to make the back bowl curve even more concave. **D,** A minus lenticular with a D6.00 D back carrier curve and a D6.00 D front curve. Again the plus back carrier helps to thin the lens edge. It would be possible to put a higher plus carrier curve on the back of the lens to obtain more edge thinning.

of lens by beginning with a semifinished lens that has a plus six or greater front curve. The minus bowl is ground into the “front” of the semifinished lens. This will become the back of the minus lenticular lens. The cylinder and remaining power is ground onto what will become the front of the lens.

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Sample Questions:

Example **1**

A prescription is to be placed into a pair of wrap-around frames with a wrap angle of 25 degree for each lens. It is ground onto a D8.00 D base curve polycarbonate lens with a 2.0-mm center thickness. What would be the amount of prism induced and in what base direction? If compensatory prism is placed in the glasses to counteract the induced prism, what base direction would be used?

Solution

Using the formula for prism induced by tilt, the prism amount is:

$$\text{D D } 100 \tan\text{D } \frac{t}{} F$$

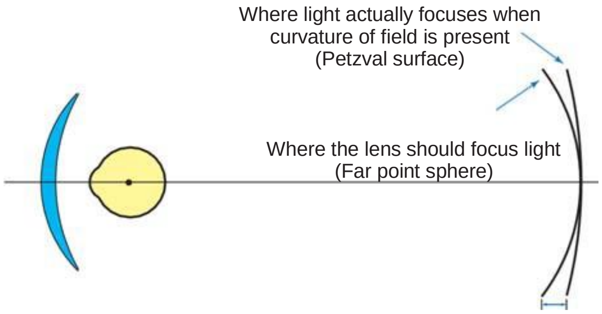


Figure 18-10. The aberration curvature of field occurs when light entering the peripheral areas of the lens does not focus

n 1 where it should; namely, on the far point sphere. (The far point

$$\text{D } 100(\tan 25) \text{D } \frac{0.002}{} \text{D } 8$$

$$1.586$$

$$\text{D } 0.47$$

The amount of prism is 0.47D. Since the light enters the lens at an angle on the nasal side, the prism base direction is on the other side, which is base out. The induced prism is 0.47D base out per eye. The prism needed to compensate for induced base out is base in.

For orders with significant wrap around and a moder- ate to high-powered prescription, use a laboratory that is experienced with making any necessary compensatory changes in refractive power and prism caused by lens tilt.

Example **2**

Suppose a lens has a prescription of D5.50 D1.00 D 70. Using Vogel's formula, what is the base curve?

Solution

Since this lens has cylinder, we begin by finding the spherical equivalent of the lens.

Base curve

(plus lenses)

D spherical equivalent D 6.00 D

Spherical equivalent D D5.50 D $\frac{DD1.00D}{2}$

D D5.00D

(The *spherical equivalent* of a lens is the sphere power plus half of the cylinder power.) For minus lenses, Vogel’s formula for base curve begins with the spherical equivalent of the lens, divides the spherical equivalent by 2, then adds 6 diopters. Written as a formula this is:

The approximate base curve is:

Base curve$_{\text{(plus lenses)}}$ D D5.00 D D 6.00 D

D D11.00 D

Base curve$_{\text{Dminus lensesD}}$

D $\frac{\text{spherical equivalent}}{2}$ D 6.00D

Example **3**

A minus lens has a power of D6.50 D1.50 D 170. Using

These formulas are summarized in Box 18-2. (Remember that this formula is to help in determining approximately what base curve might be expected for a given lens power. Actual base curves for lenses will vary. Plus lenses will be somewhat flatter than calculated and lenses of higher index of refraction may be considerably flatter.)

Example **4**

Using Vogel’s formula, find an approximate base curve for a

Vogel’s formula, what is the approximate base curve?

Solution

The spherical equivalent of D6.50 D1.50 D 170 is:

Spherical equivalent D D6.50 D $\frac{D1.50}{2}$

D D7.25D

The base curve formula for minus lenses is different than that for plus lenses; therefore the approximate base curve is:

lens having a power of D2.00 D sphere.

Solution

For spheres there is no need to calculate a spherical equivalent. So for this lens, the base curve is:

Base curve$_{\text{Dminus lensesD}}$

D $\underline{\text{D7.25}}$ D 6.00D2

D D3.62D D 6.00D

D D2.38D

Base curve$_{\text{(plus lenses)}}$ D D 2.00 D D 6.00 D

D 8.00 D

Rounded to the nearest $^{1}/2$ D, this is D2.50 D. (In practice

this would be rounded to the nearest base curve in the series stocked by the laboratory.)

Unit 9:

Segmented Multifocal Lenses

Learning Objective:

At the end of this chapter, students will be able to learn:

1. What are multifocal lenses, their uses, advantages and disadvantages.
2. What are different types of bifocal lenses and trifocal lenses, with uses, advantages and disadvantages.

Most spectacle lenses correct for just one distance. These are called *single vision lenses*. Yet a person's visual needs may require different

lens powers for different distances. These needs can be met by changing the power in one or more areas of a lens.

MULTIFOCAL LENSES

Multifocal lenses meet the wearer's needs for focusing light at more than one, or *multi*ple distances. Originally all multifocal lenses had visible segments. There were no progressive addition lenses with gradually changing powers hidden from view. To help distinguish multifocal lenses with progressive optics from multifocal lenses with distinctly different powers in sharply demarcated areas of the lens, the lenses with visible segments may be referred to as *segmented multifocals*.

The Concept of a Near Addition

The crystalline lens within the eye becomes nonelastic as a result of the aging process. This condition is called *presbyopia*. Because of presbyopia, a person becomes unable to see clearly at close range, regardless of how well vision is corrected for distance. To see clearly at near, the wearer needs additional plus lens power.

Suppose a person has no need for correction of dis- tance vision. If no distance correction is required, the only factor to be considered is the necessary plus lens power to see clearly at near. The amount of plus power needed for near vision is 02.00 D. This can be given in the form of a regular, single vision lens having the same

02.00 D power over the whole lens. It can also be given as a lens with no power in the main portion of the lens, but with a small area of plus power in the lower portion nation of the distance power and the add power is termed the *near power,* or *near Rx*.

An example of how the power of the near addition is written in prescription form is:

O.D. 03.25 D sph
O.S. 03.25 D sph Add 02.00 D

By this it is understood that both lenses are to contain a near segment whose power of 02.00 D adds that much more plus power to that part of the lens.

In the above example, since an addition is made to the distance power, the measured power through the dis- tance portion of the right lens is 03.25 D sphere, and the measured power through the near portion is 05.25 D sphere (Figure 19-2). In simplified terms, if the near object is at the focal point of the near addition "lens," the add allows incoming light to enter the distance lens as if it were coming from a distant object. This way light focuses at the same point as it does for distance vision (Figure 19-3).

To go one step further, consider an example of a lens that has both sphere and cylinder power. If a lens has a distance power of 02.00 00.75 0 180 with a 02.00 D add, then the actual measured power through the near portion will be 04.00 00.75 0 180. This may be explained with two power crosses, as shown in Figure 19-4. When both meridians are added together, the total near power still contains the same cylinder power. Regardless of whether the distance portion is plus or minus in power, the near portion is still the algebraic sum of distance power and near add.

of the lens, as shown in Figure 19-1. This is the concept of a bifocal lens.

However, if the wearer does have a correction for distance, the extra required power for near must be "added on" to the power found in the distance prescrip- tion already being worn; hence the term *near addition*. The near addition is the same as a small plus lens placed in the lower portion of the lens. For that reason, it is often referred to as the *near segment* or, in abbreviated form, the *seg*. The net power resulting from the combi-

Example **19-1**

The distance portion of a lens is a 02.50 D sphere. The near add power is 02.50 D. What is the near power through the segment portion?

Solution

Since the total near power is calculated as:

(distance power) 0 (near addition) 0 (near power)

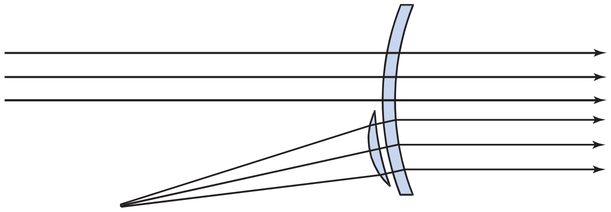


Figure 19-1. A bifocal segment is a small plus lens positioned on a lens that normally corrects for distance vision. Here the bifocal is placed on a lens that has no power in the distance portion.

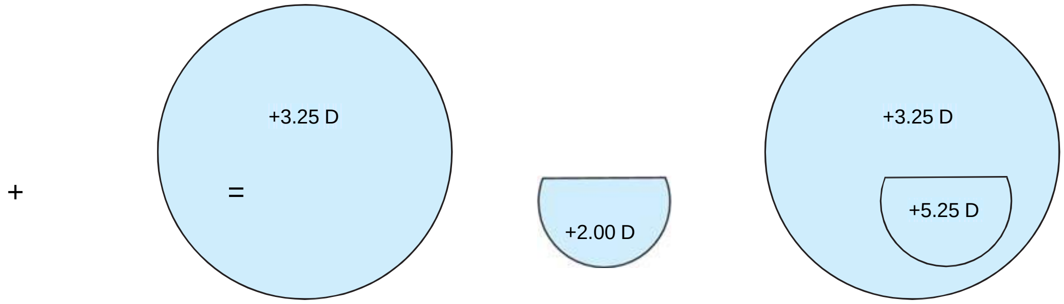


Figure 19-2. A bifocal addition is just that—an addition to the distance power. Here the distance power of 03.25 D is supplemented with a 02.00 D add for near viewing. The total power at near is 05.25 D. The 05.25 D power is the power that would be used in a pair of single vision lenses intended to be used only for reading.

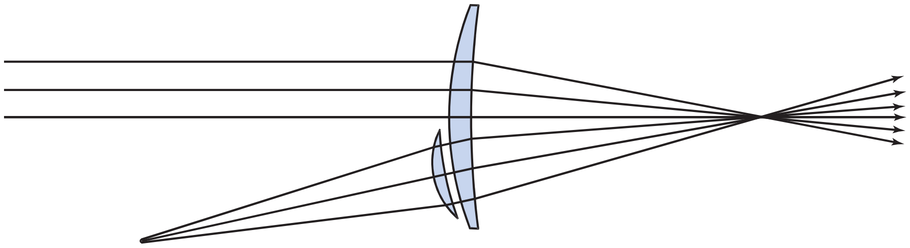


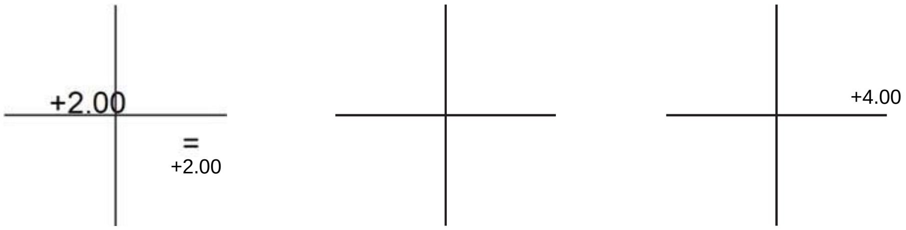
Figure 19-3. A plus lens with a bifocal near addition.

+1.25 D

+2.00

+3.25

+



Distance power

Near power

Total power

at near

Figure 19-4. The near portion of a lens having an add of 02.00 D does not necessarily manifest a 02.00 D power, but rather will be the sum of the distance power and near addition combined.

then

(02.50) 0 (02.50) 0 0.00

ability. This eliminates the need for an intermediate trifocal area. For this reason, most trifocals are not available in add powers below 01.50.

The total power through the bifocal will be zero. Looking at

the near power this way for people with lower minus-powered distance prescriptions makes it easier to understand why they are not enthusiastic about going into multifocals. Theycan do very well just removing their glasses.

The Trifocal Intermediate

Some lenses have an intermediate area between distance and near portions. This area is used for viewing objects that are not at the normal reading distance. Yet what is being looked at is close enough to make clear vision through the distance portion impossible. The solution for these situations when using segmented multifocal lenses is a *trifocal* (Figure 19-5).

In trifocals the power of the intermediate portion is normally one half that of the prescribed near add. It is expressed as a percent. Normally the intermediate portion will be 50% of the near add. Lenses for special intermediate viewing distances may also be obtained having intermediate powers of 61% of the near addition.

To calculate the expected power through the inter- mediate portion of a trifocal lens, first the prescribed trifocal percent of the near add is found. For example, a lens having a 02.50 D add has an intermediate power that is 01.25 D greater than the distance power. Since

01.25 D is half of 02.50, the lens has an intermediate power of 50%. This 01.25 D intermediate add value is added to the distance power to find the expected total intermediate power as measured in the lensmeter.

When to Use a Trifocal

Eyes that still have a limited ability to focus and only require additions of 01.50 D or less will have clear vision in all areas of viewing. When looking through the upper (distance) part of the lens, the eye can focus on objects at an intermediate distance by using its own focusing

After the add power increases above 01.50, there will be intermediate areas of vision that are not clear through either the distance portion or the near portion of a normal bifocal. To see these areas clearly, the wearer will either have to look through the upper part of the lens and back away from the object, or look through the lower bifocal part of the lens and move closer. A trifocal inter- mediate will furnish clear vision at this previously blurred in-between distance. (A progressive addition lens will solve this problem as well. For more information on progressive addition lenses, see Chapter 20.)

Terminology

Bifocals are available in a wide variety of segment shapes and sizes from small, round segs to segs that occupy the entire lower half of the spectacle lens. Their size and locations are quantified by means of a few standardized terms.

The size of a seg horizontally, or *seg width,* is measured across the widest section of the segment area (Figure 19-6). If part of the segment area has been cut away in edging the lens for the frame, the dimension is still considered to be the widest portion that the segment had before edging.

The longest vertical dimension of the seg is the *seg depth*. *Seg height* is dependent on the frame for which the

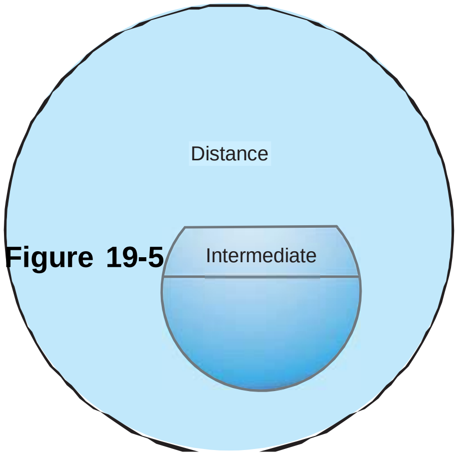
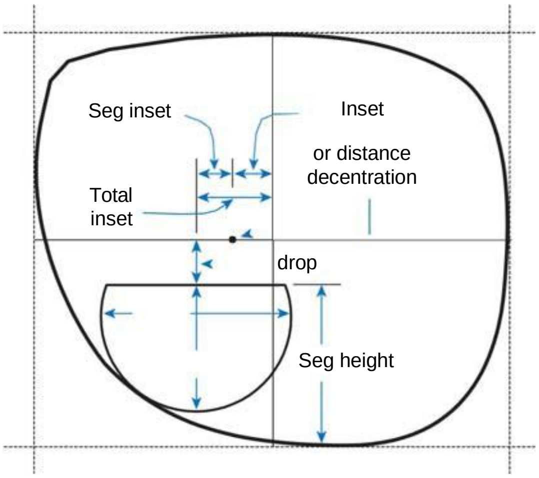


Figure 19-5



has three viewing areas.

Figure 19-6. The *major reference point (MRP)* of a lens is positioned in the same vertical plane as the pupil and a few millimeters below it. If no prescribed prism is present in the prescription, the MRP and the optical center of the lens are one and the same point. (When prescribed prism is present in the distance portion, the optical center is no longer in the same location as the MRP.) The amount the MRP is moved laterally from the geometric center of the lens is the *inset* or *outset* (also referred to as *distance decentration*). The additional amount the center of the near segment is moved inward from the MRP is the *seg inset*. The inset plus the seg inset is known as *total inset* (or *total seg inset*).

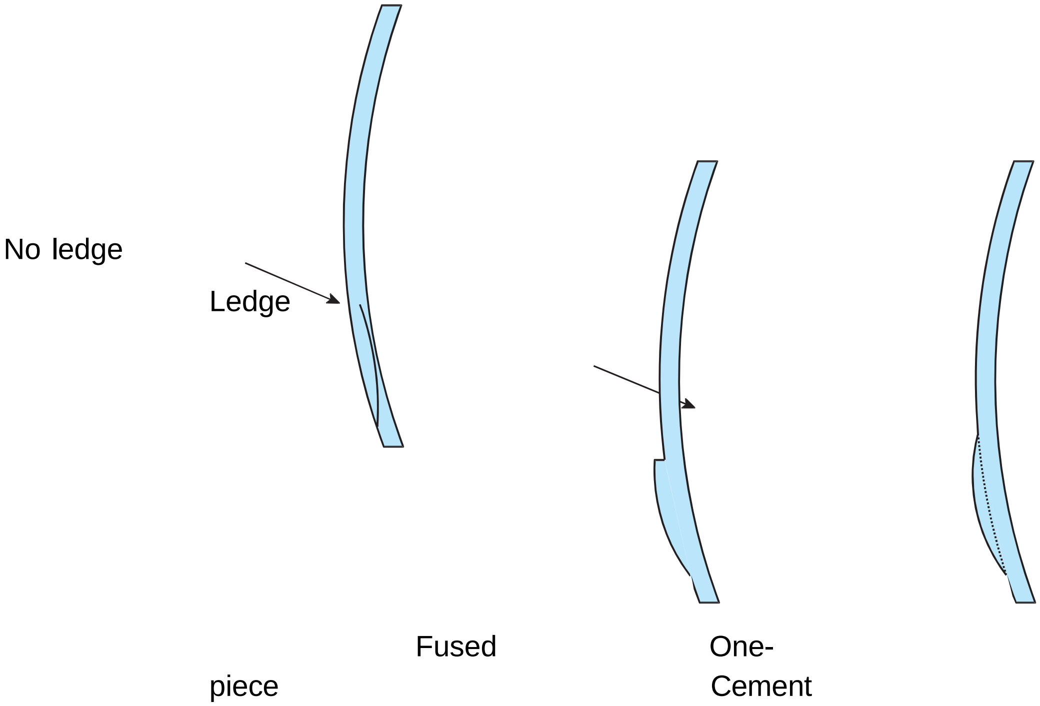


Figure 19-7. A fused segment lens as shown on the left is made using glass that has a higher index of refraction in the segment than in the main part of the lens. One-piece lenses have a ledge that can be felt and may be made from almost any lens material. Cement segs are made by gluing a single vision distance lens and a small, segment-sized lens together.

lenses have been edged and is measured vertically from the lowest point on the lens to the level of the top of the seg (see Chapter 5). *Seg drop* is the vertical distance between the major reference point (MRP) of the lens and the top of the seg.

The distance portion of the lens must be decentered from the geometric center of the lens opening of the frame to correspond to the wearer's interpupillary distance (PD). This is referred to as *inset* or *outset*. The segment must be further decentered to correspond to the near PD. This seg decentration is referred to as *seg inset*.

Inset (or outset) 0 seg inset 0 *total inset*

(Outset would be written as a negative number.)

How Multifocals Are Constructed

Bifocals and trifocals are usually constructed in three main ways: fused, one piece, and cemented (shown in cross section in Figure 19-7).

1. *Fused*—Fused multifocals are available only in glass. The segment of the lens is made from glass having a higher refractive index than that of the distance "carrier" lens.* A fused glass bifocal has no ledge or change of curvature on the front. The segment cannot be felt because it is fused into the distance portion.
2. *One piece*—One-piece multifocals are made from one lens material. Any change in power in the segment portion of the lens is due to a change in the surface curvature of the lens. One-piece multifocals can be identified by feeling the segment border. If either a ledge or a change in curvature is felt, the lens is not fused and is most likely a one-piece design.

   One-piece multifocals may be made from any lens material. All plastic lenses are made as one-piece multifocals. One-piece glass multifocals are usually either the full-segment Franklin-style lens with the near portion occupying the entire lower portion of the lens, or they are large round-segment lenses.
3. *Cement lenses*—Cement lenses are custom-made lenses that have a small segment glued onto the distance lens. Used only for specialized custom purposes, such lenses are usually in the form of small, round segments.

Another occasionally used segmented lens is one that is actually two lens sections glued together. The upper half is a distance lens, and the lower half is a near lens. Both are cut in half, and half of each is used. The most common application for such lenses is for creating horizontal prism in the near portion only.

TYPES OF BIFOCALS

There are a few major groupings of bifocal segment styles, but many variations within those styles (Figure 19-8 and Table 19-1). The basic styles include round segments, flat-top segments, curve-top and panoptik segments, and Franklin- or Executive-style segments.

Round Segments

Round segments vary in size from a small lens of 22 mm up to the largest, 40 mm. The most common size is 22 mm. For large, round seg sizes, 38 mm may be occa- sionally used. Logically the optical center (OC) of a round segment is always at the center of the segment. The round segment lens is a versatile lens because the

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*The distance lens is denoted the "carrier" lens because it is the portion to which the multifocal segment is attached. The segment is carried by the distance portion.

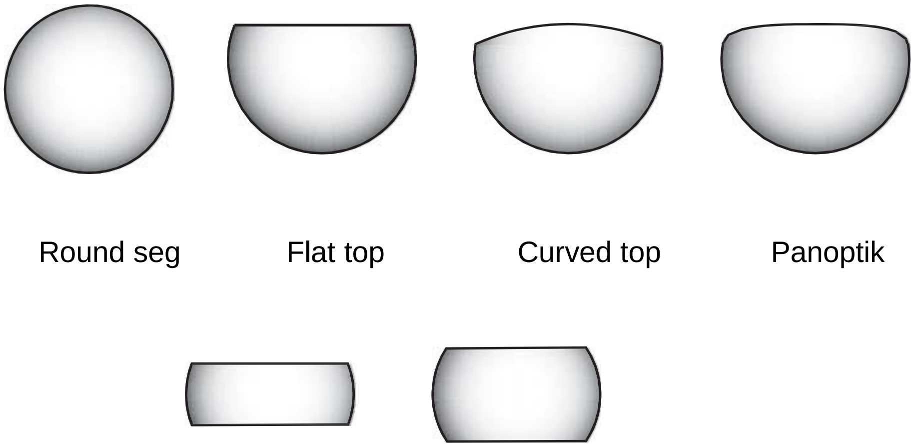


Figure 19-8. A sampling of available bifocal segment types.

round segment can be rotated and still not look tilted. It can also be positioned at odd locations on the lens, such as in the upper temporal corner of a golfer's right lens. (Assuming, of course, that the golfer is right-handed.) This keeps the segment out of the golfer's way and still allows access to a near add for score card marking and reading.

Blended bifocals are round-segment bifocals with the border smoothed out to keep the segment from being seen.

Flat-Top Segments

Flat-top segments are basically round segments with the top cut off. The top is generally "cut off" 4.5 to 5.0 mm above the center of the segment. Stated another way, the segment OC is about 5 mm below the seg line. This allows the lens segment to have maximum reading width where a person will be reading. Very wide flat tops have the segment OC on the line. Flat tops are also known as *D segs*.

Flat tops are the mainstay of lined multifocal lenses. Segment sizes range from 22 up to 45 mm. Most flat tops used now are 28 mm or greater.

Curve-Top and Panoptik Segments

Curve-top segments look similar to flat tops, except that the upper line is arched, rather than flat. There is a dis- tinct point on either corner. The top of panoptik segments are curved as well, but the corners are rounded.

Ribbon Segments

Ribbon segments are basically round segments with the top *and* bottom cut off. There are two types: a B and an R segment. The B is only 9 mm deep and is good for someone who must be able to have distance vision below the bifocal area. Some remember the letter and function by identifying “B” with *b*ricklayer. Bricklayers often work in high places and can appreciate the ability to look below the segment and have clear distance vision.

The R segment has a 14 mm depth. It is seldom used as a regular bifocal lens. The R-segment bifocal is the same lens that is modified to create the “compensated ‘R’ ” segment pairs that may occasionally be used for the correction of vertical imbalance.

Both B and R segments have their segment optical centers in the middle of the segment. Ribbon segments are available only in glass.

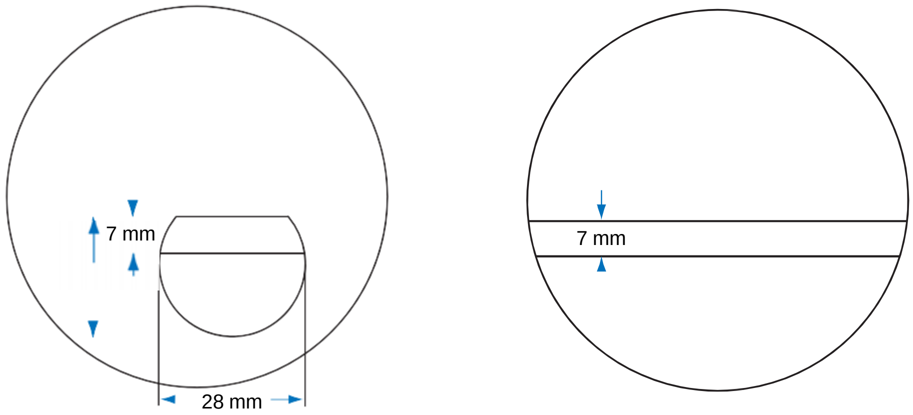
Franklin-Style (Executive) Segments

Franklin-style lenses are more commonly known by the trade name, *Executive*. It is a one-piece lens with the segment extending the full width of the lens. The lens has the advantage of a very wide near-viewing area.

There are some disadvantages to this lens. As the add power increases, the segment ledge gets bigger and more unsightly. Because the thickness of the lens is dependent on the near power rather than the distance power, the whole lens is thicker than a flat top would be. Thickness also increases with each increase in add power, making the lens progressively heavier. (It is possible to thin the lens by using yoked base-down prism. This principle is used for progressive addition lenses and is explained in Chapter 20.)

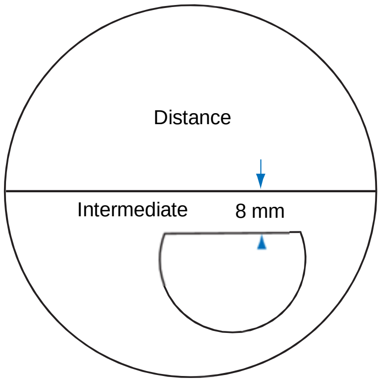
The Franklin-style bifocal has the segment OC on the segment line. For this reason, some have referred to these lenses as “monocentric” bifocals. However, a monocentric bifocal is one where the distance and segment OCs occupy exactly the same spot on the lens. It *is* possible for an Executive lens to be monocentric, but only if the lens is surfaced so that the distance OC is on the bifocal line at the same location where the segment optical center is found. This would not be expected to happen using today’s surfacing practices.

If Executive lenses are used, it is important to avoid large eye sizes and large effective diameters. A better alternative to the Franklin-style lens for someone desir- ing a large bifocal reading area is a large flat-top lens,



A Flat top trifocal

Franklin style (executive) B trifocal



C E/D trifocal

Figure 19-9. A-C, Types of trifocal lenses.

such as a flat-top 35. A large flat top will reduce weight and thickness, but still allow as wide a near field of view.

TYPES OF TRIFOCAL LENSES

Most bifocal styles are also available in a corresponding trifocal style. Trifocals offer the convenience of inter- mediate vision in a moderately large field of view (Figure 19-9 and Table 19-2).

Flat-Top Trifocals

Flat-top trifocals come with intermediate sections that vary in width from 22 mm to 35 mm and in depth from 6 mm to 14 mm (see Figure 19-9, *A*).

Any trifocal that has a depth of more than 8 mm should not be considered an all time–wear lens. Such lenses are better for occupational situations requiring a large intermediate working area. Trifocals are also

available with intermediate powers other than the standard 50% intermediate.

Franklin (Executive) Trifocals

The Executive, or Franklin-style, lens is a full-width segment lens with a 7-mm full-width intermediate (see Figure 19-9, *B*). It suffers from the same problems as the Franklin-style bifocal lens and because of the very visible twin ledges, loudly announces the wearer's need for an age-related lens correction.

The E/D Trifocal

The E/D trifocal combines the characteristics of the Executive-type lens with a 25-mm *D* (flat-top) segment (see Figure 19-9, *C*). It is constructed with a full, wide line across the lens dividing the distance portion from the intermediate portion and looks just like an Executive lens trifocal line. A flat-top segment is also placed in this lower, intermediate-powered portion. This is the segment needed for the near-working distance.

The lens is an excellent segmented lens for working at a desk. Intermediate viewing is available not only in the area 8 mm above the near seg, but also on either side of the near segment. This gives clear vision for wide, arm's-length working areas in every direction.

OCCUPATIONAL MULTIFOCALS

Any lens that is chosen by careful forethought and positioned for a specialized viewing situation may be classified as an occupational lens. However, there are certain lens styles that are specifically designed with certain work circumstances in mind. These lenses are called *occupational multifocals* (Figure 19-10 and Table 19-3). The following three sections discuss those available at the time of this writing.

Double-Segment Lenses

Some people require intermediate or near viewing while looking upward, including plumbers, pharmacists, librarians, electricians, auto mechanics, and many others in specialized working situations. Double-segment lenses were developed with these types of individuals in mind. Double-segment lenses have a segment in the normal position and a second segment at the top of the lens (see Figure 19-10, *A*). The two segments are normally separated by a 13-mm or 14-mm vertical distance (see Table 19-3 for more detailed information).

Double-segment lenses are underused. There are a great many people who would benefit from being able to see at close range just by looking up through an upper segment area. Instead they are required to tilt their head back in a very uncomfortable position for long periods of time because no one has told them that there is a lens that could solve their neck problems.

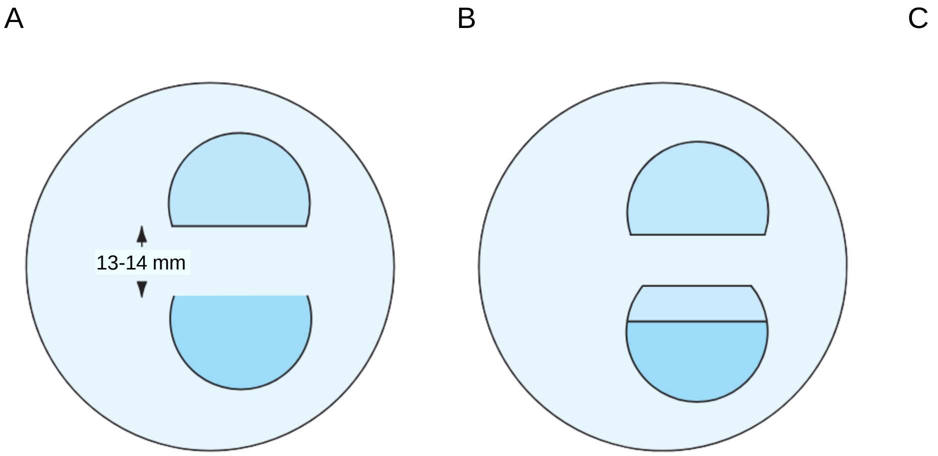
The upper segment comes in a variety of power possibilities. These include:

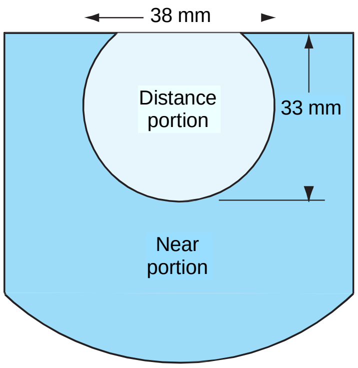
1. An upper segment that is identical in power to the lower segment.
2. An upper segment with a power that is ½ D less than the lower segment power.
3. An upper segment that is a given percentage of the lower segment, such as 50% or 60%, much like a trifocal.

The right way to decide which segment is most appropriate is to recreate the wearer's working situation, measure the working distances, and determine what the upper power should be. Once that has been done, choose the lens that fulfills the prescribed power needs. (For information on how to measure segment heights for double-segment lenses, see Chapter 5.)

Double-segment lenses are most commonly seen as flat tops, such as the double D.

The *quadrafocal* lens is a double-segment lens with a flat-top trifocal on the bottom and an upside-down flat-





Double D (Occupational flat top)

Quadrafocal

Figure 19-10. Three types of occupational multifocals.

Rede-rite (Minus add upcurve)

top segment on the top (see Figure 19-10, *B*). It is appro- priate for those who have need of both a trifocal and a double-segment lens. Since "quad" means four, the lens takes its name from the four distinct viewing areas. This lens is only available in glass.

The Minus Add "Rede-Rite" Bifocal

The *Rede-Rite* bifocal is a lens with a long history. It is a so-called upcurve bifocal because it has a large round segment at the top (see Figure 19-10, *C*), most of which is cut off after edging. This leaves the upper edge of the lower portion in the form of a circle that curves upward; hence, the term *upcurve*. It is a minus add, which means that the segment at the top has more minus power than the rest of the lens. In reality the lens is a bifocal with a

Rede-Rite. (For more information on these occupational progressives, see Chapter 20.)

ORDERING THE CORRECT LENS POWER FOR READING GLASSES

When a spectacle lens prescription is written with an add power, it is often written before a decision is made on what type of lenses are to be used. This means that the prescription may have to be written in a different form when ordered so that the same optical effect is main- tained. For example, if an individual wants reading glasses only, the order form will not be written with an add, but will be written for single vision lenses.

huge add area at the bottom and a small distance-viewing area at the top. It is a lens for people who want a seg- mented lens and need a full, near-working area. But they still want to see clearly in the distance without taking their glasses off.

More versatile alternatives are progressive add lenses that have wide near portions but also give clear, wide vision in the intermediate. Two such lenses are the AO Technica and the Hoya Tact. The Technica has a small distance portion located in the same place as that of the

Example **19-2**

A prescription is written as follows:

00.25 00.50 0 180
00.25 00.50 0 180
Add: 01.50

The wearer decides they do not want anything but single vision reading glasses. What power would be ordered?

Solution

The power ordered for reading must be the same as would be found through the bifocal segment. Earlier in this chapter, we stated that:

(distance power) 0 (near addition) 0 (near power)

Since reading glasses must be made for the near power, in this example, the near power is figured by adding the add power to the sphere power of the distance prescription.

00.25 00.50 0 180
01.50
01.75 00.50 0 180

A common mistake is to simply order 01.50 D sphere for reading. The needed near power is really 01.50 D sphere *in addition* to the distance prescription. The add power is *added to* the distance sphere power *and* the cylinder contained in the distance prescription to create the correct power for reading glasses. Astigmatism is still present in the eye regardless of whether distant or near objects are viewed. This requires that the cylinder power be included.

Ordering the Correct Lens Power forIntermediate and Near Only

Certain individuals work in circumstances in which theyneed to see at intermediate and near-viewing distances only. A distance correction is not needed. It is as if they need only the intermediate and near-viewing powers of a trifocal (Figure 19-11).

Example **19-3**

A prescription reads as follows:

R: 00.25 00.25 0 170 L: 00.25 00.25 0 010
Add: 02.50

The wearer has half-eye frames, is satisfied with them, andis not interested in a distance prescription. The wearer needs to see at intermediate distances. The decision is made to place a bifocal lens in the half-eye frame. What power lens should be ordered?

Solution

To find the new “distance” power, we need to know what thepower of the lenses through the intermediate area of a regular trifocal in this prescription would be. To do this, wemust first know the “intermediate add.”

A normal intermediate power is 50% of the near addition.Fifty percent, or half of the 02.50 near addition, is:

$$\frac{02.50}{2} 0\ 01.25$$

Therefore the top of the new half-eye bifocal must be the wearer’s distance Rx plus the addition in the intermediate,or 01.25 D. For the right eye this is:

00.25 00.25 0 170
01.25
01.50 00.25 0 170

and for the left eye:

00.25 00.25 0 010
01.25

01.50 00.25 0 010

These are the powers of the new “distance” portions of thelenses.

The near portion of the half-eye bifocal must read the samein the lensmeter as a regular bifocal lens would have read if it had been made in the original prescription. In the originalprescription, the near power for the right eye is:

0distance power0
+ 0nearaddition0
0near power0

or

00.25 00.25 0 170
02.50
02.75 00.25 0 170

So through the lensmeter, the near power must read: 02.75 00.25 0 170.

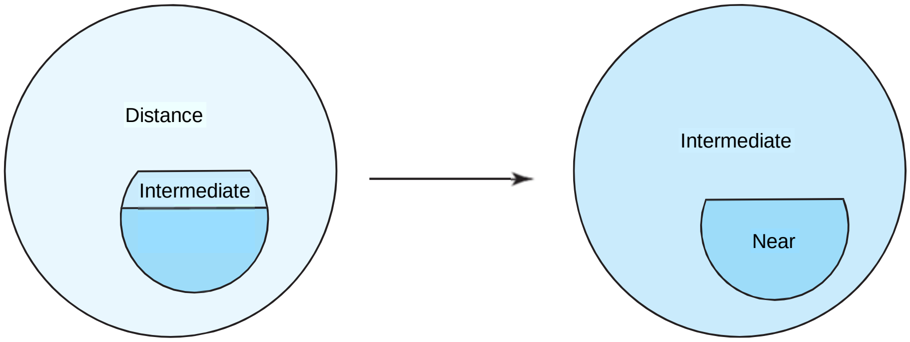


Figure 19-11. If a segmented multifocal lens is to be used for intermediate and near viewing only, the intermediate power goes where the distance power would

normally have been found. This will affect how the lens must be ordered, with even the add power changing to remain correct.

If

(distance power) 0 (near addition) 0 (near power)

diate for the right eye is the wearer’s distance Rx plus the intermediate addition.

02.50 01.25 0 160

then we know by transformation

(near addition) 0 (near power) 0 (distance power) This can be written as:

0near power0

– 0distance power0

0near addition0

and for the left eye:

01.12

01.37 01.25 0 160

02.50 01.25 0 015
<u>1.12</u>   <u>01.12</u>
01.37 01.25 0 015

So the add power is:

002.75 00.25 0 1700
<u>0001.5000.2501700</u>
01.25 add

Therefore the half-eye bifocal must be ordered as:

01.50 00.25 0 170
01.50 00.25 0 010
Add: 01.25

When ordered like this, the lens powers come out the same as they would have in the original prescription.

Example **19-4**

After wearing a new pair of trifocals for awhile, the individual returns, saying the trifocals are acceptable, but do not have enough reading area through the intermediate area. Instead they want a pair of bifocals just to wear at work. The strength through the top of a new bifocal lens should be the same as the existing trifocal intermediate. They do like the size and strength of the near portion and want it left as is. Their current prescription reads:

02.50 01.25 0 160
02.50 01.25 0 015
Add: 02.25

Another pair of frames is chosen, and bifocal heights are measured. What powers should be ordered for the new lenses?

Solution

First, determine the power through the present trifocal inter-mediate area. This could be done with a lensmeter, but is better accomplished by looking at the written prescription. Assuming that the intermediate is 50%, or half of the add power, the “intermediate add” will be:

$\underline{02.25}$ 0 01.122

The power of the new “distance” portion will be the powerthrough the old intermediate. Power through the old interme-

To stay with the nearest quarter diopter, we must change the 01.37 sphere power to either 01.50 or 01.25. We chooseto round up so that the new “distance” prescription for theright eye will be 01.50 01.25 0 160.

Next we need to know the near power of the prescription so that we can determine the add power for the new glasses. In the original prescription, the near power for the right eyeis:

0distance power0
$+$ $\underline{\text{0nearaddition0}}$
0near addition0

or

02.50 01.25 0 160
$\underline{\text{02.25}\qquad\qquad}$
00.25 01.25 0 160

So through the lensmeter, the near power must read:
00.25 0 1.25 0 160.

Since

0near power0
$-$ $\underline{\text{0distancepower0}}$
0near addition0

the new add power is

000.25 01.25 0 600
$\underline{\text{0001.5001.250 600}}$
01.25 add

Therefore the half-eye bifocal must be ordered as:

R: 01.50 01.25 0 160 L: 01.50 01.25 0 015
Add: 01.25

(NOTE: If we had chosen 01.25 0125 0 160 for the “distance” power when we rounded, the add power would have been 01.00 D.)

As demonstrated in the above examples, to maintain the intent of the prescription, it is sometimes necessary to change the powers of the lenses. Using these examples

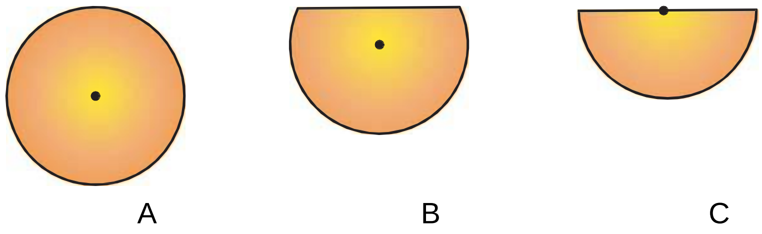


Figure 19-12. A-C, The distance from the top of the seg to the seg optical center varies with seg style. Three different seg styles, all set at the same height, can have very different locations for their segment optical centers.

as a beginning, it is possible to see how specialized eye- glasses can be designed to suit specific needs while main- taining the intent of the original prescription.

IMAGE JUMP

The segment portion of a bifocal lens is like a minilens. It has the same characteristics as a normal single vision lens, except it is smaller. The bifocal section is really a smaller lens on a larger lens. When the segment is round,

Solution

Since the segment is round with the seg OC in the middle, the upper bifocal border is 11 mm above that center. When looking through a point 11 mm away from the OC of a 02.00 D lens, a prismatic effect is created equal to:

$$0\ 0\ cF\ 0\ (1.1)(2.00)\ 0\ 2.20$$

Therefore a 22-mm round seg of 02.00 D add power has an image jump of 2.200.

the segment's OC will be exactly in the middle of the

seg (Figure 19-12, *A*). For example, if the segment is 22 mm round, the seg OC will be 11 mm from the top of the seg.

However, not all segs are round. Some are shaped with the upper section cut off so that the upper dividing line is closer to the OC of the seg (Figure 19-12, *B*). It is also possible to have a segment constructed such that the OC is exactly on the upper line (Figure 19-12, *C*). The style of segment chosen depends on the wearer's occupational visual requirement.

One noticeable side effect of segment shape happens as a result of the position of the segment OC compared with the location of the upper edge of the segment. The farther from the OC the eye looks, the greater will be the prismatic effect.

When wearers drop their eyes while wearing single vision lenses, prismatic effect increases as the eyes travel downward. If the lens is a bifocal, the segment also contains a prismatic effect. The value of the prismatic effect in the segment is dependent on the location of the segment optical center. When crossing the border of the seg, the prism induced by the distance portion is sud-

ACCOMMODATION AND EFFECTIVITY

There are several mysteries when it comes to comparing plus and minus lens wearers. Here are a few of them:

- Why do hyperopic spectacle lens wearers seem to need bifocals or progressives before myopic lens wearers?
- Why do middle-aged myopes sometimes have trouble with reading when switching into contact lenses, but middle-aged hyperopes do not? In fact the hyperopes going into contact lenses seem to postpone the need for a reading correction.Why do some previous spectacle lens–wearing myopes have trouble with reading after undergoing refractive surgery?

All of these questions stem back to the effect that spectacle lenses have on what is called accommodative demand. In this section, we will be showing how accommodative demand is affected by spectacle lenses, compared with contact lenses and no lenses at all.

Who Needs Bifocals or Progressives First,the Hyperope or the Myope?

The amount of accommodation required for an individual to see clearly at near is determined by three things:

1. The near-viewing distance
2. The power of the distance spectacle lens prescription being worn
3. The distance from the lens to the principal planes of the eye

The primary and secondary principal planes of the eye are those planes perpendicular to the optic axis at which refraction of incident and emergent light is con- sidered to take place. The distance from the spectacle lenses to the principal planes of the eye can be consid- ered as being the vertex distance plus 1.5 mm.* There- fore this distance is the vertex distance plus 1.5 mm.

To tell who will need a bifocal first, consider the situ- ation of an emmetrope[†] who wears no lenses at all. Suppose an emmetrope is wearing an empty frame at a 12.5-mm vertex distance. No accommodation is required for viewing objects in the distance.

.

0 07.76 D

For a near object at 40 cm, the vergence of light striking the lens is 1/00.40, which is the same as 02.50 D (Figure 19- 14). This vergence must be added to the power of the lens to find the vergence of light leaving the lens. The vergence of light leaving the lens is:

$$0\frac{1}{00.40}0\;0\,F_v 0$$

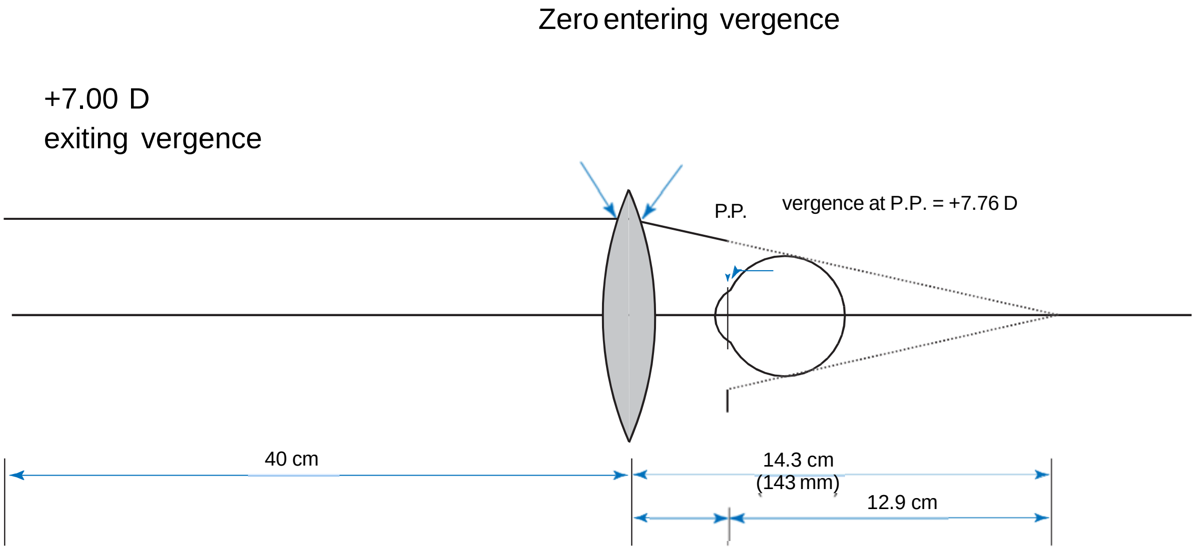


Figure 19-13. When light travels through a spectacle lens, the vergence of light reaching the eye is different from the vergence of light that left

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*According to Gullstrand's schematic eye, the principle planes of the eye are 1.47 mm and 1.75 mm behind the cornea.

[†] An emmetrope is neither nearsighted (myopic) nor farsighted (hyperopic).

[‡] In this case, the vergence of light is found by taking the reciprocal of the distance in meters from the eye to the source.

the back surface of the lens.

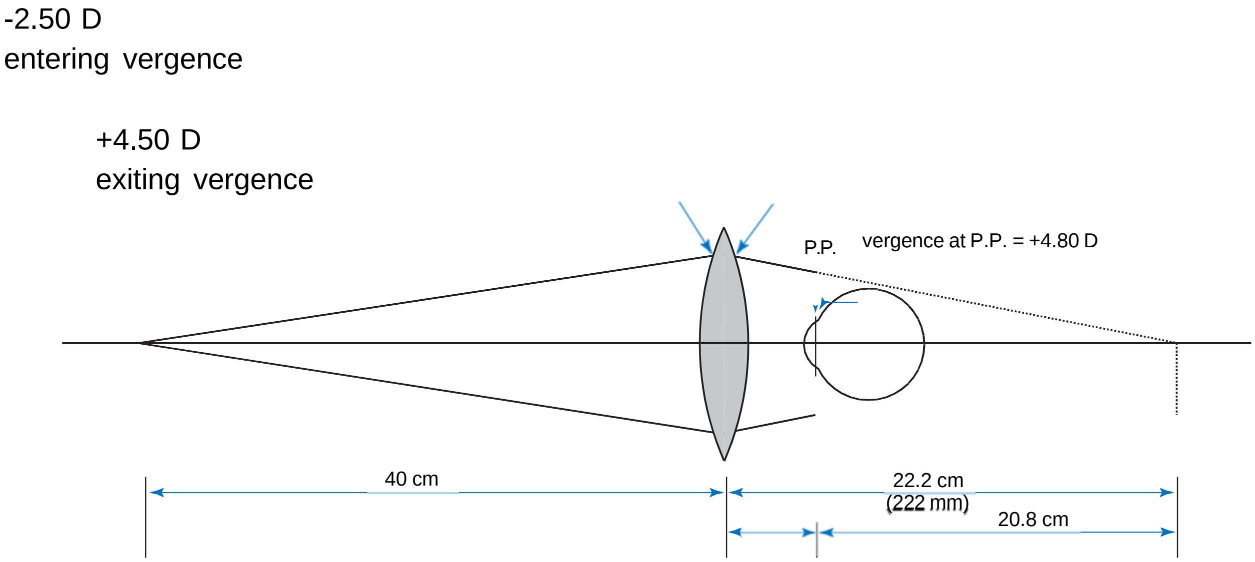

Figure 19-14. The amount of ocular accommodation required is the difference between distance and near vergence at the eye. In this case the amount of ocular accommodation required is 07.76 0 4.80 0 02.96. This is more than the approximately 02.50 D of accommoda- tion expected for an object viewed at 40 cm.

This means that the vergence of light for the near object atthe principal planes of the eye would be:

L 0 1

n 0 0

0 1 0

− d

0 0 1 0 0 F 0 0 v

If, then for a 07.00 D hyperope, the amount of accommoda- tion required to clearly see an object at 40 cm would be
07.76 04.80 0 2.96 D. This amounts to approximately ½ D
more accommodation required than for an emmetrope.

If the same calculations were done for a 07.00 D myope, the ocular accommodation would be found to be only
02.00 D. This is less than would normally be expected. In

0 00.40 0

v 00

other words, a 07.00 D hyperope wearing single vision lenses

0 1

0 1 0 0 *d*

02.50 0 *F*v00

0 1

0 1 0 0 0.014

0 02.50 0 *7.00* 0

0 1

( ) 0 1 0 0 0.0144.5

0 1

0.208

0 04.80 D

must accommodate almost a full diopter more to clearly see an object at 40 cm than a 07.00 D myope. *This means that a spectacle-wearing hyperope will require a near addition to their glasses before a myope will.*

How Contact Lenses Affect Required Accommodation In spite of differences in required accommodation for spectacle lens–wearing myopes and hyperopes, a contact lens–wearing hyperope will not need bifocals any sooner than a contact lens–wearing myope. This is because the spectacle lenses are the factor causing the difference in accommodation required. Contact lenses rest directly on the eye. This will return high plus and high minus lens wearers to a situation that closely resembles the emmetrope, equalizing accommodative differences.

What Happens as Add Power Increases

Interestingly, once a spectacle-lens wearer goes into bifocals, as the add power increases, differences in the amount of accommodation required for hyperopes and myopes decrease. When full presbyopia is reached, the 07.00 D hyperope does not need the nearly 03.00 D add that might be expected. This is because light from 40 cm

diverges to
02.50 D at the spectacle plane, but the 02.50 add in the spectacle plane changes the diverging light back to parallel. Thus light rays leaving the add enter the distance lens parallel and are able to be focused on the retina just as if they were coming from a distant object.

Determining Occupational Add Powers for New Working Distances

When someone needs a second pair of glasses for a specific occupational need, the working distance may not be the same as it is for normal wear. Usually the near prescription has been determined for a 40-cm working distance. At the new working distance, the wearer needs to be accommodating the same amount as they did for their regular working distance. This ensures that the near prescription will be neither too strong nor too weak. Therefore there must be a change in the add power. The prescriber can test at this new working distance and find the correct add power, or if the prescription is already written, it is possible to calculate the new add power using the optical principles previously described.*

Why Some Nonpresbyopes Need a Different Cylinder Correction for Near

Occasionally a nonpresbyope with an occupation requiring intense near work complains of eye fatigue with near viewing. In spite of all efforts on the part of the examiner to uncover the source of the problem by checking and rechecking the refraction, the solution remains illusive.

When the prescription contains a high cylinder power, there may be an optical answer that is not immediately obvious.

As shown previously, the power of a spectacle lens will affect the amount of accommodation required for near viewing. A spectacle lens containing a large cylinder component has a considerable difference in refractive power between its two major meridians. This means that a single vision lens wearer may require a different amount of accommodation for one meridian of the lens than for the other when comparing the effectiveness of that lens at distance and near. If the distance sphere power is also large, this effect can be even more significant. The net effect of these differences results in a new astigmatism at near that is different from the value found for distance vision. This new amount of astigmatism is not fully corrected at the near reading distance and may be the root of the problem.

The initial response may be to calculate a new cylinder correction for near. Yet rather than try and calculate a new cylinder correction to remedy the near problem, the best solution is to test for cylinder power and axis for near vision. Retesting with a near target during refraction is better than recalculating because there can sometimes be a slight amount of cyclorotation† of the eyes on convergence. A slight cyclorotation will change the cylinder axis. Therefore in cases like this it is best to test for both cylinder power and axis at near.

If there is a difference between distance cylinder values and near cylinder values, a second, single vision pair of glasses is needed for near work.

Fortunately, this problem also resolves as presbyopia advances.

Sample Questions:

1. Describe how multifocals are constructed?

Bifocals and trifocals are usually constructed in three main ways: fused, one piece, and cemented (shown in cross section in Figure 19-7).

4. *Fused*—Fused multifocals are available only in glass. The segment of the lens is made from glass having a higher refractive index than that of the distance "carrier" lens.* A fused glass bifocal has no ledge or change of curvature on the front. The segment cannot be felt because it is fused into the distance portion.
5. *One piece*—One-piece multifocals are made from one lens material. Any change in power in the segment portion of the lens is due to a change in the surface curvature of the lens. One-piece multifocals can be identified by feeling the segment border. If either a ledge or a change in curvature is felt, the lens is not fused and is most likely a one-piece design.

   One-piece multifocals may be made from any lens material. All plastic lenses are made as one-piece multifocals. One-piece glass multifocals are usually either the full-segment Franklin-style lens with the near portion occupying the entire lower portion of the lens, or they are large round-segment lenses.
6. *Cement lenses*—Cement lenses are custom-made lenses that have a small segment glued onto the distance lens. Used only for specialized custom purposes, such lenses are usually in the form of small, round segments.

Another occasionally used segmented lens is one that is actually two lens sections glued together. The upper half is a distance lens, and the lower half is a near lens. Both are cut in half, and half of each is used. The most common application for such lenses is for creating hori- zontal prism in the near portion only.

2. Discuss different types of bifocals?

TYPES OF BIFOCALS

There are a few major groupings of bifocal segment styles, but many variations within those styles (Figure 19-8 and Table 19-1). The basic styles include round segments, flat-top segments, curve-top and panoptik segments, and Franklin- or Executive-style segments.

Round Segments

Round segments vary in size from a small lens of 22 mm up to the largest, 40

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*The distance lens is denoted the "carrier" lens because it is the portion to which the multifocal segment is attached. The segment is carried by the distance portion.

mm. The most common size is 22 mm. For large, round seg sizes, 38 mm may be occa- sionally used. Logically the optical center (OC) of a round segment is always at the center of the segment. The round segment lens is a versatile lens because the round segment can be rotated and still not look tilted. It can also be positioned at odd locations on the lens, such as in the upper temporal corner of a golfer's right lens. (Assuming, of course, that the golfer is right-handed.) This keeps the segment out of the golfer's way and still allows access to a near add for score card marking and reading.

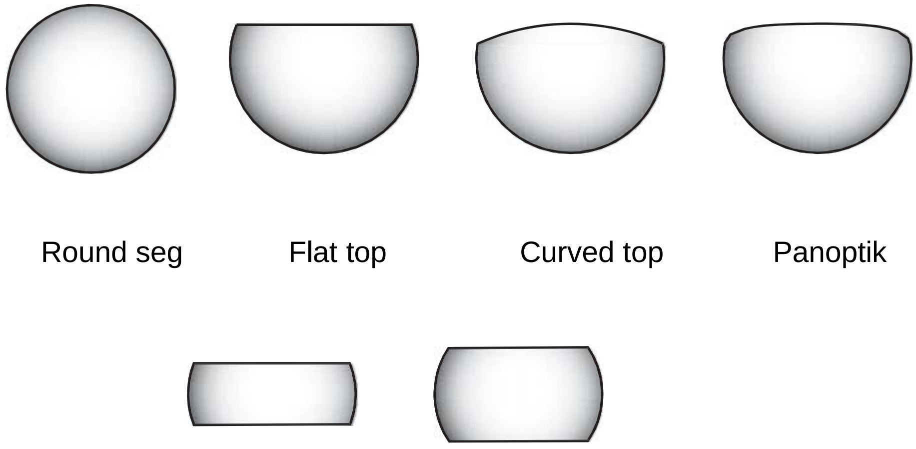


Figure 19-8. A sampling of available bifocal segment types.

Blended bifocals are round-segment bifocals with the border smoothed out to keep the segment from being seen.

Flat-Top Segments

Flat-top segments are basically round segments with the top cut off. The top is generally "cut off" 4.5 to 5.0 mm above the center of the segment. Stated another way, the segment OC is about 5 mm below the seg line. This allows the lens segment to have maximum reading width where a person will be reading. Very wide flat tops have the segment OC on the line. Flat tops are also known as *D segs*.

Flat tops are the mainstay of lined multifocal lenses. Segment sizes range from 22 up to 45 mm. Most flat tops used now are 28 mm or greater.

Curve-Top and Panoptik Segments

Curve-top segments look similar to flat tops, except that the upper line is arched, rather than flat. There is a dis- tinct point on either corner. The top of panoptik segments are curved as well, but the corners are rounded.

Ribbon Segments

Ribbon segments are basically round segments with the top *and* bottom cut off. There are two types: a B and an R segment. The B is only 9 mm deep and is good for someone who must be able to have distance vision below the bifocal area. Some remember the letter and function by identifying "B" with *b*ricklayer. Bricklayers often work in high places and can appreciate the ability to look below the segment and have clear distance vision.

The R segment has a 14 mm depth. It is seldom used as a regular bifocal lens. The R-segment bifocal is the same lens that is modified to create the "compensated 'R' " segment pairs that may occasionally be used for the correction of vertical imbalance.

Both B and R segments have their segment optical centers in the middle of the segment. Ribbon segments are available only in glass.

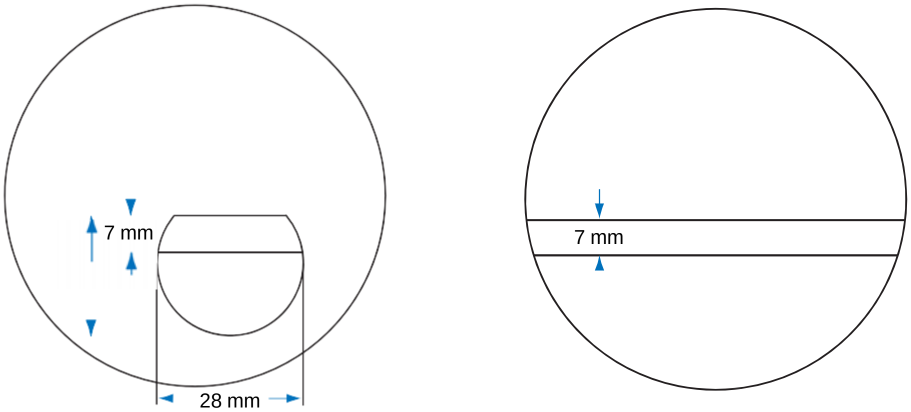
Franklin-Style (Executive) Segments

Franklin-style lenses are more commonly known by the trade name, *Executive*. It is a one-piece lens with the segment extending the full width of the lens. The lens has the advantage of a very wide near-viewing area.

There are some disadvantages to this lens. As the add power increases, the segment ledge gets bigger and more unsightly. Because the thickness of the lens is dependent on the near power rather than the distance power, the whole lens is thicker than a flat top would be. Thickness also increases with each increase in add power, making the lens progressively heavier. (It is possible to thin the lens by using yoked base-down prism. This principle is used for progressive addition lenses and is explained in Chapter 20.)

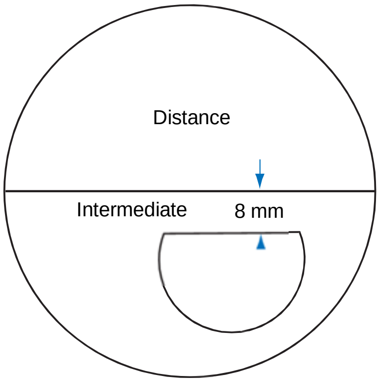
The Franklin-style bifocal has the segment OC on the segment line. For this reason, some have referred to these lenses as "monocentric" bifocals. However, a monocentric bifocal is one where the distance and segment OCs occupy exactly the same spot on the lens. It *is* possible for an Executive lens to be monocentric, but only if the lens is surfaced so that the distance OC is on the bifocal line at the same location where the segment optical center is found. This would not be expected to happen using today's surfacing practices.

If Executive lenses are used, it is important to avoid large eye sizes and large effective diameters. A better alternative to the Franklin-style lens for someone desir- ing a large bifocal reading area is a large flat-top lens,



A Flat top trifocal

Franklin style (executive) B
trifocal



C E/D trifocal

Figure 19-9. A-C, Types of trifocal lenses.

Unit 10:

Progressive Additional Lenses

Learning Objective:

At the end of this chapter, students will be able to learn:

1. Indications, uses, advantages, disadvantages of PAL's.
2. Selection of lens and frames for PAL's.
3. Verification of lenses and frames.

Progressive addition lenses are sometimes referred to as invisible bifocals. However, invisible bifocals have round segments where the demarcation line between the distance portion and the bifocal segment has been polished out, causing the two areas to appear as if blended together. Invisible bifocals are really blended bifocals, not progressive addition lenses.

SECTION 1

Measurement and Dispensing of Progressive Lenses

Progressive addition lenses are made with the help of specially designed front surface curves. These changing surface curves cause the lens to gradually increase in plus power, beginning in the distance portion and ending in the near portion. These variable-powered progressive addition lenses should, according to design, permit clear vision at any given viewing distance merely by positioning the head and eyes.

PROGRESSIVE LENS CONSTRUCTION

Like a segmented multifocal, a progressive addition lens, or *PAL,* has certain distinct areas to the lens. But those areas in a progressive lens are not visible. If we were able to see them, they would look like the lens in Figure 20-1.

The upper portion of the lens is basically the distance portion. The near portion of the lens, where the full near addition power is found, is down and inward. In between the distance and near portions is a *progressive corridor* where the power of the lens is gradually changing.

SELECTING THE FRAME

When choosing a frame for someone wearing a progressive addition lens, there must be enough room for the progressive zone and near portion. Because these areas are not visible like a bifocal segment is, they may be unintentionally cut off. This was a problem when progressive lenses were first introduced in the United States. At that particular time, many frames had narrow vertical dimensions. When progressive lenses were dispensed in these frames, much of the near portion was cut off. Since people could not see very well up close, dispensers falsely concluded that the lenses were no good, So, frame selection is an important part of fitting progressives. Here are some important points to keep in mind:

The frame must have sufficient vertical depth. Each lens type has a manufacturer-recommended minimum fitting height. The recommendations of the lens manufacturer should be followed. Standard minimum progressive addition lens fitting heights will vary, going down to a low of about 18 mm. If there is not enough vertical depth to allow the minimum fitting height, then either a different frame must be chosen, or a special short corridor lens that is designed for frames with a narrow vertical dimension should be used. Otherwise, there will not be enough reading area left.

The frame must have sufficient lens area in the lower nasal portion where the near progressive optics are found. Sometime the frame has a large enough "B" dimension, but the shape is cut away nasally. Aviator shapes are an example of this type of frame.

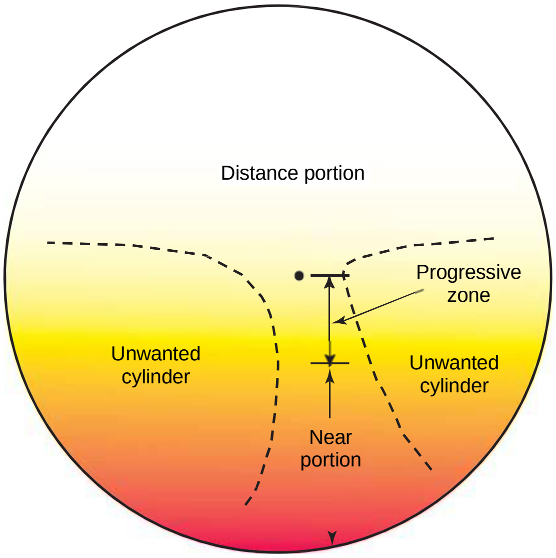
The frame should have a short vertex distance. The closer the frame is to the eyes, the wider the field of view will be for both reading and distance vision.

The frame must be able to be adjusted for pantoscopic angle when facial structure will allow a10- to 12-degree angle is recommended. The intermediate and near fields of view are effectively wider when the progressive and near zones are closer to the eyes.

The frame must have sufficient face form. This also allows a wider viewing area through the progressive corridor Frame selection criteria for progressive lenses are dis- cussed in greater detail in Chapter 4. The reader is encouraged to review this section, noting especially Figure 4-14.

CHOOSING THE RIGHT TYPE OF PROGRESSIVE

Most progressive lenses are made for general purpose wear since the majority of wearers only have one pair of glasses. Although general purpose progressives work for most people, here are some additional considerations:



Basic areas of a progressive addition lens

Figure 20-1. The basic construction of a progressive addition lens consists of a distance portion in the upper lens area, a near portion in the lower central area (slightly displaced nasally), and a progressive corridor between the distance and near areas where power gradually increases. On both sides of the progressive and near zones are areas containing a certain amount of unwanted cylinder. New designs are able to control the optics in these peripheral areas better, making them considerably more useful than might be anticipated.

1. What type of general-purpose progressive is appropriate? It is possible to choose a certain type of general-purpose progressive to fit the needs of the wearer. This is discussed in more detail in Section 2 of this chapter under General Purpose Progressives.
2. Does the wearer have a significant amount of cylinder power in the prescription? If so consider using a lens design that is atoric. (See the sections found on pages 474 and 475, beginning with “Designs Using Aspheric and/or Atoric Surfacing Methods.”) Using such a design will reduce the amount of unwanted distortion that will otherwise be present in the periphery of the lens.
3. If the vertical “B” dimension of the frame is small, choose a short corridor progressive lens. A short corridor lens is still used for general purposes, but is meant for this type of frame. For more on this topic, see Section 3, Specialty Progressives.
4. Does this person use a computer a lot? Do they work in a small office environment where intermediate vision is important? If so they may need a near variable focus occupational progressive lens. This type of lens is made for closer viewing distances through the top of the lens and has both a wider intermediate

progressive corridor and a wider near-viewing area. An occupational progressive lens should not be used as a person's only pair of glasses, unless this person does not need a distance prescription and would otherwise only be wearing reading glasses. These lenses should be considered for a second pair of glasses. For more on this topic, see Section 3, Specialty Progressives.

MEASURING FOR AND ORDERING THE PROGRESSIVE

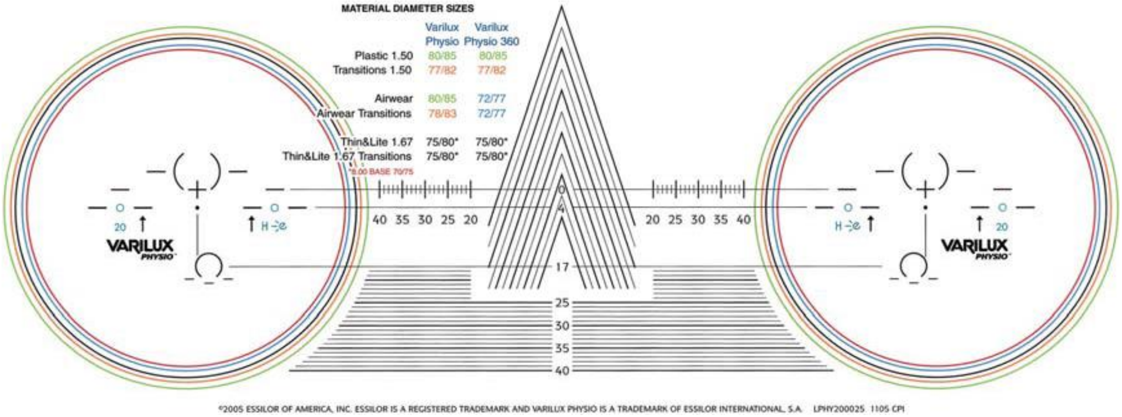
A progressive addition lens has a rather narrow progressive corridor linking the distance and near portions of the lens. It is through this corridor that intermediate vision takes place. Unless the eye tracks down the exact center of this corridor, the lenses do not work very well. Therefore, PD measurements must be taken for each eye individually and an exact vertical height specified for each eye.

To help make sure the progressive corridor is where it should be, the manufacture uses a *fitting cross*. The fitting cross is usually 4 mm above the start of the progressive corridor and is intended to be placed exactly in front of the wearer's pupil center.

Standard Method for Taking ProgressiveLens Fitting Measurements

The following measurement techniques are applicable to all manufacturers or designs of progressive lenses, provided the centration chart of the specific manufacturer is used for the lenses being measured. An example of such a chart is shown in Figure 20-2.

1. Measure monocular distance PDs. The recommended method is to use a pupillometer. (The use of a pupillometer is explained in Chapter 3.)
2. Fit and fully adjust the actual frame to be worn. This includes pantoscopic tilt, frame height, vertex distance, face form, and notepad alignment. Make certain the frame is straight on the face. If the temples are not adjusted, hold the frame in place while measuring so that it will not slip down the nose.
3. If the frame does not contain clear plastic lenses or the wearer's old lenses, place clear (non frosted), transparent tape across the eye wire of the empty frame.
4. The dispenser is positioned with his or her eyes at the wearer's eye level. With the wearer looking at the bridge of the fitter's nose, the dispenser draws a horizontal line on the lens or tape. The line should go through the center of the pupil. This is done for both right and left eyes. Place the frame on the manufacturer's centration chart and move it left or right until the bridge is centered on the diagonally converging central alignment pattern. Then move the frame up or down until the marked horizontal pupil center lines are on the chart's horizontal axis (Figure 20-3). Mark the previously measured PD for each eye as a vertical line that crosses the horizontal one (Figure 20-4).



MATERIAL DIAMETER SIZES

	Varilux Physio	Varilux Physio 360
Plastic 1.50	80/85	80/85
Transitions 1.50	77/82	77/82
Airwear	80/85	72/77
Airwear Transitions	78/83	72/77
Thin&Lite 1.67	75/80*	75/80*
Thin&Lite 1.67 Transitions	75/80*	75/80*

*8.00 BASE 70/75

Figure 20-2. The manufacturer's centration chart allows for easy reading of the fitting cross height. When monocular interpupillary distances have not been previously measured with a pupillometer but were marked on the lenses, their distances may be easily determined with the help of the horizontal scale on the chart. (The circles are for determining minimum blank size.) (Courtesy of Essilor of America, Dallas, TX)

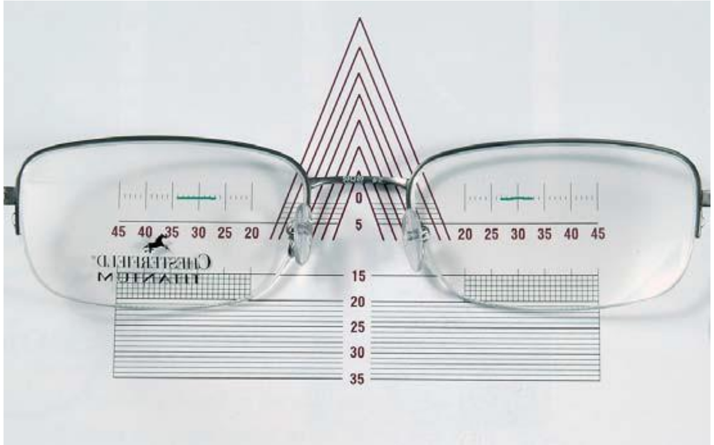


Figure 20-3. For this pair of glasses, the fitting cross heights are marked. The frame bridge is centered on the arrowhead lines. The fitting cross lines are positioned on the horizontal line, and their heights read as the lowest level of the lens on the lower, horizontal line scale.

5. For first one lens, then the other, read the fitting cross heights from the chart. (Fitting cross height is the vertical distance from the fitting cross to the level of the inside bevel of the lower eyewire of the frame.) Record these fitting cross heights and the monocular PDs on the order form and in the wearer's record. (Note: Fitting cross heights are usually erroneously referred to as major reference point (MRP) heights, which they really are not.)

6. Check the size and shape of the frame on the lens picture portion of the centration chart. Do this by placing the frame on the lens blank circles of the centration chart so that the cross on the glazed lens overlaps the fitting cross on the picture (Figure 20-5). The circle should completely enclose the frame's lens shape.

7. Send the frame to the laboratory with the marks still on the lenses or tape.

Fitting Cross Heights for Children

Progressive addition lenses are sometimes used for children. If they are, it is recommended that the lenses be fitted 4 mm higher than normal. An example of when progressives might be used for children is in the case of accommodative esotropia. The only time a child would not be fitted 4 mm higher than pupil center would be if the child has no accommodation, as after cataract surgery. In this case the fitting cross is positioned normally.

A fitting cross height 4 mm higher than the pupil center helps to ensure that the child is actually looking through the near zone for reading. This is consistent with the recommendation for children's bifocal fitting height. For children bifocals are normally fit with the segment line at the center of the pupil. Children adapt well to a 4-mm fitting cross raise and use the near portion for their near

The progressive addition lens wearers were fit with the fitting cross 4 mm above the pupil center. Most children with mild to moderate myopia are able to successfully adapt to PALs with a modified fitting protocol 4 mm higher than the adult standard protocol. This higher fitting protocol will help ensure that children are getting the full benefit of the near addition. Just like with adults, it is important to demonstrate and reinforce the proper use of PALs to children, including possible changes in head posture, head movements, and eye movements, as well as providing information about possible initial adaptation symptoms.

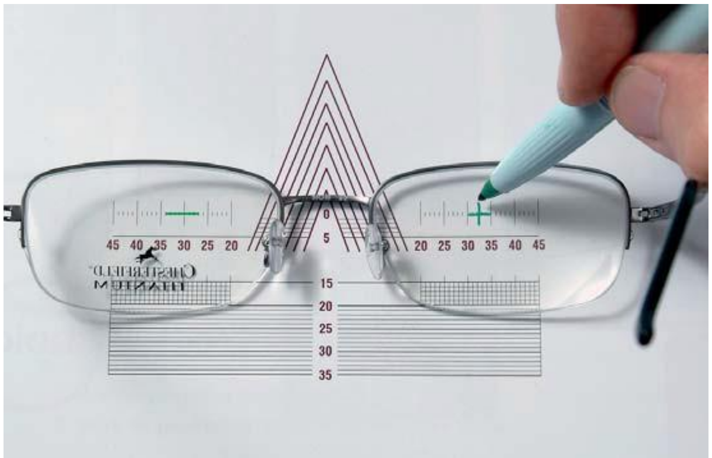


Figure 20-4. In preparation for checking whether a lens blank will be large enough for the frame chosen, the wearer's previously measured monocular interpupillary distances are marked on the lens.

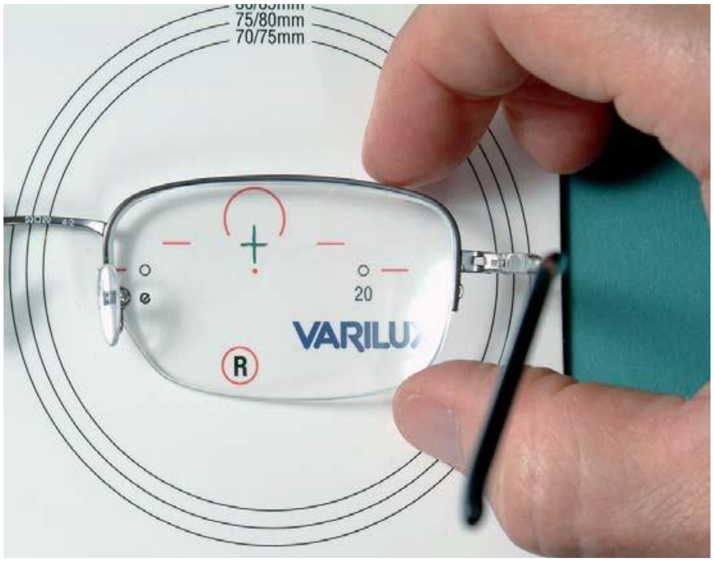


Figure 20-5. To see if the lens blank will be large enough for the frame, the fitting cross that has been drawn on the glazed lenses is placed over the fitting cross in the picture of the lens blank. The smallest lens size that completely encircles the edged lens or lens opening is the minimum blank size needed. If the largest pictured lens blank size fails to encircle the edged lens or lens opening, the frame is too large, and another frame must be selected.

Alternative Methods for Taking Progressive Lens Fitting Measurements

Marking a Cross on Glazed Lenses or Tape

Sometimes a pupillometer is not available for measuring monocular PDs. If this is the case, here is a method that uses only an overhead transparency pen and the frame:

1. Fully adjust the frame to fit the wearer correctly.
2. Position yourself at the same level as the wearer and approximately 40 cm away.
3. Close your right eye and instruct the wearer to look at your open left eye.
4. Use an overhead transparency marking pen to mark a cross on the right lens. If there is no lens in the frame, place clear tape across the lens opening and mark the tape instead. Draw the cross directly over the center of the wearer's right pupil (see Chapter 3, Figure 3-5).
5. Next close your left eye, open your right eye, and instruct the subject to look at your open eye. Then mark a cross on the lens or tape directly over the left pupil center.
6. Because of the movement involved in marking pupil centers and the ease with which unintentional head movement can occur, it is important that these markings be carefully rechecked. If the wearer turns the head slightly to one side, an error in monocular PDs will occur. It may be hard to catch this error since both monocular PDs may be slightly off, but still add up to what would otherwise be a correct binocular PD.
7. When you are confident that pupil centers are accurately marked, remove the frames. Measure and record the distances from the center of the bridge to the center of each cross using the progressive lens manufacturer's centration chart.

For those who prefer to use corneal reflections instead of the geometric center of the pupil, a penlight positioned directly below the dispenser's open eye will provide the source for the needed reflection (see Chapter 3).

Using the Red Dot Procedure to Subjectively Verify Fitting Cross Positions

To subjectively verify the position of the fitting cross, use the preceding method, but either substitute a red dot for the cross, or draw a red dot in the center of the cross. When measurements are complete, ask the wearer to look straight ahead and view a distant object. The object should appear pink if the wearer is correctly viewing through the red dots. First one eye and then the other is covered. If the wearer must move the head to see pink with either or both eyes, the lenses need to be remarked.[3]

VERIFYING A PROGRESSIVE LENS

Major Points or Areas

When the Rx is returned from the laboratory, it contains removable markings, such as a distance power arc, the fitting cross, horizontal dashes, and a prism reference point (PRP) dot. It may also contain a near-point power circle (Figure 20-6). The distance power arc indicates the recommended position of the lens through which the distance power should be read on the lensometer.

- The distance reference point (DRP) is at the center of the arc.
- The fitting cross will normally be centered in the pupil.
- The two horizontal dashes to the left and right sides of the lens help to tell if the lens is level or tilted.
- The centrally located PRP dot is used to verify prism power. This is the same as the MRP.

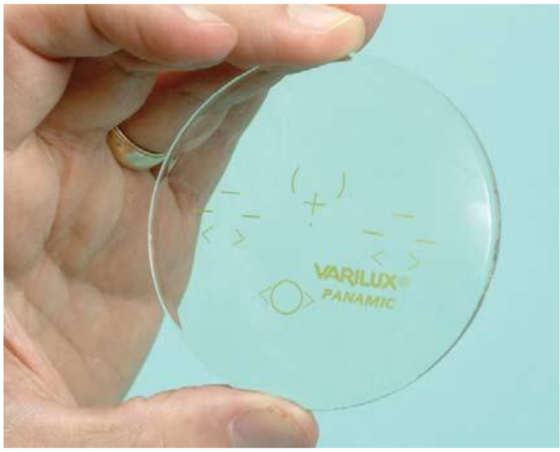


Figure 20-6. A progressive addition lens usually arrives with visible markings or a decal. These markings are used for verification and fitting purposes and are shown in the photograph. The upper semicircle or parentheses area is where the lens is verified for distance power. The fitting cross should fall directly in front of the pupil. The dot directly below the fitting cross is the location of the prism reference point (major reference point) and is where prismatic effect is verified. The lower circle is where near power is verified. The left and right sets of dashes denote the location of hidden marks used for remarking the lens once the visible markings shown here have been removed. The left and right sets of carets <> bracket the locations of the hidden identifying trademark and the marking for the add power. A hidden trademark, whether denoted by an oval or not, is on all progressive lenses and is important in identifying the brand of an unknown progressive lens.The circle in the lower part of the lens locates the near reference point (NRP) and is used to verify near power (Figure 20-7).

it is preferable that these markings on the surface of the progressive lens be left on the lens until the finished prescription is both verified and fitted on the patient. This enables the dispenser to verify the powers at far and near and to more easily judge the accuracy of the positioning of the lenses on the wearer's face when the frame is finally adjusted. When the temporary markings are gone, they can be reconstructed using hidden surface engravings.

Verifying Distance Power, Prism Amount,and Add Power

The distance power of a progressive lens should be measured with that portion of the lens that is marked by the distant power arc or circle positioned in front of the lensmeter aperture (Figure 20-8). The place where distance power should be measured is set by the manufacturer and is known as the DRP. Prism, however, is measured at the specified location of the PRP (Figure 20-9), even though the target may Progressive lens fitting and verification points

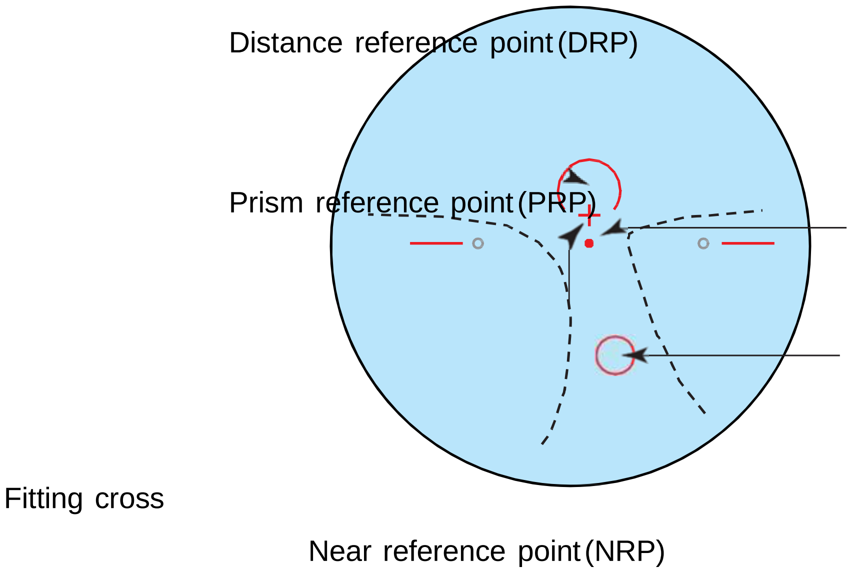


Figure 20-7. In verifying a progressive addition lens, the distance power is verified higher on the lens than it would be on any other type of lens. The manufacturer determines where it should be verified, calls it the distance reference point (DRP), and marks its location with a semicircle. Prism is verified at the prism reference point (PRP), which is the same thing as the major reference point (MRP). (Note that the fitting cross where the pupil center is located is *not* the same as the MRP. Nevertheless, many dispensers erroneously use the terms "fitting cross height" and "MRP height" interchangeably.) The add power is verified at the location set by the manufacturer, marked with a circle, and called the near reference point (NRP). No verification is done at the fitting cross.

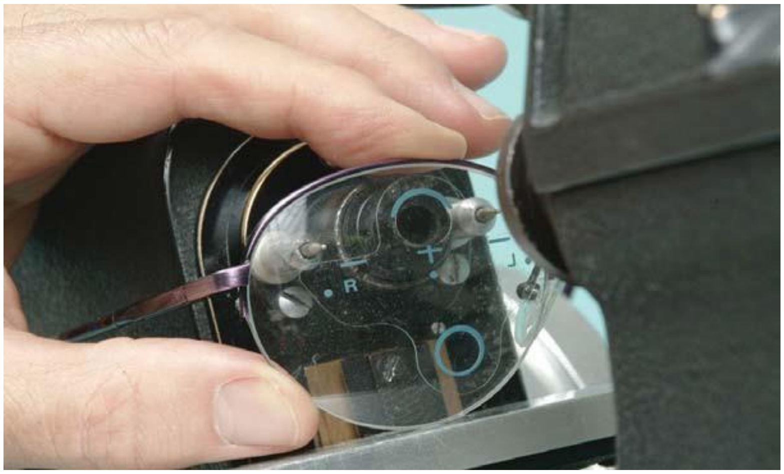


Figure 20-8. To verify distance power on a progressive addition lens, the lens must be positioned with the arc around the lensmeter aperture as shown. This ensures that the power reading will not be affected by the changing power in the progressive zone.

In practice the power of the near addition is seldom measured for progressive lenses. This is because the near addition power amount appears as a hidden number on the front surface of the lens. Instead of using the lens- meter for near power, verifying this hidden number is common practice.

Verifying Fitting Cross Height and MonocularInterpupillary Distances

Fitting cross height and monocular PDs can be checked by centering the bridge of the glasses on the diagonally converging central alignment pattern of the manufacturer's centration chart. The horizontal lines on the lens must be on (or parallel to) the horizontal axis of the centration chart with the fitting cross height at the "zero" level. From this position, the monocular PDs and fitting cross heights can be verified.

It is important to verify the location of the hidden engravings on the lens as well (Figure 20-12). This will ensure that the lens is indeed properly marked. It is not unusual for the laboratory to have to reapply the visible markings if they were removed during processing. If the visible markings appear correct but the hidden engravings do not coincide with them, the lens is not correct.

Locating the Hidden Engravings on aProgressive Lens

All progressive lenses have fairly similar markings or engravings on their surfaces. These markings are directly used to identify design, manufacturer, and add power. They are used indirectly to reconstruct the temporary markings that allow distance power, PRP, and near power to be found. The engravings that allow reconstruction of temporary markings are found in the forms of circles, squares, triangles, or trademarks at lateral positions on either side of the lens.

On most brands, the power of the add is engraved 4 mm below the temporal symbol, although it may be above that symbol on some. On many brands, but not all, a mark identifying the design or the manufacturer is engraved 4 mm below the nasal symbol. The hidden engravings can sometimes be hard to see. The following three sections discuss methods that may help dispensers locate them.

Use a Black Background

Using a black background, hold the lens so that there is plenty of light on it. It is often helpful to locate the light source on the other side of the lens, off to the side or above it. Tilt the lens to inspect the front surface from different angles until the markings become visible.

Use a Fluorescent Bulb

It may be possible to find the hidden markings on a lens by using a fluorescent light source behind the lens. To use this method, hold the lens up with a fluorescent ceiling light in the background and view the lens surface.

Use a Hidden Circle Finding Instrument

The Essilor instrument for finding hidden circles con- sists of a magnifier and an area for the lens that is illuminated with a bulb. This facilitates lens identification in a controlled manner (Figure 20-13). Markings are considerably easier to see because they are clearer and also appear larger. Figure 20-14 shows a view of what the hidden markings look like through this instrument.

Identifying an Unknown Progressive Lens

When someone is wearing a progressive lens and the lens manufacturer, lens design, or lens material of the progressive are unknown, the hidden markings will reveal the needed information. Remember that normally a hidden marking identifying the design is engraved

4 mm below the nasal hidden circle or symbol. To "decode" these markings, look in the Optical Laboratory

Progressive lens reference points

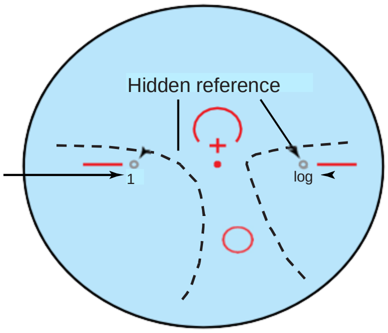


Figure 20.9. Manufacturers place hidden marks on the front surface of a progressive lens for four reasons: (1) to identify their product so that the dispenser is certain the product is the brand ordered, (2) to identify unknown lenses already being worn, (3) to indicate power, and (4) to provide reference points to allow the reapplication of visible markings for verification purposes. In this illustration, the number 17 indicates a D1.75 D add power.

Hidden add power engraving

Manufacturer's hidden identifying logo

Association's (OLA) *Progressive Identifier* (Figure 22-15). This publication shows pictures of each type of progressive lens with all their hidden markings. In the front is an index by symbol. Find the symbol in the index and look up the lens on the appropriate page. The *Progressive Identifier* gives information on lens type, material, fitting cross location, and minimum recommended fitting height. It is available through wholesale optical laboratories or direct from the OLA.

Remarking a Lens Using Hidden Engravings

To remark a lens, the two hidden engraved circles (or marks) can be emphasized by dotting their centers on the front side with a thin felt-tip or fiber-point pen. These dots are then placed on the respective manufacturer's centration or verification chart. The other markings for the power control circle, fitting cross, and optical center (OC) can be traced from the chart. Alternatively a set of plastic dispensing decals may be used, if available. The decals form a set of two, one for each eye, with the near circle decentered nasally on each.

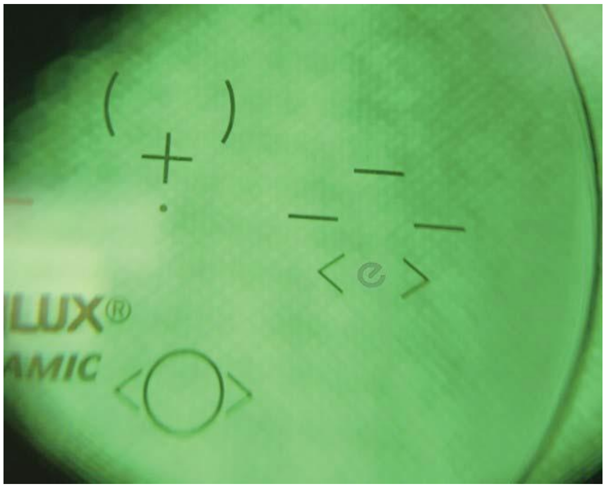


Figure 20-13. This Essilor instrument allows the hidden markings on a progressive addition lens to be seen much more easily than with the naked eye. The open placement of the lens on the instrument means that the markings can be dotted with a marking pen while looking through the instrument.

Figure 20-14. This photo shows the permanent, hidden marking on a progressive addition lens using the Essilor instrument. The permanent lens identification logo is found between the nonpermanent, caret marks. (The photographic view through the instrument as seen in this figure has been retouched for clarity.)

Figure 20-15. This is a page from the Optical Laboratory Association's (OLA) *Progressive Identifier* used to find information about progressive addition lenses.

DISPENSING PROGRESSIVES

Validation on the Patient

Once the prescription has proved to be correct, it is adjusted to fit the wearer. Normal frame fitting rules apply. In addition, to provide the maximum possible field of view, adjust the frame for:

1. A small vertex distances
2. Adequate face form
3. A maximum pantoscopic tilt that still looks appropriate for the wearer

With the visible markings still on the lenses, also check the following:

1. The fitting crosses should be in front of each pupil center. (Ensurance of the placement of the fitting crosses is especially important when the two eyes are not at an equal vertical height.)
2. The horizontal dashes on the lenses should be exactly horizontal and not tilted.

Removing the Visible Markings

The visible marks that are on a progressive addition lens when it comes back from the laboratory are nonwater soluble. To remove them, use alcohol or an alcohol swab. Sometimes these marks can be stubborn. Some say that stubborn markings will come off easier if the lens is first heated in the hot air frame warmer. The alcohol may work better on the heated mark.

Instructing the Wearer at Dispensing

Adapting to progressive lenses can be made easier for a new wearer if the characteristics of the lenses are demonstrated at the time they are dispensed.

To demonstrate the full range of progressive lens versatility, hold a near-point chart at eye level at an inter- mediate distance. Instruct the wearer to look directly at the near-point card through the distance portion. Next ask the patient to tilt his or her head back until the letters on the card are clear. Gradually, bring the card closer to the eyes as the head is tilted still farther back, demonstrating the full range of viewing available.

More head movement is required with progressive lenses. Therefore, some fitters recommend instructing the wearer to first point his or her nose at the object to be seen, then to move the head somewhat up or down until things clear.

Attention should also be called to any distortion present during peripheral gaze so the wearer understands that this is to be expected. While the wearer holds the head still, demonstrate areas where vision is not as clear by moving the near-point card to the left and right in the reading area while the wearer follows the card with the eyes. As observed in some studies, adjustment to distortion and increased head movement are adaptations that depend on steady wear of the lenses. In other words, wearing the lenses at all times will speed the adaptation process. Emphasize this point to the new wearer.

Once again remember that it is better to point out any areas of distortion, rather than having the wearer “dis- cover” them and report back with a problem. If this lens characteristic is pointed out ahead of time, the dispenser is considered to be knowledgeable when it occurs. If the wearer discovers the problem and points it out, the dispenser is in the awkward position of having to explain after the fact.

TROUBLESHOOTING PROGRESSIVE PROBLEMS

Most problems encountered by progressive lens wearers are a direct result of basic fitting principles being ignored. Here are a few typical errors that should never occur, but do.

- One monocular PD is correct; the other is wrong. This happens when the monocular PDs are done with a ruler or by marking the PD measurements on the lenses, and the fitter uses only one eye to measure both lenses.
- The PD is given as a binocular PD, rather than as two monocular PDs.
- Fitting cross height is measured for one eye, and the same measurement is written down for both eyes. Fitting cross heights must be individually measured for both eyes.

When a wearer does come back with a complaint, the most straightforward way to check for possible problems is to ***first*** put the progressive markings back on the lenses and see if they are correct in relation to where they should be when the prescription is worn. Often the problem will be obvious. If the solution is not immediately apparent, Table 20-1 gives some common complaints with reasons they may occur and possible solutions.

Using the Near PD Method When Near PD Proves Incorrect

Sometimes it becomes necessary to troubleshoot a problem of insufficient near-viewing area. There are numerous possible reasons for this happening. These are listed in Table 20-1. When none of the other solutions are applicable, it may be that monocular distance PDs are correct, but the monocular near PDs are either too large or too small. Here is one way to solve the problem.

For many progressives add lenses, the near-viewing area is inset from 2.0 mm to 2.5 mm per lens. Most manufacturers use 2.5 mm per lens. (Newer progressives

SECTION 2

General Purpose Progressives

OPTICAL CHARACTERISTICS OF GENERAL PURPOSE PROGRESSIVES

The first successful progressive addition lenses were designed to maintain some of the characteristics of a bifocal. One criterion considered to be important was maintaining traditional lens optics in the upper half of the lens. If this is done, the power from the midline upward corresponds exactly to the prescribed distance power. At the midpoint of the lens and downward following the expected path of the eyes, plus power begins to increase. Once the full add power is reached, lens power does not vary. The progressive zone connects distance and near lens areas. These types of lenses are said to have *spherical upper halves* because the front surface of the upper half of the lens is spherical, rather than aspheric.

The first really successful progressive lens was the original 1959 Varilux lens.[5] The 1959 Varilux lens used this design philosophy.

Unwanted Cylinder

Unwanted cylinder is the greatest problem inherent in progressive addition lenses. Although the progressive zone gives clear vision when properly fitted and dispensed, the area to either side of this zone will have some unwanted cylinder power. This cylinder varies in amount and orientation, depending on design and add power. It will be noticeable if the eye moves far enough laterally from within the progressive zone.

A Sandbox Analogy

There are certain design characteristics that change the amount of unwanted cylinder in the periphery of the lens. To help understand how this works, we will use an oversimplified example of a sandbox. Think about a round sandbox with the surface of the sand smoothed to a spherical shape to resemble the front surface of a regular, single vision lens. Suppose we want to change the surface curvature of one area of the sand. The object is to give the surface a new “power” so that it will resemble the near portion of a progressive addition lens.

We can do this by starting at the center and gradually increasing the curvature of the surface in a certain area corresponding to the progressive portion of a lens. In other words, we start shaving the surface of the sand, removing sand from that area. But one of the first sandbox rules is, “You are not allowed to throw sand out of the sandbox. So where do we put the sand? If we wanted to keep the upper half of the lens at exactly the distance power, it could not go there. So sand would have to be piled on either side of the progressive zone and then smoothed out. This changes the curve of the surface and causes unwanted cylinder.

Interrelating Progressive Design Factors

Here are some general design factors that may influence unwanted cylinder power and other lens parameters. †

1. *Add power*—as add power increases, so will the amount of unwanted peripheral cylinder.
2. *Rate of progressive power change*—progressive power can change from distance to near zones in either a rapid or slow fashion, making the progressive corridor either short or long. A rapid change means that the progressive zone surface curvature changes over a very short distance resulting in a short corridor lens. When the power changes rapidly
   - The intermediate zone width will generally be smaller.
   - The near zone is generally wider and larger.[6]

   If the progressive zone is longer, the plus power changes more slowly. A longer progressive zone means less unwanted cylinder; a shorter progressive zone means more unwanted cylinder.
3. *Intermediate zone width*—a larger minimum zone width is associated with lower amounts of unwanted cylinder.[6] The smaller the intermediate zone width and area, the greater the unwanted cylinder will be. However, there is not as direct a relationship between the amount of unwanted astigmatism and near-viewing zone size.
4. *Zone widths*—distance and intermediate and near zone widths influence each other. When one zone is made larger or wider, the other two zones will become narrower and smaller.[6]

The Use of Contour Plots to Evaluate Progressive Lenses

In 1982 a standard format was initiated for representing the surface characteristics of progressive addition lenses. This took the form of connecting points having equal powers. The concept is similar to that of topographic maps that show mountainous heights. These line diagrams are known as contour plots. One form of contour plot maps the amounts of unwanted cylinder power, showing how fast cylinder power increases over the lens surface. Areas of equal

cylinder power is plotted with a connecting line. These lines are called *isocylinder lines* (Figure 20-16, *B*). Another type of contour plot maps areas having equal spherical equivalent powers (Figure 20-16, *A*). With these it is possible to see:

1. How fast the power increases in the progressive corridor
2. What kind of power changes take place in the upper and lower lens peripheries

Being able to read contour plots allows for a greater understanding of the features common to all progressive lenses and the individual characteristics that may differentiate one lens design from another. It should be understood, however, that contour plots in themselves may not precisely convey a given lens' actual performance when being worn. Clinical choices made by progressive addition lens wearers may not agree with predictions anticipated from contour plots.

Contour plots do demonstrate relative progressive zone width, the presence of a hard or soft optical design, and the anticipated amount of unwanted cylinder in the upper half of the lens. They may also be helpful in matching a certain style of progressive addition lens to the optical needs of the wearer.

HOW PROGRESSIVE LENS DESIGNS HAVE CHANGED

We would not expect today's progressive addition lenses to be the same as they were when first successfully used. Progressive lens designs come forth as a result of professional judgments as to what lens characteristics are most important when worn. These judgments do not always agree. In addition, one philosophy may be correct for one wearing situation, but not for another. Here are some of the contrasting ways lenses have been designed.

Spherical and Aspherical Distance Portions

Originally, progressive lenses were designed to maintain an upper half just like a regular single vision lens. The upper half had a spherical front surface (Figure 20-17). In 1974 Varilux introduced a design that attempted to reduce the intensity of unwanted cylinder by spreading it out over a larger area. * It soon became evident that small amounts of induced astigmatism could be tolerated in the periphery of the distance portion. Lenses designed in this manner are aspherical[†] in the upper *and* lower portions of the lens surface instead of just in the lower section containing the progressive corridor (Figures 20-18 and 20-19). Returning to the oversimplified sandbox *Keep in mind that this is an analogy only and is not what really happens with progressive lenses. It is only meant to characterize the problems faced by lens designers.

[†] Much of the information found in this section is taken from Sheedy JE: Correlation analysis of the optics of progressive addition lenses, Optometry and Vision Science 81(5):350–361, May 2004.

*This lens was called the Varilux 2 or Varilux Plus.

[†] An aspherical surface is one that does not maintain a constant spherical curve, but changes in curvature over a given area. Aspherical means no spherical.

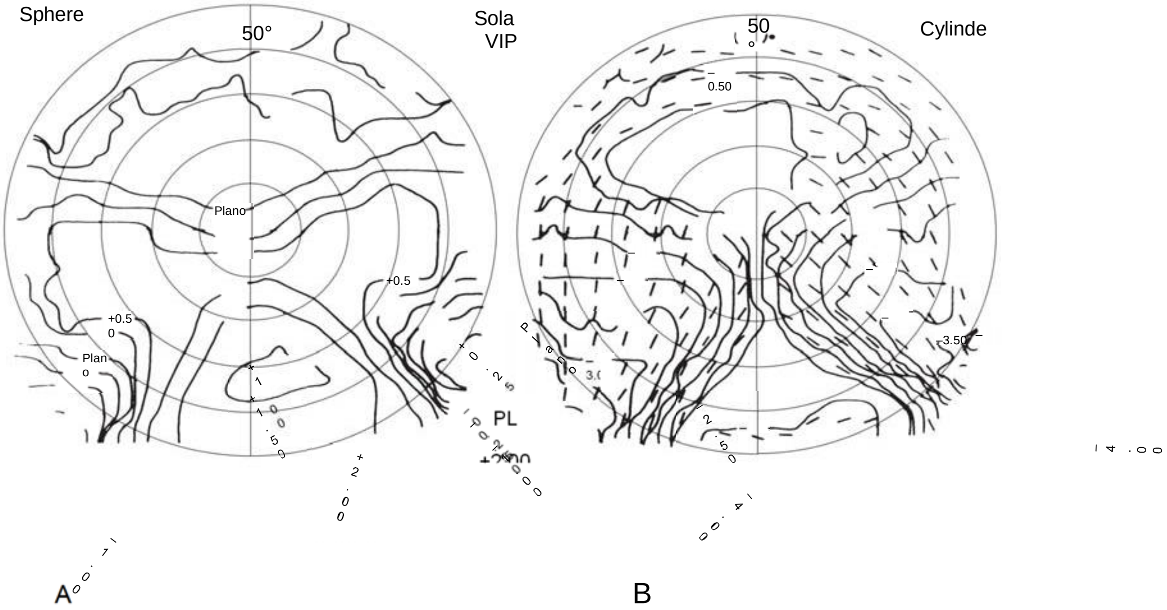


Figure 20-16. The contour plot in **A** shows changes in lens power plotted as the spherical equivalent.

Spherical equivalent D sphere D $\frac{\text{cylinder power}}{2}$

The contour plot shown in **B** is plotted as unwanted cylinder alone. Both plots are of the same lens having a plano distance power and a D2.00 add power. (From Sheedy JE, Buri M, Bailey IL et al: Optics of progressive addition lenses, Am J Optom Physiol Optics 64:90-99 1988, Figure 1.)

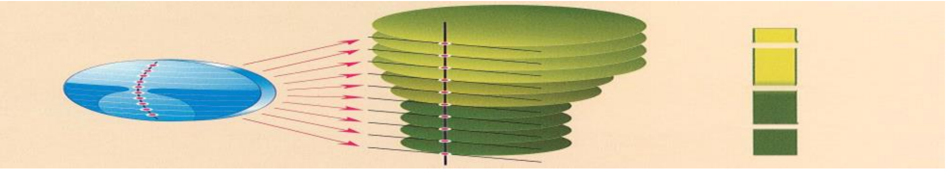


Figure: 20.17

The original Varilux lens was designed to maintain a spherical surface in the upper half of the lens. It had two large and spherical distance and near vision zones linked together. (From Progressive addition lenses, Ophthalmic Optics File,p. 28, Figure 25, Essilor Interna- tional, Paris France, undated publication.)

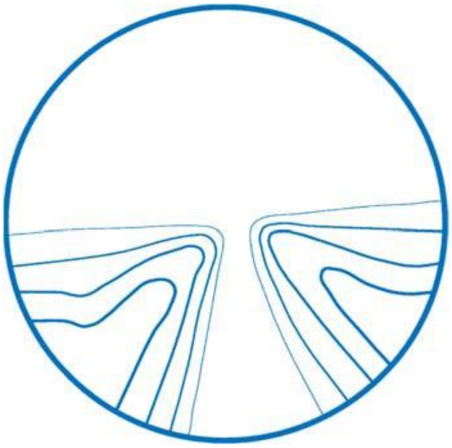


Figure 20-18. This simplified contour plot shows a lens with a spherical upper front surface. The concentric lines represent the areas of increasing astigmatism. (This contour plot is theoretical only and is not a representation of any existing lens.)

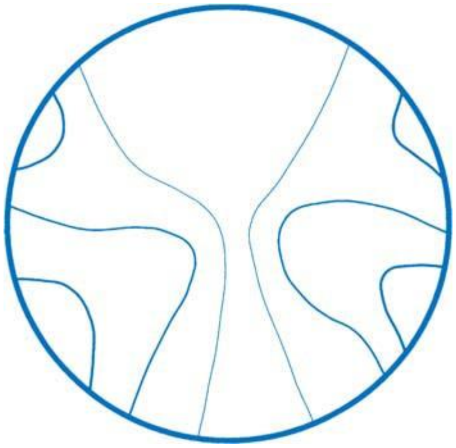


Figure 20-19. This progressive lens representation shows a lens with an aspheric upper front surface. Asphericity is allowed to continue into the upper half of the lens, with small amounts of astigmatism being evident in the periphery of the top half of the lens. (This contour plot is theoretical only and is not a representation of any existing lens.)

analogy, we can see that in allowing the displaced "sand" to be spread over a larger area the amount of unwanted cylinder in any given area will be reduced. Usually, a lens with a spherical upper half resembles a "hard" design and one with an aspherical upper half, a "soft" design. These terms will be explained shortly.

Hard Versus Soft Designs

When an individual wearing a progressive addition lens is using the near-viewing area of the lens and slowly looks to one side, the eyes begin to leave the region of

the near zone. Outside of this near zone, the power begins to change, and unwanted cylinder power increases.

Hard Designs

With a bifocal lens, there is a distinct, lined border between the near-viewing area and the rest of the lens. There is no question as to where the near portion ends. With some types of progressive addition lenses, the change in power and increase in astigmatism is more demarcated than in others. For example, the unwanted cylinder may rapidly increase from nothing up to 0.50 D, then move quickly to 1.00 D, and on up to 1.50 D in the space of only a few millimeters. Because of the rapid change along the border between viewing areas, this type of design is known as a hard design (Figure 20-20).

Hard designs generally offer larger and more delineated areas of unvarying optical power for distance and near viewing. Often in hard designs, the power in the progressive channel increases rapidly. When a person looks down, the eyes reach the level of full add power sooner.

The disadvantages of hard designs are linked with the rapid increase in cylinder power and the areas in which that unwanted cylinder is concentrated. Distortions caused by more rapid power change may mean a slightly longer period of adaptation. Straight lines may appear more curved when viewed through the lower half of the lens than they do with other designs. (It should be noted that all progressive add lens designs cause this effect to some extent, at least during initial adaptation. Even the near portion of a bifocal lens can cause a straight line to appear curved.) The intermediate viewing area of the lens may be more limited both vertically and horizon- tally, requiring the wearer to zero in more consciously to view intermediate objects with clarity.

Soft Designs

A soft design is one in which the change from the near zone to the peripheral area is gradual when compared with a hard design (Figure 20-21). As the wearer's eye begins to leave the near zone laterally, the amount of unwanted cylinder increases, but more gradually. From the wearer's point of view, it is not easy to determine where the near zone ends. A soft design has a slower vertical change in power as the wearer looks from distance to near. In other words, the progressive channel is longer and usually wider. This means that the wearer has to drop the eyes farther down into the lower areas of the lens before reaching the full near power.

The advantages of a soft design are easier, more rapid adaptation times; less distortion of peripherally viewed objects; and less "swim" of objects with head movement. Soft designs typically start with a smaller near zone and allow aberrations to spread over a larger area, including parts of the upper half of the lens. This means that the

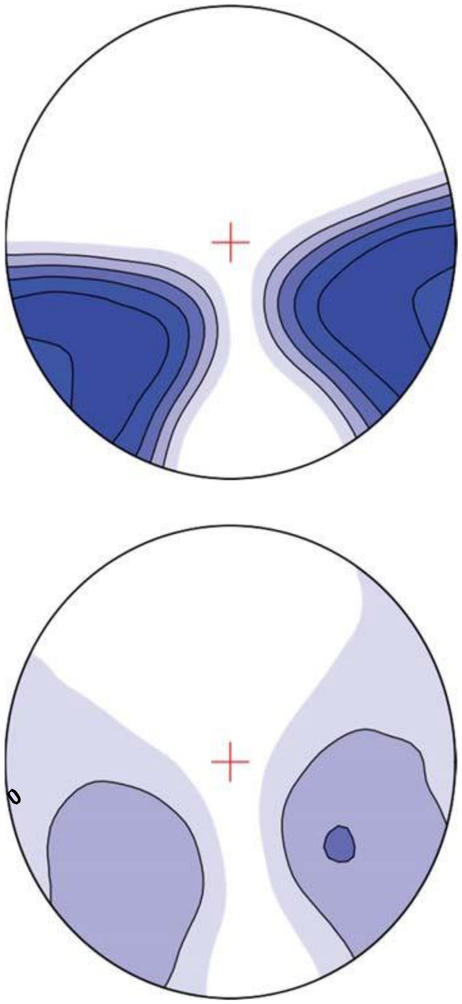


Figure 20-20. This is an example of a lens that has a some- what hard progressive addition design. **A,** The contours of increasing astigmatism start at the border of the corridor and near zone. Each contoured area farther from the zone shows darker in on the diagram and represents a change in measured cylinder power. The near portion is fairly wide, and the contour lines are closely spaced at the border of the progressive and near zones. This indicates a more rapidly changing cylinder power. **B,** This 3-dimensional rendition of the same lens shows increasing cylinder as seen by increasing elevation. The lens is a 50 mm round lens. (Illustration's courtesy of Darryl Meister, Carl Zeiss Vision.)

The disadvantages of soft designs include the possibility of a slight reduction in visual clarity in the upper peripheral areas of the distance lens, the necessity of dropping the eyes farther to reach the full add power* and a “smaller” near zone. It should be noted, however, that wearers do not always find the near zone to be functionally as small as it may appear on an astigmatic contour plot. Because the amount of unwanted cylinder increases so gradually as the eyes leave the near zone laterally, the wearer may be able to use the outer limits of the near area anyway, even though these areas contain a certain amount of unwanted cylinder power. For a summary comparing hard and soft designs, see Box 20-2.

Monodesigns Lead to Multidesigns

As can be imagined, there are a multitude of ways to design a progressive addition lens. It is the job of the designer to try and anticipate the needs of the wearer. Initially, all progressives had a single design for all powers. This was later called a “monodesign.” A monode- sign is limited in its effectiveness.

When a person first enters the age of presbyopia, the power of the needed near addition is low. This means that a new presbyope still has a considerable amount of accommodation left. For example, an individual with a D1.00 D add power really does not need a special correc- tion for intermediate distances. If presbyopes with a *To counter this problem, the designer may increase power progres- sion so that most of the add power is reached earlier. For example, a Varilux Comfort lens reaches 85% of add power 12 mm below the fitting cross.

D1.00 D add needed a special correction for intermediate viewing, there would be people wearing trifocals with a
D1.00 D add. Yet trifocals are not made for add powers below D1.50 D.

With this in mind, designers began to ask whether or not consideration should be given to using more than one design for the same progressive lens, depending on the power of the near addition for that lens.

If changing add power is a major factor that alters the design needs for a progressive add lens, it would be logical to design a different lens for each add power. This is the basis for the *multidesign* lens, which varies to allow for changing needs with changing add powers.

Progressives Should Be Uniquely Rightand Left Specific

From a historical perspective, when progressives were first emerging, it was not unusual for both left and right lens blanks to be identical. There was no difference between a right and left lens blank. Since the eyes turn inward for reading, the progressive corridor must tilt inward. Each lens was rotated so that the channels tilted nasalward. This was not the best design, because when the lenses are rotated, prismatic effects are different for left and right eyes in certain directions of gaze. If both eyes looked into the lower right areas of their respective lenses, those two locations were not the same in power and prismatic effect.

Right- and left-specific lenses should be designed to work as a pair so that peripheral power, cylinder, and vertical prism are matched for binocular viewing.

NEW MANUFACTURING METHODS ALLOW NEW LENS DESIGNS

Recently there have been some major changes in the way lenses can be manufactured. These changes employ a method of generating the lens surface that differs from what is normally done. It is now possible to individually shape a lens surface to a unique form with a varying surface curvature and then polish that surface to optical quality. This type of manufacturing has commonly been referred to as *free-form generating,* although Shamir has trademarked that term, and a general term to replace it has not yet emerged.

Here are some examples of what these changes in manufacturing mean in terms of possibilities for progressive lenses. Some possibilities may be used by one design, some by another. Not all will be used for the same lens.

The back surface of the progressive can be made as an aspheric or an atoric surface. Atoric curves can reduce the peripheral aberration called oblique astigmatism. (See Chapter 18.) This is especially important for progressive addition lens wearers with cylinder. When uncorrected oblique astigmatism is present, it combines with the peripheral distortion inherent in progressive addition lenses and can further degrade peripheral vision. An atoric design can improve peripheral vision. Progressive lenses are normally made as semifinished lenses with certain fixed base curves. These semifinished lenses are then surfaced in the laboratory. With free-form generating, the front surface can be custom surfaced to any base curve and the progressive optics included during surfacing. Then the back surface is generated at the completion of the front surface. This way the base curve can be more closely matched to the power of the lens. If a frame is fit with a specific vertex distance, the prescribed power of the lens can be altered for the vertex distance of the frame. These power changes are not limited to quarter diopter increments. The smoothing (fining) and polishing process no longer uses power-specific tools to bring the surface to optical quality. When a lens is tilted, there is a change in the sphere power, and a cylinder is induced whose axis is in the meridian of rotation. (See Chapter 18.) This power change can be compensated for on an individual basis, whether the tilt is pantoscopic tilt or face form. Again the compensation may be done more exactly because it is not limited to quarter diopter increments.

With this type of generating, it is possible to make a progressive lens to order with the progressive power on the front of the lens, the back of the lens, or on both the front and the back of the lens. (The Definity lens is made this way with the progressive add split between the front and back surfaces.)

This type of generating allows for the progressive portion of the lens to be made at different widths, depending upon the needs of the wearer.

The progressive zone of a lens can be shortened or lengthened to custom fit the vertical depth of the frame and the vertical height of the wearer’s eyes.

DESIGNS USING ASPHERIC/ATORIC SURFACING METHODS

Lens quality is limited by how well lens aberrations can be corrected. In Chapter 18, the basics of spectacle lens design were explained. One of the limiting factors has been the ability to correct oblique astigmatism for lenses with cylinder power. Oblique astigmatism could be corrected for spherical lenses by using a specific base curve or by using an aspheric surface. But if the lens had two different powers, as it does when prescribe cylinder power is present, then oblique astigmatism could only be corrected for both meridians at once if an atoric lens design was used. Atorics are easier to make for single vision lenses because they can be molded at the factory. But atorics could not be made for a segmented multifocal or progressive lens because these lenses were surfaced for the correct power in the optical laboratory. The laboratory could only surface a spherical or a toric surface, not an atoric surface.

It is now possible to custom grind and polish an aspheric or atoric surface (although the equipment required is quite expensive). This makes it possible to correct more of the oblique astigmatism present in any spectacle lens, not just progressive lenses.

Progressive lenses have unwanted cylinder in the periphery of the lens simply because they are progressives. Oblique astigmatism caused by lens aberrations will combine with this cylinder and degrade peripheral vision even more. If this oblique astigmatism can be reduced, peripheral vision will improve.

One of the first types of progressives to include aspheric/atoric surfacing methods was the so-called *position-of-wear* or *as-worn* progressive lens design.

POSITION-OF-WEAR OR AS-WORN LENS DESIGNS

A major change in progressive lenses that took place because of free-form generating resulted in lenses sometimes referred to as *position-of-wear* or *as-worn* designs. A primary example of this is the Rodenstock Multigressiv 2 lens. This lens includes all the following factors in the design of the lens on an individual basis:

- Pantoscopic tilt
- Vertex distance
- An aspheric or atoric surface to optimize correction of lens aberrations

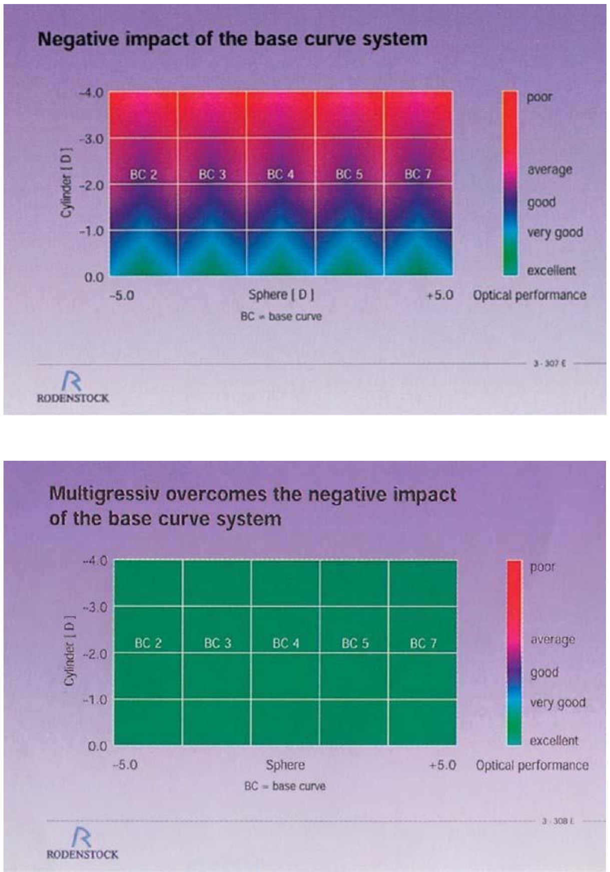
The practitioner specifies the sphere, cylinder and axis measures, along with vertex distance and pantoscopic tilt. When the prescription is received, an optimum base curve is chosen for the front surface of the lenses, and the prescription is modified to allow for tilt and vertex distance (Figures 20-22 and 20-23.) Then the amount of asphericity needed in each major meridian back surface is calculated. When the lenses are returned, the accompanying order information will include the sphere, cylinder, axis, and add power as originally ordered. It will also include new sphere, cylinder, axis, and add powers based on the calculated changes. For example, a lens may be ordered with powers of

D4.00 D0.25 D 45
D2.00 add

The order may be returned with powers listed as

D3.96 D0.27 D 36
D1.82 add

The second set of powers is what the lens actually will be. This second set of numbers is used for verification purposes.


Negative impact of the base curve system

Multigressiv overcomes the negative impact of the base curve system

Figure 20-22. When a lens is made from semifinished blanks that come in certain finite intervals, the optical quality varies, depending upon how close that base curve comes to the ideal. However, even the ideal base curve does not deliver ideal optics when the lens has a high amount of cylinder. This figure shows conceptually how an ideal base curve, made with spheri- cally curved surfaces, cannot be ideal for two different powers at the same time. It is not meant to show actual measures of vision or visual acuity.

ATORIC PROGRESSIVES

A progressive lens does not have to be a position-of-wear lens to incorporate atoric optics into the lens. Lenses dispensed in the United States are less likely to be measured for vertex distance and pantoscopic tilt. However, using atoric optics can be a large advantage, particularly for lenses with prescribed cylinder. Each lens may still be more exactly corrected for aberrations and individualized for prescription powers. However, the lenses must be custom surfaced using free-form generating techniques. At the time of this writing, such lenses are, with limited exceptions, only available through major manufacturers.

Examples of these lenses are Shamir Autograph, Zeiss Gradal Individual and Zeiss Short i,* and the Varilux Physio 360.

The Varilux Physio is a lens that is designed using wave front technology, but is surfaced in the traditional manner. It is not atoric. The Varilux Physio 360 uses the same basic design as the Varilux Physio, but also uses generating procedures necessary to make the lens atoric, optimizing optics for all meridians of the lens.

Figure 20-23. This figure shows conceptually what can happen to optical quality when optics can be corrected for base curve in both meridians of a lens surface at once when a prescription has cylinder power. This is done using an atoric surface custom cut for the prescription. The illustration is not meant to show any actual measures of vision or visual acuity. (From Baumbach P: Rodenstock Multigressiv—a technical prospective, Rodenstock, RM98052, p. 7, Figure 15.)

PERSONALIZED PROGRESSIVES

Because of the ability to generate any surface on demand, the next logical step in progressives is to produce a lens with the progressive optics tailored to the distinct, individual needs and habits of the wearer. The Varilux Ipseo lens takes a major step into this area. The Ipseo lens is designed to match the unique head and eye movement habits of the wearer. Some individuals turn their eyes much more than they turn their head to see an object. Others are head turners, moving their head more than others do. The Varilux Ipseo uses an instrument called the VisionPrint System to measure head and eye movement (Figure 20-24). The lens is designed so that the near-viewing area will better match the personal viewing habits of the wearer.

In addition, the Ipseo lens design program takes the prescription and frame characteristics into consideration. When the lens returns from the laboratory the ordered prescription powers will have been altered because of surface asphericity and should be verified using the modified parameters.

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*The Zeiss Short i is designed for frames with a small vertical dimension.

Figure 20-24. The VisionPrint System is used to measure head and eye movements. Results determine how the Varilux Ipseo personalized progressive lens will be custom designed for the head and eye movement requirements of the wearer.

It would be expected that other lens manufacturers may develop lenses that have alternate designs based on other personal characteristics, visual habits, and occupational needs of the wearer.

SECTION 3 Specialty Progressives

For years bifocal and trifocal lenses were worn by the majority of presbyopic spectacle lens wearers. Yet they were not able to satisfy all the visual needs for every wearing situation. As a result, a number of segmented specialty lenses developed. Even though progressive lenses are clearly overtaking segmented multifocals, it is also unrealistic to think that general purpose progressives are able to fulfill everyone's specialized needs any more than segmented lenses could. If a progressive lens is truly for specialized tasks and will not be used for full-time wear, the lens may be called an *occupational progressive lens* and may be abbreviated *OPL*. Progressive addition lenses as a general category are often abbreviated as *PALs*.

SHORT CORRIDOR PROGRESSIVE LENSES

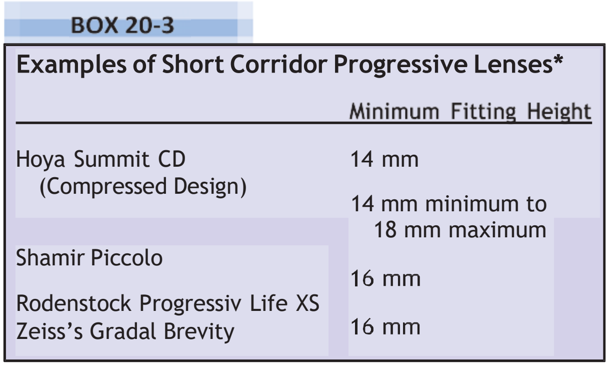
The *short corridor* category of specialty progressives is really a subcategory of general-purpose progressives. The thing that makes this lens unique is that it is designed to allow a progressive addition lens to be worn in a frame with a small vertical dimension. Regular progressive lens corridors are too long. Too much of the near portion of a regular progressive lens is cut off when the lens is edged for frames with narrow B dimensions.

The short corridor progressive has a faster transition between the distance and near portions of the lens. This means that the wearer is quickly into the near portion when looking downward. Because the transition is short, near vision is suitable. Yet it is only logical that there will be some sacrifice of the otherwise larger intermediate portion. When choosing a short corridor progressive, be certain that the minimum fitting height is suitable for the frame. Even short corridor progressives can come up short on near viewing if the frame is exceedingly narrow. Some examples of short corridor progressives are shown in Box 20-3. Short corridor progressives are fitted in the same manner as regular progressive lenses. Monocular PDs are needed, and the fitting cross is placed in the center of the pupil.

NEAR VARIABLE FOCUS LENSES

Near variable focus lenses started out as a replacement for single vision reading glasses. This lens also goes by other names, including, *small room environment progressives, reader replacements,* or simply *OPLs*. Over time the lens has become the lens of choice for someone working in a small office where intermediate and near vision are the primary viewing needs.

To get an idea of how the lenses are constructed, take the example of a prescription that has no power in the distance and a D2.00 D add. The normal progressive addition lens would have powers as shown in Figure 20- 25 with no power in the upper (distance) portion. Power gradually increases until it reaches the prescribed D2.00 D add power in the lower near portion.



BOX 20-3

Examples of Short Corridor Progressive Lenses*

	Minimum Fitting Height
Hoya Summit CD (Compressed Design)	14 mm
Shamir Piccolo	14 mm minimum to 18 mm maximum
Rodenstock Progressiv Life XS	16 mm
Zeiss's Gradal Brevity	16 mm

*These are only a small number of the short corridor progressive addition lenses available. It is not meant to be an inclusive list. Nor will it necessarily be a current list. Short corridor lens designs, like other progressives, will continue to change.

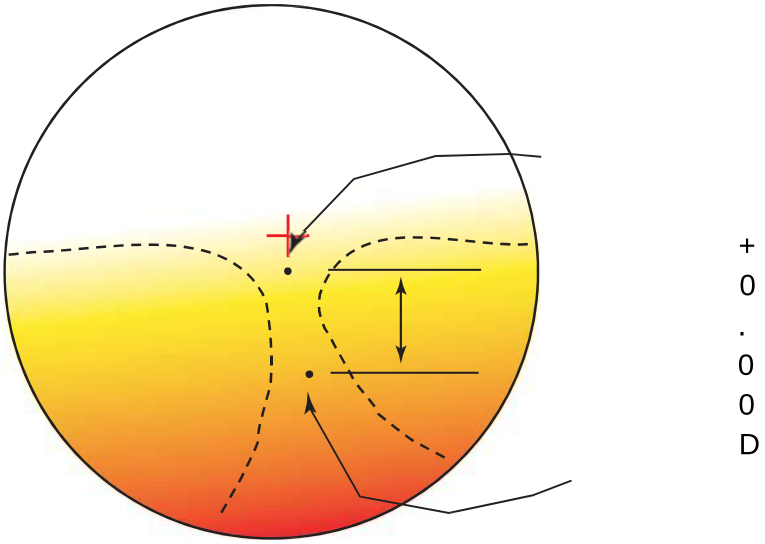
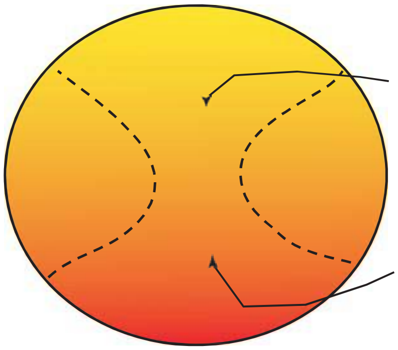


Figure 20-25. This is a simplified drawing of the structure of a progressive addition lens with a plano distance prescription and a D2.00 D add. The “power range” of this lens is a full two diopters.

Figure 20-26. When a prescription with plano distance power and a D2.00 D add is placed in near a variable focus lens having a 1.00 D power range, the power difference between upper and lower portions is less. The progressive zone is also lengthened. This makes the progressive zone wider and reduces the intensity of peripheral distortion. This simplified drawing of the lens structure, based on the same prescription, can be compared with the standard progressive in Figure 20-25.



Progressive corridor (1.00 D change) +2.00 Intermediate/Near specialty progressive

This is usually not the case with most near variable focus lenses. The farthest distance that people who work in small office environments need to see clearly might be the distance of someone sitting across the desk from them. They also need a clear view of a computer monitor placed at an intermediate viewing distance and at the normal 40-cm near-working distance for reading. With this in mind, our example lens could be designed with a moderate amount of plus power in the distance.

If we use D1.00 D of power in the upper portion of the lens, we can gradually increase plus power until a total of D2.00 D is achieved for near. This would appear as shown in Figure 20-26. Note that the progressive zone for this type of lens is longer and wider than the normal progressive corridor found in a general wear progressive lens. This works well, and for this type of working environment, these OPLs give excellent intermediate and near vision with less peripheral distortion. Here is why: A longer progressive zone will result in less peripheral distortion. In a near variable focus lens, the difference between the powers in the upper and lower halves of the lens are usually smaller. In the example, instead of having or a difference of D2.00 D, this lens has a difference of only D1.00 D. In reality this is a D1.00 D add instead of a D2.00 D add. The smaller the add power, the smaller will the unwanted cylinder be When wearing a near variable focus lens, more visual work will be done with midlevel and downward viewing than with a standard progressive where clear distance vision is important. The designer has the option of moving a larger proportion of the peripheral distortion inherent in progressive lenses into the upper periphery of the lens.[7] Increasing the area of distortion decreases its intensity.

Power Ranges

With regular progressives we think of beginning with the distance power in the upper portion and increasing plus power as we go downward. With near variable focus lenses, we begin with the near power. The reference power is the near power instead of the distance power. We start with the near power in the lower portion and decrease plus power moving up to the distance portion. This is no longer an addition, but a decrease in power. This decrease in power is called a *degression*.[7] Manufacturers often call this the *power range* of the lens.

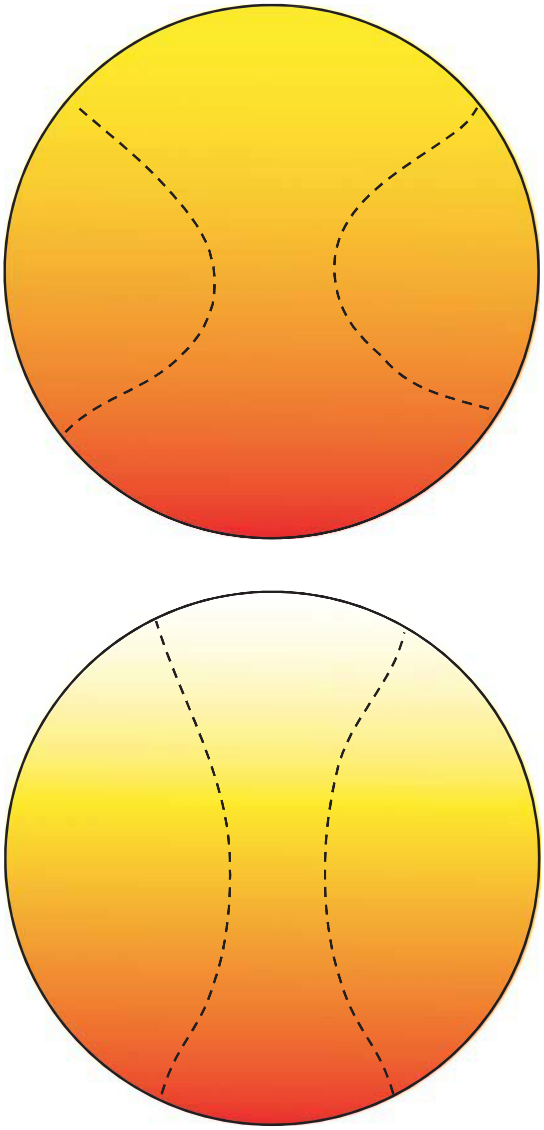
This means that near variable focus lenses do not come in regular add powers like general purpose progressives. They instead come with one or more power ranges. Again the *power range* is the difference in power between the lower and upper areas of the near variable focus lens.

Power Changes in the Vertical Meridian

As may be seen from Table 20-2, power degressions among lenses will vary considerably. The greater the power degression, the more the contour plot of the lens will resemble that of a general-purpose progressive. Figure 20-27 shows a simplified representation of a lens with a small degression compared with a lens with a larger degression. Higher degressions result in narrower progressive zones and greater amounts of unwanted peripheral astigmatism. (Yet even with higher degressions, the OPL zone will be considerably wider than that of the standard progressive lens because of its increased length.)

Customizing the Near Variable Focus Lens to the Needs of the Wearer

When someone has two specific distances at which they do most of their work, the examiner may decide to pre- scribe for those distances. In this case the type of lens should be chosen with a power range appropriate for the prescription. Here is how it is done.



This distance is found to have an intermediate add power of D1.25. If a near variable focus lens is to be used: What would the prescription read in the lensmeter through the upper and lower portions of the appropriate near variable focus lens? (Assume that the power of the upper portion and mid portion of the lens will be the same.) What would the correct power range be? When choosing from the lens types found in Table 20-2, which lenses would have this power in the upper portion of the lens?

Fitting the Near Variable Focus Lens

Near variable focus lens fitting recommendations vary widely, depending upon the lens style. For example, the Access lens only requires a binocular near PD and does not require any measured fitting height. It is fit just like a single vision prescription for reading glasses. The reason it is possible to use a binocular PD instead of monocular PDs is because the progressive zone of the lens is much wider than in a standard progressive lens. So if the eyes do not track down the exact center of the zones, there are not the same problems encountered.

In contrast the Rodenstock Office lens is fit like a standard progressive lens using monocular distance PDs and fitting cross heights measured to the center of the pupil. The distance prescription and standard near addi- tion would be specified. If no power range is specifically requested, the laboratory will use the recommended range for the add power of the prescription.

OCCUPATIONAL PROGRESSIVES THAT INCLUDE DISTANCE POWERS

There are occupational progressive lenses that are used for small office environments and computer viewing, but still include a small distance portion located at the very top of the lens. This requires that the wearer drop the chin and look through the upper portion to see in the distance. Yet since the lens is entirely an occupational lens, this is not necessarily a disadvantage and may be considered an expected trade-off for intermediate viewing enhancement.

The intermediate area of the lens is positioned in front of the eye, as if looking through a trifocal segment straight ahead (Figure 20-28). Because the progressive zone is longer, going almost from the top to the bottom of the edged spectacle lens, the intermediate and near zones will still be considerably wider than standard progressives, though not as wide as near variable focus lenses with smaller degressions.

These lenses are fit like regular progressives, but require enough vertical depth to the frame to keep from cutting off the needed top and bottom areas of the lens. They are certainly not feasible for frames with narrow B dimensions.

Two examples of these lenses are the AO Technica and the Hoya Tact. Neither of these lenses should be used as a replacement for regular, full-time-wear progressive addition lenses.

SECTION 4

Prism and Progressive Lenses

PRISM THINNING

One slight drawback to progressive addition lenses in certain power ranges is thickness. Increased thickness is especially evident when the distance powers are either plus or low minus. Progressive lenses in plus or low minus power ranges will be thicker than a flat-top mul- tifocal lens of equal power. This increased thickness is a result of the steepening front curve in the lower half of the lens. (This same problem also occurs in “Executive” multifocals and can be solved in the same way.)

As the lower progressive portion of the lens increases in plus power, the surface curvature steepens. This thins the bottom edge. To keep the lower lens edge from becoming too thin, the whole lens must be thickened.

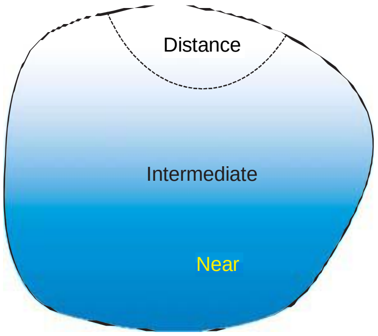
To overcome the problem, the lower edge must somehow be thickened without thickening the upper edge. This can be done by adding base-down prism to the whole lens. When this is done properly, overall lens thickness will actually decrease. The technique, known as yoked base-down prism, is illustrated in Figure 20-29. Naturally, both right and left lenses must receive the same amount of base-down prism, otherwise the wearer will experience double vision as a result of unwanted vertical prism differences.

The exact amount of prism needed to thin the lens effectively varies according to the strength of the addition, the size and shape of the lens after edging, and the design of the lens. As a rule of thumb, Varilux suggests adding prism power amounting to approximately two thirds of the power of the add. (The use of yoked base-down prism for Varilux lenses has been referred to by the name Equithin.)

Most wholesale optical laboratories now use prism thinning routinely without consulting the account. Prism thinning has a very positive effect on reducing lens thickness and weight for lenses in the appropriate power range and should be used.* According to a study by Sheedy and Parsons,[9] small amounts of yoked

Figure 20-28. The Technica lens shows a large functional intermediate zone area with a small distance area in the upper portion of the lens.

*Darryl Meister points out that in some cases high minus lenses may be prism thinned using base-up prism. This would occur if the fitting cross of a minus lens were located high enough in the lens to result in a thicker bottom edge.[8]



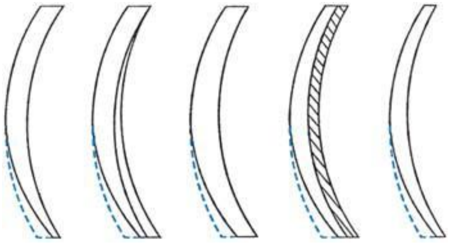


Figure 20-29. This figure shows the use of base-down prism to thin a progressive addition lens. **A,** The progressive addition lens as ground without prism thinning. The dotted lines indicate how the lens would be curved if it were a single vision lens instead of a progressive lens. **B,** Adding base-down prism thickens the bottom of the lens only. **C,** The line between prism and original lens has been removed. It is now possible to see how this lens with newly added base-down prism could be further thinned because both top and bottom are thick. **D,** The hatched area shows how much lens thickness may be removed now that both edges are equally thick. **E,** Excess lens thickness has been removed and progressive lens prism thinning achieved. base-down prism are not disturbing to the wearer. Those tested could not differentiate between the absence of prism and 2D base down in both eyes. However, when prism was increased to 4D base down, there were significant postural changes by the wearer.

Prism Thinning Causes Prism at the PRP

It should be mentioned that base-down prism used to thin the lens will show up at the PRP of the lens. This is particularly important to note when only one lens is to be replaced since both right and left lenses must have the same amount of vertical prism. Thus vertical prism found at the PRP of the lens is acceptable when both left and right lenses have the same amount of vertical prism.

THE EFFECT OF PRESCRIBED PRISM ON PROGRESSIVE LENS FITTING

Success in fitting progressive addition lenses depends on accurate horizontal placement of the monocular PDs. If monocular PDs are incorrect, the eyes do not track down the progressive corridor. This reduces intermediate vision. Incorrect PDs also displace the reading zone, reducing its usable size.

Success in fitting progressive addition lenses is also influenced by the accuracy of fitting cross heights. An inaccurate fitting cross height will cause one eye to track down the corridor ahead of the other. This means that

the add power is not increasing equally for the two eyes. The eye farther down one corridor is looking through more plus power than the partner eye following a few steps behind. An inaccurate fitting cross height also causes the eye to track down the progressive corridor off-center, narrowing the effective width of the intermediate viewing.[10]

When prism is placed before the eye, it causes the image of an object to be displaced in the direction of the prism apex. The eye must turn toward the apex to view the displaced image. For example, if base-down prism is placed before one eye, that eye turns upward toward the apex to fixate the displaced image. (This concept was explained in Chapter 5 and is shown in Figure 5-29.)

Vertical Rx Prism Changes Fitting Cross(and Bifocal) Heights*

When vertical prism is present in a prescription, it causes one of the wearer's eyes to turn slightly up or down. But when fitting cross height measurements are taken, the prism is not present. When the wearer is able to keep the eyes working together without the prism the eyes are looking straight ahead. One eye will not likely be turned upward or downward in relationship to the other.

*Much of the information presented in this section is taken from Brooks CW, Riley HD: Effect of prescribed prism on monocular interpupillary distances and fitting heights for progressive add lenses, Optom Vis Sci 71:401–407, 1994.

However, once the prescription lenses are in the frame, the eye must turn in the direction of the apex of its pre- scribed prism. The amount of displacement in the spec- tacle plane will be 0.3 mm for every 1D of prescribed prism.

When vertical prism is present, the fitting cross should be raised 0.3 mm for every diopter of base-down prism or lowered 0.3 mm for every diopter of base-up prism.

If the entire amount of vertical prism is prescribed before one eye, the vertical displacement of the fitting cross should be carried out on one lens. But if the vertical prism is split, the displacement of the fitting crosses should also be split in the same proportion.

To be certain of vertical fitting cross positioning with perscription prism, cover the wearer's left eye when mea- suring the fitting cross for the right eye. Then when measuring fitting cross height for the left eye, cover the wearer's right eye.

Horizontal Rx Prism Changes PDMeasurements

When horizontal prism is prescribed, failure to horizon- tally compensate the MRP placement will cause the eyes to track along the inside or outside edge of the progressive corridor. This greatly reduces the usefulness of the inter- mediate zone and narrows the field of view for near work.

When Might the Amount of Horizontal Prism Be Modified?

When prism is prescribed in conventional, nonprogres- sive, multifocal lenses, the PD is not modified to allow for a change in pupil location. This is quite acceptable because the widths of nonprogressive multifocals are so wide in comparison with the corridors of progres- sive addition lenses that there is little need for modification.

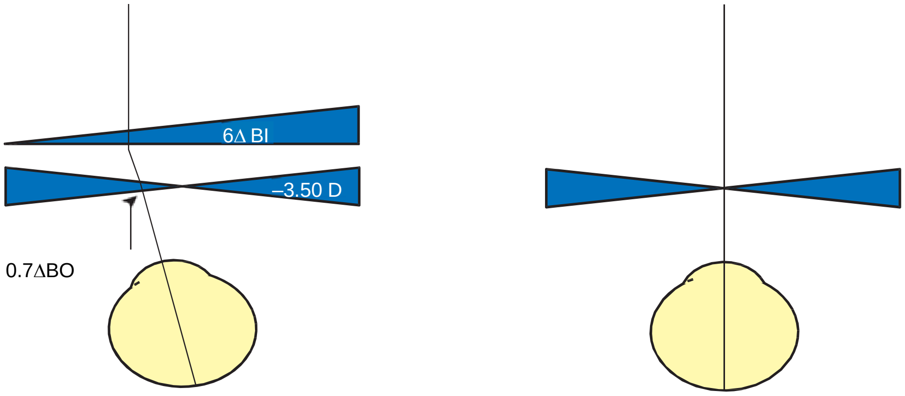


Figure 20-30. A measuring prism in front of the refractive lens will cause the eye to turn outward. As it turns, it leaves its previous loca- tion directly behind the optical center of the lens. (From Brooks CW, Riley HD: Effect of prescribed prism on mon- ocular interpupillary distances and fitting heights for progressive add lenses, Optom Vis Sci 71:403, 1994. Figure 4.) that was present during refraction disappears. Without decentration prism, the net prismatic effect that was present during refraction has changed. When prescrip- tion sphere and cylinder powers are small, this is of minimal consequence. As the refractive power increases, however, the prismatic amount becomes more evident. It is helpful to note that when the MRP is moved in the direction of eye deviation, there will always be a reduction of prescribed prism for minus lenses and an increase in the amount of prescribed prism for plus lenses. In other words: For minus lens: *reduce* the Rx prism by an amount equal to the calculated decentration prism.

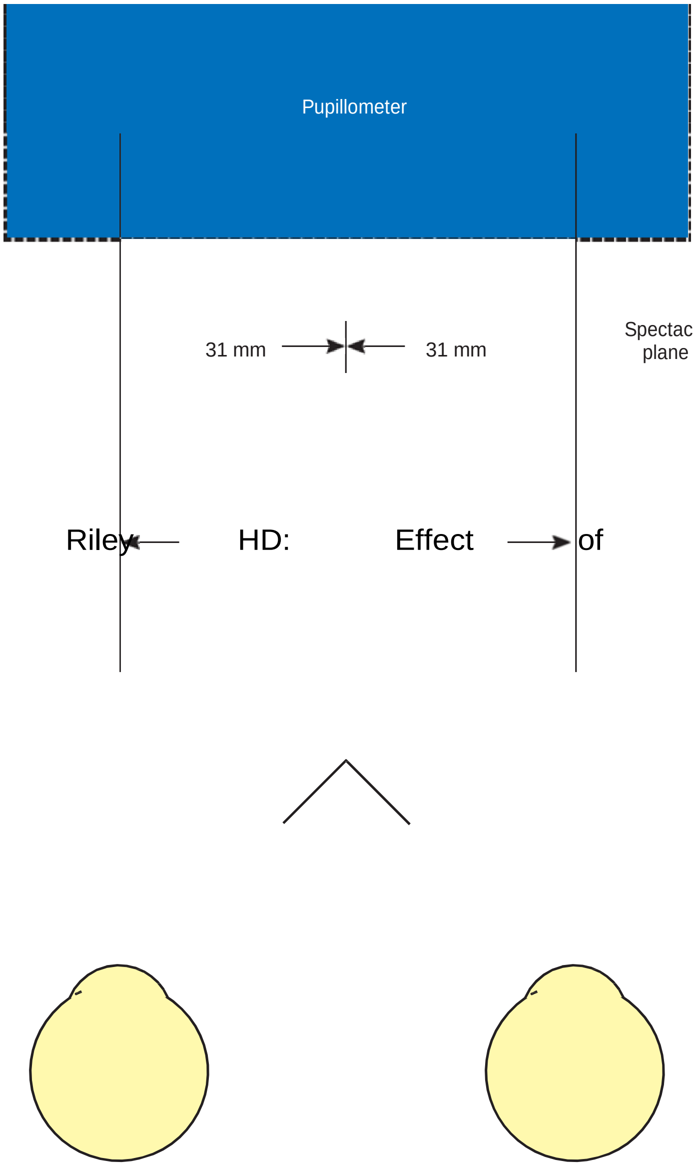


Figure 20-31. A pupillometer normally measures the interpupillary distance with no lens correction in place and with the eyes in a straight-ahead position. (From Brooks CW, Riley HD: Effect of prescribed

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prism on monocular interpupillary distances and fitting heights for progressive add lenses, Optom Vis Sci 71:403, 1994. Figure 5.)

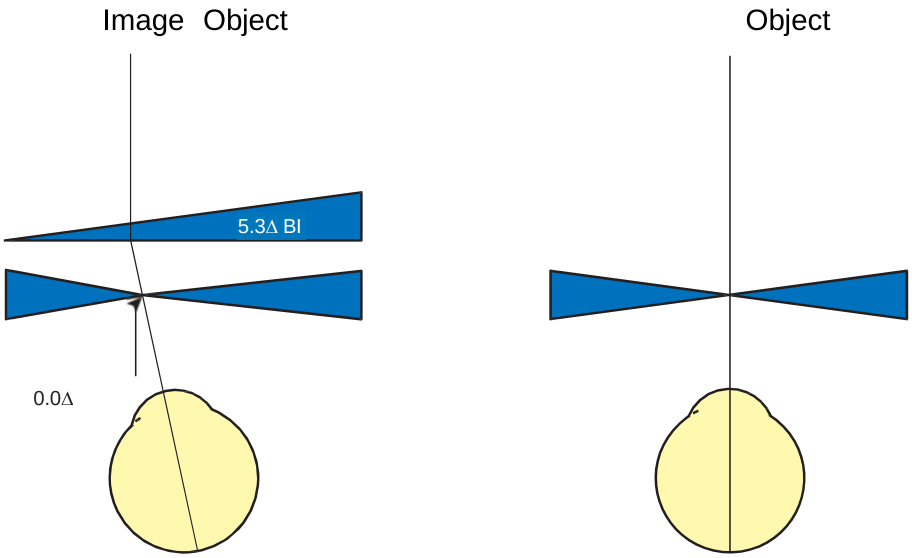

Figure 20-32. If the monocular interpupillary distance were to be altered to compensate for prismatically induced eye movement and correct progressive corridor placement, the net effect would be to change the amount of prism in the prescription. The decentration prism resulting from eye movement caused by the measuring prism will no longer be present.

(From Brooks CW, Riley HD: Effect of prescribed prism on monocular interpupillary dis- tances and fitting heights for progressive add lenses, Optom Vis Sci 71:403, 1994. Figure 6.)

For plus lenses: *increase* the Rx prism by an amount equal to the calculated decentration prism. When filling an existing prescription, it should be noted that a modification to the Rx prism amount that is done to maintain the prescribed optical effect is no different than changing sphere and cylinder power in response to a change in lens vertex distance (see Chapter 14). Changing the amount of "Rx prism" to compensate for decentration prism does not change the prescription.

SUMMARY

Prescribed vertical prism in progressive add lenses requires that the fitting cross be moved up or down by an amount equal to 0.3 times the prism amount. The direction of movement is opposite from the base direc- tion of the prism.

Prescribed horizontal prism in progressive add lenses requires that the monocular PDs be increased or decreased by an amount equal to 0.3 times the prism amount. The direction of eye and MRP movement is opposite to the base direction of the prescribed prism. Steps to take when modifying fitting cross height are found in Box 20-4, *A*. Steps to take when modifying monocular PD amounts are summarized in Box 20-4, *B*.

Changing the prism amounts should only be done if there would be clinically significant changes to the pre- scribed prism. This does not happen unless the prescribed prism is greater than or equal to 6.00D and the refractive power in the prism meridian is greater than plus or minus 2.50 D. If this is the case, then prescribed prism may be altered according to the summary found in Box 20-5.

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Sample Questions:

1. Suppose a person is wearing or needs a prescription as follows:

R: D3.50 sphere
L: D3.50 sphere with 6D base-in prism
D2.25 add

(Although it may not be advisable to place all prism in front of one eye, we will use this example for simplicity.)

Before refraction the monocular PDs are measured using a pupillometer. There are no refractive lenses in place. The PD measures as follows (Figure 20-31):

R monocular PD = 31 mm L monocular PD = 31 mm

How should the monocular PDs and prescribed prism amounts be modified to allow the eyes to accurately track down the progressive corridor and still maintain the same net prismatic corrective effect?

Solution

Placing 6D of base-in prism before the left eye will cause the eye to deviate outward by

6 D 0.3 mm = 1.8 mm, which will be rounded off to 2 mm.

During phoria testing, the eye was looking 2 mm temporally through the D3.50 D refracting lens (see Figure 20-30).

Using Prentice’s rule, we see that prism caused by the eye being decentered in relation to the lens is

D = *cF*
= 0.2 D 3.5
= 0.7D

Since the lens is minus, prism caused by the eye moving in relationship to the refractive lens is base out. Therefore the net prismatic effect for the eye is

(Prescribed D) D (Decentration D) = (Total D).

Or in this case

6 base in D 0.7 base out = 5.3 base in.

To position the progressive zone in front of the eye, the MRP must be moved 2 mm outward. (When the position of the MRP moves, so does the fitting cross location. The fitting cross is directly above the MRP.) When the MRP moves outward, the finished spectacle lens prescription will no longer duplicate the refractive situation. This is because the 0.7D of decentration prism caused by the D3.50 D lens no longer exists (Figure 20-32). To maintain the same total prismatic effect, the prescribed prism must be reduced from 6D base in to 5.3D base in.

The PDs are ordered as follows:

R monocular PD = 31 mmL monocular PD = 33 mm

2. Suppose a prescription reads as follows:

R: D2.25 D0.50 D 180 5D base in
L: D2.25 D0.50 D 180 5D base in

Using a pupillometer, the monocular PDs are measured asfollows:

R: 29.5 mm
L: 30.0 mm

What monocular PDs should be ordered to compensate forthe prescribed horizontal prism?

Solution

Noting horizontal prism, the amount of pupil displacementis calculated as follows:

5 D 0.3 = 1.5 mm.

Base-in prism will cause the eye to move outward by an amount equal to 0.3 mm for every diopter of horizontal prism. In this case 5D of base-in prism will cause each pupil to be displaced outward by 1.5 mm. The resulting monocular PDs are modified to

R: 31.0 mm
L: 31.5 mm

3. Suppose a variable focus lens made by a certain manufacturer comes in only one power range and that power range is 1.00 D. This means that there will always be 1.00 D dif-

Since the lens has a power range, or degression of 1.00 D, the upper area of the lens will have 1.00 D less plus power than the lower area of the lens. So the upper area of the lens has a power of

Dtotal near powerD
DD DdegressionD
D Dupper power of the lensD

or

D2.25 D
D1.00 D
D1.25

In a lensmeter, the upper portion of the lens reads D1.25D, and the near portion reads D2.25 D.
For the left lens, the total near power is

Ddistance powerD
DD Dadd powerD
D Dtotal near powerD

or

D0.25 D0.50 D 180
DD2.25
D D2.50 D0.50 D 180

So the upper area of the lens has a power of

D2.50 D0.50 D 180
DD1.00
D D1.50 D0.50 D 180
ference (degression) between the lower and upper portions

---

of the lens. If a person has a prescription of

R: plano
L: D0.25 D0.50 D 180
Add: D2.25

what powers would be found in the lower and upper areas of the lenses when using this manufacturer's near variable focus lenses?

Solution

When trying to anticipate the powers in a variable focus lens, begin with the total near power. Total near power is the sum of the distance power and the near add.

For the right lens this power is

Ddistance powerD
± Dadd powerD
=Dtotal near powerD

4. A prescription reads as follows:

R: D2.75 D1.00 D 180 3D base up
L: D2.75 D1.00 D 180 3D base down

The frame of choice is adjusted to fit as it should when being worn. Next fitting cross heights are marked on the glazed lenses to correspond to pupil center location. Heights are measured to be as follows:

R: 27 mm
L: 27 mm

What fitting cross heights should be ordered?

Solution

Vertical prism for the right lens is noted. The amount of vertical compensation is calculated as follows:

Vertical prism amount x 0.3 =
change in fitting cross height in millimeters.

Or in this case

3 D 0.3 = 0.9 mm.

This is rounded off to 1 mm. Because prescribed prism causes the pupil of the right eye to be displaced 1 mm downward, the fitting cross must be moved 1 mm downward as well.

The left lens has an equal but opposite amount of vertical prism. Therefore, the prism in the left lens necessitates moving the left fitting cross 1 mm upward. The end result is that the two fitting cross heights are modified and should be ordered as

R: 26 mm
L: 28 mm

Unit 11:

Anisometropia

Learning Objective:

At the end of this chapter, students will be able to learn:

1. What is anisometropia and its different types.
2. How does it affect vision and patients' quality of life.
3. How it can be treated and managed through spectacles.

When left and right lenses in a prescription are significantly different from one another, problems can occur that are primarily a result of the spectacle lenses causing the two images of the same object to differ from one another. This chapter examines those problems and then presents possibilities for their solution.

INTRODUCTION

Anisometropia is when there is a difference in refractive power between the left and right eyes. Anisometropia can work to an individual's favor in presbyopia. When one eye is emmetropic and needs no correction and the other is somewhat myopic, such a person can avoid the need for reading glasses. One eye is used to see for distance vision, the other for near. In fact such a situation is often created in contact lens wear and is called mono-vision. One contact lens contains a weak near correction instead of a distance correction so that a presbyopic individual can avoid having to wear glasses for reading. On the whole, however, a significant amount of anisometropia ends up creating problems. With young children, an unnoticed difference in refractive error between the two eyes can result in the blurred eye failing to develop good visual acuity—a condition termed amblyopia. An amblyopic eye will be unable to obtain 20/20 vision, even when the refractive error is fully corrected. So it is important to correct for anisometropia as soon as it is detected.

When anisometropia is corrected with spectacle lenses, problems are not always over. The spectacle lenses themselves can create difficulties. Spectacle lenses worn at a distance from the eye will magnify or minify everything viewed through the lens. Different lens powers magnify different amounts. When one lens has different power than the other lens, the image of an object seen through the right lens is not the same size as the image of that same object seen through the left eye. The brain tries to fuse these two images into one single object.

Spectacle lenses have prismatic effects that increase with increasing lens power. Viewing an object below the optical center of a low-powered lens creates only a little image displacement. But viewing that same object at that same distance below the optical center of the other more highly powered lens may cause a more significant dis-placement of the image. Since the two images appear to be at different locations, the two eyes have to turn down-ward by differing amounts to keep from seeing double. This chapter talks primarily about those problems that arise as a result of anisometropia and what can be done to overcome them with spectacle lenses.

ANISEIKONIA

Aniseikonia is a relative difference in the size and/or the shape of the images seen by the right and the left eyes (Figure 21-1). This image size difference can be a result of the eyes themselves or can be produced by the optics of the correcting lenses.

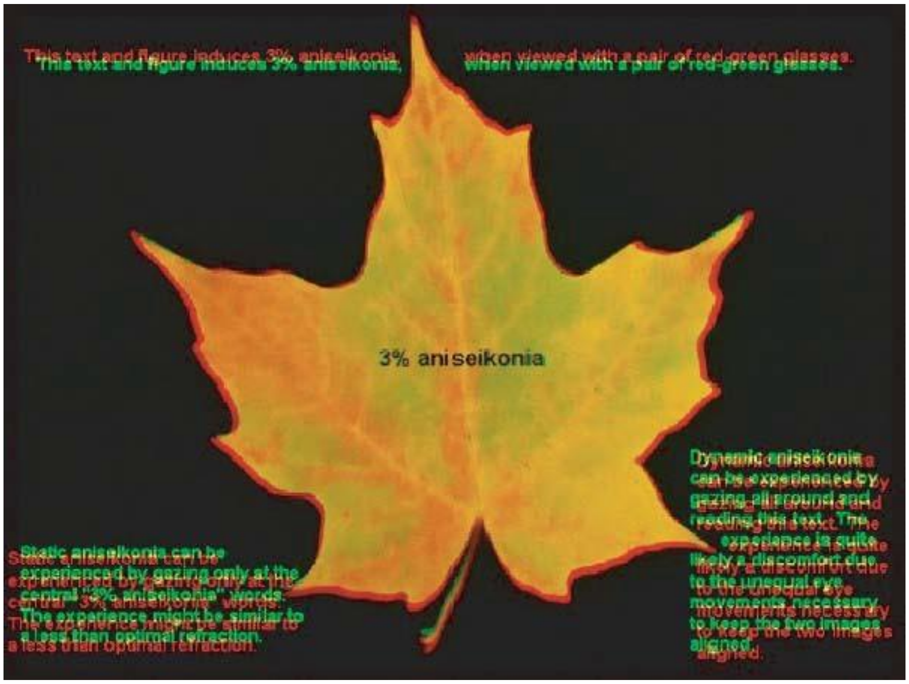
Types of Aniseikonia

Physiologic Aniseikonia

Aniseikonia occurs in a limited but useful amount even for individuals with eyes that are identical to one another. Suppose a person turns their eyes to the left to look at an object. The right eye will be slightly farther away from the object than the left eye. The image of the object in the right eye will be slightly smaller than the image see by the left eye. These size differences give clues that help in localizing the object in space. This type of aniseikonia is expected and is referred to as *physiologic (or natural) aniseikonia*. Any other aniseikonia present to a clinically significant degree is an anomaly and is called *anomalous aniseikonia* or just plain *aniseikonia*. Anomalous aniseikonia can be caused by either the anatomic structure of the eye, or by the optics of either the eye or the correcting spectacle lens.

Symmetrical Aniseikonia

One eye may see an image that is symmetrically larger than the other eye (i.e., it is equally larger in every meridian). This is called *symmetrical aniseikonia* (Figure 21-2). Another type of aniseikonia is still symmetrical, but has a meridional size difference in a meridian of one eye compared with that of the other eye. This is called *meridional aniseikonia.* Meridional aniseikonia can be in either horizontal or vertical meridians or may be found in an oblique meridian (Figure 21-3).



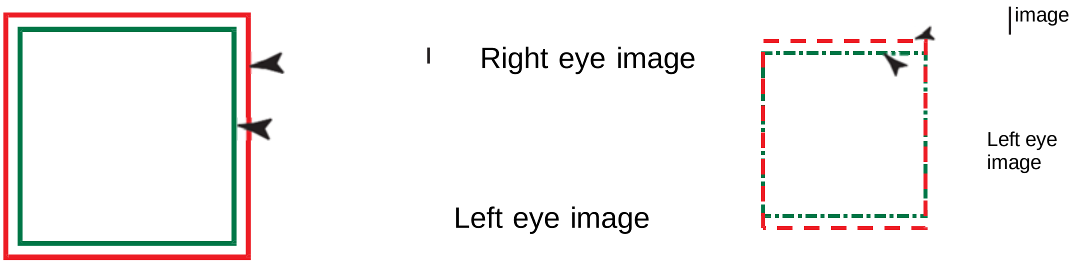


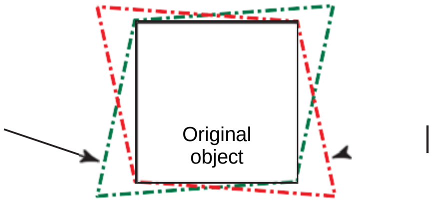
Figure 21-1. This figure will only be realistic if viewed through red-green anaglyph glasses. With red-green glasses on, the eyes will try to fuse both images as one, simulating what happens to a person with aniseikonia.
(From de Wit GC, Remole A: Clinical management of aniseikonia, Optom Today 43(24):39-40, 2003.

Figure 21-2. Symmetrical aniseikonia occurs when the image of one eye is equally larger in every meridian than the image seen by the other eye.

Vertical meridional magnification

Asymmetrical aniseikonia is when there is a progressive increase or decrease across the visual field. The image for one eye will get progressively larger across the visual field (Figure 21-4). This does not occur naturally, but occurs when a flat prism is placed before the eye. Distortion is caused by plus and minus spectacle lenses. This is due to the variable base-towards-the-center effect of plus lenses and base-towards-the-edge prismatic effect of minus lenses. Such variable magnification creates a form asymmetrical aniseikonia. This was shown in Chapter 18, Figure 18-11 as pincushion and barrel distortion.

Left eye image



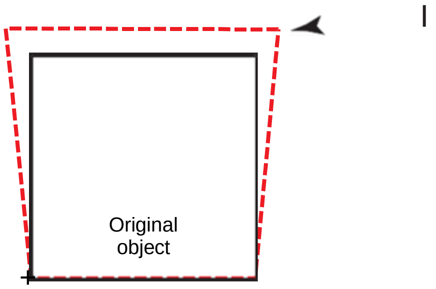
Oblique meridional magnification

Right eye image

Anatomic Versus Optical Aniseikonia

When aniseikonia is caused by the anatomic structure, it is referred to as *anatomic aniseikonia*. Anatomic aniseikonia can be caused by an unequal distribution of the retinal elements (rods and cones) of one eye compared with the other.

Figure 21-3. Meridional aniseikonia is still symmetrical, but has a meridional size difference in a meridian of one eye com- pared with that of the other eye. Meridional aniseikonia can be in either horizontal or vertical meridians. In the top illustration, the aniseikonia is vertical. Meridional aniseikonia may also be found in an oblique meridian, as shown in the bottom illustration.



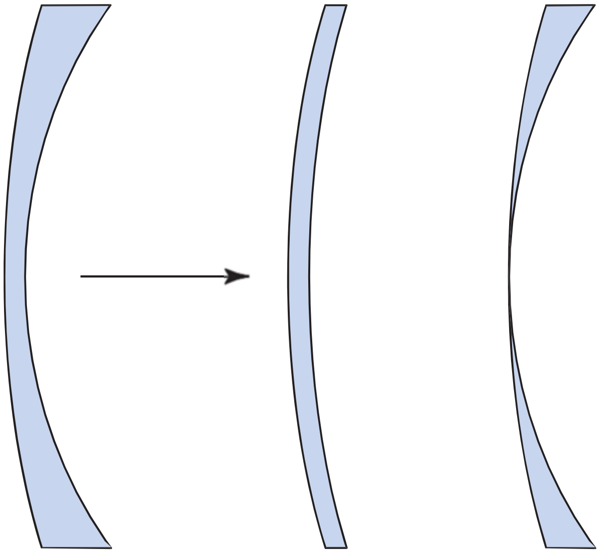


Figure 21-4. Asymmetrical aniseikonia is when there is a progressive increase or decrease across the visual field. The image for one eye will get progressively larger across the visual field, as shown in this figure.

Aniseikonia may also be caused by the optics of the eye or the optics of a correcting lens. When aniseikonia is a result of the optics of the eye, it is called *inherent optical aniseikonia*. When it results from an outside source, as from correcting ophthalmic lenses, it is called *induced* Shape factor Power factor *aniseikonia*.

Spectacle Magnification: How a SpectacleLens Changes the Image Size

In this section, we will look only at how a spectacle lens changes the magnification of an image for a single eye. We are not yet comparing differences in magnification between two eyes. The magnification change brought about by a single spectacle lens is called *spectacle magnification*.

Spectacle magnification compares the size of the image seen by a person when wearing glasses with the size of the image seen when that same individual is not wearing glasses. In other words,

SM D retinal image size in corrected eye D D
retinal image in same eye uncorrected

There are two factors within a spectacle lens that contribute to magnification (or minification) of an image. One has to do with the power of the lens, and the other concerns how the lens is shaped. The shape factor has no net power to it, yet can cause a change in magnification. This is like a telescope. A telescope changes the magnification of an object, but since the rays leaving the telescope are parallel, it could be said to have no net power. So think of a spectacle lens as two components:

1. An afocal (telescope-like) component
2. A power component

t D the thickness of the lens in meters, n the index of refraction,

F_1 D the front surface refractive power of the lens,

F_VD D is the back vertex power of the lens, and

h D the distance in meters from the back vertex of the lens to the entrance pupil of the eye. (The entrance pupil is normally assumed to be 3 mm from the front surface of the cornea.)

Here is an example of how spectacle magnification is calculated.*

These components contribute to magnification independently. The afocal components of thickness, index and front curve account for the shape factor; the power

*If the lenses are toric, having a cylinder component, each meridian must be computed separately.

Theoretically, What Was the Best Correction Thought to Be for Preventing Aniseikonia?

To answer this question, we need to know about two types of ametropia.

Axial and Refractive Ametropia

"*Ametropia* is the refractive condition in which, with accommodation relaxed, parallel rays do not focus on the retina.[1]" Ametropia includes myopia, hyperopia, and astigmatism. Ametropia may occur because the axial length of the eye is either too short or too long. This type of ametropia is called *axial ametropia*. On the other extreme, the eyeball may be of normal length, but still ametropic. Then the error is caused by the curves of the refractive components in the eye. In this case the ametropia is called *refractive ametropia*. According to "classical theory" of aniseikonia, the type of ametropia determines how the aniseikonia is corrected.

Producing a "Normal" Image Size (Relative Spectacle Magnification)

Normal image size is customarily taken as the image size for a standard emmetropic eye with a D60.00 refractive. Stated another way, if a person's eye is too long or too short, the image size will be larger or smaller than it would be normally. And Knapp's law says that using spectacle lenses* on such an eye will bring the retinal image size back to normal.

Having explained Knapp's law, it is imperative that we note the following: In spite of what optical theory says, aniseikonia is still present when axial ametropia is corrected with ordinary spectacle lenses that are placed at the theoretically correct position. This appeared to be a result of "differential retinal growth or stretching.[3]" The incongruity between Knapp's law and clinical practice should be kept in mind when reading the rest of the material on aniseikonia. It has important clinical implications when deciding upon appropriate methods of aniseikonia correction.

When myopic anisometropia is present, optical theory says that we want to return both image sizes back to that of the emmetrope so there will be no magnification differences. Knapp's law would say that in the presence of myopic axial ametropia, spectacle lenses return both images back to normal size. In theory this would make spectacle lenses the correction of choice. However, from a clinical perspective, axial anisometropias were reduced when corrected with contact lenses. Winn, et al also state that contrary to Knapp's law, spectacles "produce significantly greater degrees of aniseikonia than contact lenses.[5]" This suggests that even though the retinal image sizes may be made equal by using spectacle lenses for axially ametropic myopes, making retinal image sizes equal does not mean cortical image sizes will also equate.

Image Size for the Axially Ametropic Hyperope. The same discrepancies between theory and practice exist for the axially ametropic hyperope. The uncorrected image size for someone whose hyperopia is caused by a short eyeball will be smaller than the image size for a normal eye. Theory says that spectacle lenses magnify the image and bring that image size back to normal, whereas contact lenses leave the image size small. According to Knapp's law, the method of choice would be spectacle lenses over contact lenses. But in practice this does not prove to be the case. Contact lenses still prove to be more advantageous. (It should be noted that refractive surgery places the refractive correction at the same location as a contact lens—the corneal plane. Therefore refractive surgery would also be able to reduced aniseikonia in the same manner as would contact lenses.)

Refractive Ametropia and Image Size

If the ametropia is refractive, the uncorrected image sizes will be the same size as the image size for a normal emmetrope. Therefore, in correcting an anisometrope with refractive ametropia, we want the image sizes to remain the same. We do not want the refractive correction to magnify or minify the image. Contact lenses are able to correct the error, yet leave the image sizes almost unchanged. Therefore, for myopes or hyperopes with refractive ametropia, the method of choice for preventing aniseikonia, both in theory and practice, is contact lenses. A common indicator for the presence of refractive ametropia is keratometer readings that are significantly different between the two eyes, revealing different front-

Anisometropes With Astigmatism. Astigmatism is a form of refractive anisometropia. If spectacle lenses are used for high astigmatism, each meridian will cause a different amount of magnification. Even for high astigmatics who are isometropic,* contact lenses have the advantage of reducing meridional magnification differences. Therefore the method of choice for anisometropes with astigmatism would be contact lenses.

Detecting Clinically Significant Aniseikonia Although there are both obvious and not so obvious signs and symptoms that may indicate clinically significant aniseikonia, it is sometimes difficult to recognize.

Aniseikonia symptoms are often the same symptoms as experienced with uncorrected refractive errors or oculomotor imbalances. The difference is that with aniseikonia, symptoms either are not helped by the correction, or appear after the other problems are corrected.

In addition to those just mentioned, here are some indications of clinically significant aniseikonia:

1. High anisometropia or high astigmatism
2. The presence of certain factors that physically alter the eye, such as pseudophakia, scleral buckling, corneal transplantation, refractive surgery, and optic atrophy[6]
3. Complaints about spatial distortion, such as slanting floors, tilted walls, or ground too close or too far away
4. Better optical comfort when only one eye is used

It is helpful to notice if the symptoms occurred after a prescription change or after the dispensing of new glasses. Assuming the refraction is correct and the lenses verify as they should, when anisometropia is present, aniseikonia is likely. There are several ways to approach the problem.

CORRECTING ANISEIKONIA WITH SPECTACLE LENSES

If an exact amount of aniseikonia is found, modifications to the spectacle lenses that change relative spectacle magnification will be of benefit whether the anisometropia is axial or refractive.[6] This is because there are specific modifications that can be made to spectacle lenses that will change their magnification. Even though contact lenses are usually indicated in the presence of aniseikonia, the patient may not want contact lenses. Changing base curves, lens thicknesses, and vertex distance can still be used with spectacles to correct the aniseikonia.

There are several ways to approach the problem of aniseikonia:

surface corneal powers for the two eyes. Another indicator of refractive ametropia would be anisometropia in the presence of a developing cataract in one eye.

*Isometropia is the state of having equal refractive errors of both kind and amount in the two eyes.

1. If you are concerned that aniseikonia might be a problem, but have no clear evidence, use a “First Pass Method.”
2. If you are fairly certain aniseikonia is present, want to address it yourself, but have no way of measuring it; then make “directionally correct magnification changes” to each lens individually.
3. Estimate percent magnification differences based on the refractive prescription and change lens parameters accordingly.
4. Measure the percent magnification differences between the two eyes and change the lens parameters accordingly.

Using a “First Pass Method” to Prevent Possible Problems

When there is a concern that aniseikonia might be a problem, there are some things that can be done with frame and lens choices that will reduce magnification differences between lenses that would otherwise occur. This can be done before anything else and will not hurt anything, even if aniseikonia is not a problem at all.

1. Use a frame with a short vertex distance and, if nosepads are present, further reduce the vertex distance.
2. Use a frame with a small eye size. This secondarily reduces vertex distance.
3. Use an aspheric lens design. This usually flattens the base curves.
4. Use a high-index lens material. This will thin plus lens center thickness.

Making “Directionally Correct” Magnification Changes

It is possible to really go after an aniseikonia problem you are fairly certain is present, but have no way of exactly measuring. This is done by making changes to each lens individually in the appropriate direction so as to either reduce or increase magnification. Sometimes it is possible to reduce magnification differences just enough to alleviate the problem, without having an “exact fix.” When using this approach, here are two important notes:

1. Remember that the greater the difference in right and left lens power, the greater will the changes need to be to meet the problem. Changes will be to vertex distances, base curves, and lens thicknesses.
2. In your concern about the aniseikonia, do not forget that with presbyopes it may be necessary to correct for vertical imbalance at the same time.

What is done with each lens will depend upon the power of the right and left lenses compared with one another.

- If both lenses are plus, but one more plus than the other, follow the instructions found in Box 21-1.
- If both lenses are minus, but one more minus than the other, follow the instructions in Box 21-2.

BOX 21-1

If Both Lenses Are Plus (Anisohyperopia)

- Choose a frame with a minimum vertex distance.
- Keep the eye size small.

For the Higher Plus Lens	For the Lower Plus Lens
• Flatten the base curve. • Thin the lens. • Decrease the vertex distance.	• Steepen the base curve. • Increase center thickness. If possible try not to go thicker than a match of the thickness of the higher plus lens. • If the edge is thick enough, move the bevel away from the front and toward the back of the lens. (Do not exceed the limits of cosmetic acceptability.) This moves the lens forward in the frame, increasing

- If one lens is plus and the other minus, follow the instructions in Box 21-3.

Estimating Percent Magnification Differences

It is possible to estimate what the percent differences in magnification are from the prescription itself.* Estimates of how much magnification changes per diopter of power vary. Linksz and Bannon[7] say we can expect 1.5% per diopter of anisometropia when anisometropia is refractive in origin. However, since the ametropia probably has at least some axial component, 1% per diopter is more realistic. One percent per diopter is now considered the rule of thumb.

To correct for estimated aniseikonia, we can figure that if there is a problem, it will probably be between 1% and 2%. How to make exact magnification changes by specifically changing lens parameters will be discussed later in the chapter.

Measuring Percent Magnification Differences The ideal way to correct for aniseikonia is to measure it directly. Historically the classical method was to use a space eikonometer. A "**space eikonometer**" is used to quantitatively measure image size differences. Space eikonometers are no longer made.

*NOTE: Screening devices that are used for estimating percent magnification are not likely to be accurate enough to be effective. Large image size differences result in loss of binocularity and produce no symptoms. Small differences are not accurately mea- sured with screening devices and are the ones that cause the most problems.

BOX 21-2

If Both Lenses Are Minus (Anisomyopia)

- Choose a frame with a minimum vertex distance.
- Keep the eye size small.
- It is not advisable to change base curves for minus lenses unless there is certainty of what the end result will produce. (If the lens is more minus than −2.00 in power, steepening the base curve alone may not do the expected. Steepening the base curve increases magnification, but also increases the lens bend. This results in increased vertex distance.* Greater vertex distance for minus lenses means increased minification and may produce the opposite of intended results.)

For the Higher Minus Lens

- Decrease the vertex distance for this lens by moving the bevel as far forward as possible.
- If a large change in magnification is required, may be necessary to steepen the base curve considerably. If this is done, then the lens must also be thickened and the bevel moved to the front surface to decrease the vertex distance. Unless this is done, steepening

For the Lower Minus Lens

- Increase the vertex distance by moving the bevel away from the front of the lens. (Moving it totally to the back is going to it look bad.)
- Do not thin the lens.

*Each 1 D change in base curve changes vertex distance by approximately 0.6 mm.

† Brown WL. The Importance of Base Curve in the Design of Minus Iseikonic Lenses.

An alternative method has been to use appropriate Keystone View stereoscopic cards, preferably in con-junction with the Keystone orthoscope (a stereoscope with “minimum-distortion” lenses). Another more accurate means of testing is the Awaya New Aniseikonia Test (Handaya Co Ltd, Tokyo, Japan).

Once aniseikonia testing is complete it is still necessary to determine which parameters of each lens should be changed by what specific amount. There are tables and nomographs in existence that give expected changes in magnification produced by changes in base curve, lens thickness, vertex distance, and index of refraction.[7]

It is also possible to construct a program using an Excel spreadsheet or the equivalent. Then the formula for spectacle magnification with its shape and power factors can be used directly.† Whenever looking at the magnifications for any given pair of lenses, there will typically be a large difference between left and right spectacle lens magnifications. This difference does not have to be reduced to zero. Instead the *difference* between the two spectacle lens magnifications should be reduced by an amount equal to the aniseikonia found between left and right eyes.

(Even then, symptoms may disappear with smaller reductions in aniseikonia.)

Fortunately, there is another method that incorporates both testing and lens design into a computer-based software program.

The Aniseikonia Inspector

The Aniseikonia Inspector is a software program that presents a screen as shown in Figure 21-6. The subject wears red-green glasses, and the screen image is adjusted until both halves of the image are of equal size. The Inspector measures for magnification differences in the horizontal, vertical, and diagonal directions.

Once a percentage magnification difference or differences are found and prescription information entered, the program contains a form listing relevant lens parameters, including base curve, thickness, vertex distance, and index of refraction. By changing the parameters that are a part of the spectacle magnification formula, resulting lens magnification percents are seen. Right and left lenses are shown in cross section and also change as lens parameters are altered. The form and/or refractive index of the lens may be modified until suitable left and right lens magnifications result.

Even if it is possible to measure the full percentage differences between left and right eye, it may not be necessary to fully correct those differences. This is especially heartening when attainment of a full magnification difference correction would result in extremely when one lens is plus in power, some suggest the use of a high- index lens for the higher plus lens. A regular index lens is used for the lower plus. This will reduce thickness, base curve, and secondarily, vertex distance for the higher plus lens.

When constructing a spreadsheet, one must remember that the front curve is the refractive power of the lens and not the 1.53- indexed base curve. A 1.53-index-referenced number may be used if a conversion formula is built into the spreadsheet.

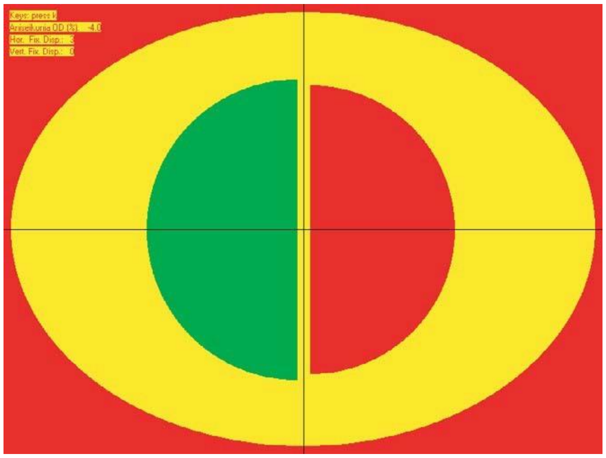


Figure 21-6. This screen simulation from the Aniseikonia Inspector program shows how the right eye would see an image that was smaller than the left.

unusual lenses with very thick centers or an inappropriately steep base curve on one of the lenses.

When using this program or when simply making changes in lens shapes to affect magnification in other aniseikonia situations, here are some points to consider. (Refer also to Boxes 21-1 to 21-3.)

1. Just reducing the vertex distance for both lenses will help.
2. Changing the base curve of even one lens may also help. (Reducing the highest base curve to equal the lower base curve can make a big change in magnification difference.)
3. Use an aspheric design. For plus lenses, both base curves will be flatter. This allows a decrease in thickness of the thicker lens. The thinner lens may then be made equal to the thicker lens.
4. Increasing the index of the lens will thin the lens.
5. If the least plus lens is thick enough, it may be possible to move the lens forward in the frame by moving the bevel back on the lens. This increases vertex distance.
6. It is possible to get a bit more of a change in magnification difference in plus lenses by leaving the weaker lens as a nonaspheric lens with a steeper base and using an aspheric design for the stronger lens.
7. Use an antireflection coating on both lenses to

done. In a study done at Emory Eye Center, Achiron et al[6] compared corrections for 34 anisometropes. They found that modifying lens design to equalize relative spectacle magnification both reduced aniseikonia and improved subjective comfort and performance. At the conclusion of the study, 93% of the study subjects preferred the spectacles that had been modified to correct for aniseikonia over traditional spectacles.

Their results also found that, contrary to Knapp’s law, axial anisometropes benefited just as much from modifications to relative spectacle magnification as refractive anisometropes did.

WHAT IS A BITORIC LENS?

It is possible to have a difference in magnification between two major meridians in right and left eyes. Magnification can be changed in each meridian independently.

Normally a cylinder lens has a front surface that is spherical and a back surface that is toric. The toric surface has a different radius of curvature in each of the two major meridians, thereby correcting for the astigmatism. However, it is possible to put a toric surface on the front of the lens *and* on the back of the lens, even if that lens is a sphere. This would happen if one chooses differing front lens curves for the purpose of creating more magnification in one meridian than the other. If this is done, then back surface curves are selected so as to counteract the cylinder power created by the toric front surface. This lens with toric surfaces on both the front and the back is called a *bitoric* lens (Figure 21-7).

PRISMATIC EFFECT OF LENS PAIRS

When depicting the optics of a pair of spectacles, the wearer is normally shown looking directly through the optical center (OC) of both lenses. This situation, of course, occurs only part of the time because the wearer's direction of gaze changes behind the lenses.
When looking to the right or left, upward or down- ward, because the object viewed is seen through a non- central lens area, there is a prismatic effect induced by each lens. This prismatic effect is predictable and maybe calculated.

If both right and left lenses are equal in all respects, then the prism powers induced by the two lenses for any position of gaze are also equal. reduce lens visibility and any otherwise noticeable differences between the two lenses.

Anisophoria

Remember that the condition of the eyes whereby a person requires lenses that differ in power—one lens being stronger or weaker than the other—is known as *anisometropia*. When such a person looks at an object through corresponding points on the lenses other than the OCs, the prismatic effects that are induced will be unequal for each eye. This situation is referred to as *anisophoria*.are of the same power, that deviation is symmetrical. Both rays emerging from the lenses, though deviated, are still parallel. Therefore, the eyes neither converge nor diverge relative to one another.

VERTICAL IMBALANCE

When differential prismatic effects are present at varying positions of gaze, resulting from a difference in power between right and left lenses, it is apparent that vertical prismatic effects may also be manifested. The most troublesome situation may occur when reading or close work is attempted over an extended period of time. When the wearer drops the eyes below the OCs of the lens and vertical prismatic effect of unequal values results for the two eyes, the differential prismatic effect induced is referred to as *vertical imbalance*.

Who Is Responsible for CorrectingVertical Imbalance?

Vertical imbalance often goes unnoticed throughout the eye examination and dispensing processes. This may happen for a variety of reasons. One major reason, however, is that unless segment and major reference point (MRP) heights are known, the amount of imbalance cannot be determined. These measurements are not known until after frame selection has occurred. Ideally the prescriber should notice the need and call for a correction on the prescription. This does not always happen, however. Therefore, unless dispenser and examiner are working in close proximity, the responsibility will rest with the dispenser. The dispenser must first recognize when a vertical imbalance correction is needed.

When Is a Correction for VerticalImbalance Needed?

The need for a vertical imbalance correction should be questioned when an anisometropic wearer progresses from single vision lenses into multifocals.

For the single vision lens wearer, if the unequal vertical prism proves troublesome with the eyes dropped for reading, simply dropping the head will solve the problem. In this manner, both lines of sight pass through the OCs, where there is a net prismatic effect of zero, alleviating the problem. For the new multifocal wearer, this option is eliminated by the positioning of the segment. To read through the bifocal portion, the wearer *must* lower the eyes and use a noncentral portion of the lens.

Tolerance to vertical imbalance in the reading area varies from person to person. Generally, any time there is a vertical meridian difference greater than 1.50 D in power between right and left lenses, vertical imbalance problems are a possibility; and when power differences are greater than 2-3 D vertical imbalance correction merits consideration. Some individuals with anisometropia are sensitive to the imbalance, whereas others with a higher amount are not bothered. Observing the individual while he or she is reading through the old anisometropic single vision prescription may give a clue as to possible difficulties.

To determine if a vertical imbalance correction may be needed, hand the person a reading card and ask him or her to read something. Notice what the person does when handed the card. If the individual drops the eyes to read, he or she is accustomed to reading with vertical imbalance, and no special compensation may be necessary. If the person drops the head to read, however, reading is being done through the distance OCs to prevent prism imbalance in the lower part of the glasses. These individuals may experience difficulty with a multifocal lens if the imbalance is left uncompensated. In some instances, only partial compensation for the imbalance may be required.

Vertical imbalance corrections are especially critical when the imbalance is of recent onset. This occurs when a person has had either cataract surgery or refractive surgery on one eye only. Both situations create anisometropia, causing a vertical imbalance at near for which a multifocal wearer is unable to compensate. In these cases because adaptation has not occurred over time, the full amount of imbalance correction is indicated.

CORRECTING FOR VERTICAL IMBALANCE

There are several methods of correcting for vertical imbalance, some of which are capable of compensating for more prismatic imbalance than others. The first four on the list attempt to avoid the problem of vertical imbalance. The last four attempt to correct for the problem.

1. Contact lenses
2. Two pairs of glasses
3. Dropping the MRP height
4. Raising the seg height
5. Fresnel press-on prism
6. Slab off (bicentric grind)
7. Dissimilar segs
8. Compensated “R” segs

It should be noted that those who benefit from the correction of vertical imbalance will also benefit from a good choice of lens parameters for offsetting aniseikonia (image size differences). Lens choices for aniseikonia are explained earlier in this chapter.

Contact Lenses

From a purely optical standpoint, one of the best options available for correcting vertical imbalance is the contact lens. The OC of the contact lens moves with the eye. When an individual wears contact lenses, the spectacle lens-induced prismatic difference disappears and the vertical imbalance problem with it.

Two Pairs of Glasses

When anisometropes wear single vision lenses, vertical imbalance seldom surfaces as a problem. This is because single vision lens wearers have the option of dropping the head and looking through the lens OCs instead of just dropping the eyes and looking below the OCs. This means that if an anisometrope decides against multifocal lenses, he or she is not forced to look into the lower portion of the lens where the near segment is located. Thus one option for overcoming vertical imbalance is to have *two pairs of single vision glasses*, one for distance and one for near. When using two pairs of glasses, the reading glasses should be ordered with the OCs lower than normal. This way the wearer looks through the lens OCs. A separate pair of single vision glasses for near does not *correct* for vertical imbalance; it *avoids* vertical imbalance. When ordering two pairs of glasses for this purpose, it is advisable to position the OCs for the near prescription 5 mm below the vertical center of the frames.

Instead of using a regular frame for the near Rx and lowering the OCs, a pair of half-eye frames may be used. In this way, the OCs are lower, even at their normal locations. They do not have to be lowered farther.

Dropping the Major Reference Point Height

Reducing the amount of vertical imbalance at nearby dropping the OC or MRP of a multifocal lens pair is used in practice, but is not as optically sound as other options. By dropping the OC, the distance from the OC to the reading level is reduced and so is the prismatic effect at near. Lowering the OC, however, will transfer imbalance from the near portion to the distance portion because gain at near is offset by an increase in imbalance in the upper portion of the lens. Dropping the MRP in multifocals might be successful in borderline cases of imbalance, but is not the best option available.

Raising the Seg Height

By raising the seg height *without* simultaneously raising the height of the distance OC (i.e., the MRP), the wearer will not have to look as far down into the lens at near. If the eyes are not as far from the distance OCs for reading, the vertical imbalance will not be as great.

If the surfacing laboratory moves the distance OC up as the seg goes up, however, then no benefit is derived. If the technique of raising the seg is to be used, it is best to specify not just the seg height but also the MRP height.

Fresnel Press-on Prism

A *Fresnel press-on lens* is made from "thin, transparent, flexible, plastic material which adheres to the surface of an ophthalmic lens when pressed in place.[1]" Thus it is possible to cut a Fresnel press-on prism to fit the lower half of one lens to counteract a vertical imbalance. Placed on the back surface of the ophthalmic lens, the Fresnel prism simulates a slab-off lens. Fresnel lenses for such an application are usually not considered to be a permanent solution, but rather are used on a trial basis to see if the wearer's visual difficulties can be alleviated. (For more on Fresnel lenses, see Chapter 17.)

Slab Off (Bicentric Grinding)

The most common option for correcting vertical imbalance produces a vertical prismatic effect in the lower half of one lens only, beginning at the level of the bifocal segment line. This type of correction is called a *slab off* or *bicentric grind.* It is identified by the presence of a horizontal line across one lens at the level of the segment top.

Slab off is almost always used unless the amount of correction required is less than 1.50D. At less than 1.50D, it is difficult to control the appearance and placement of the slab line. Fortunately, problems with vertical imbalance do not occur as frequently once vertical imbalance drops below 1.50D. Slab off can be made in fairly large amounts. Before using greater than 6D of slab off on a given lens, however, it may be advisable to consider using regular (base up) slab off on one eye and reverse slab off (base down) on the other. (Reverse slab off begins at 1.50D and progresses in increments of ½D up to 6D.)

Slab off can be custom ground on any lens, whether it is made from glass or plastic.

Slab Off for Fused Glass Multifocals

When bicentric grinding (slabbing off) is done on a fused glass multifocal lens, base-up prism is created in the reading area. Slab-off grinding is done on one lens only. The lens chosen is that which has more minus (or less plus) power in its 90-degree meridian. The process by which this is accomplished is shown and described in Figure 21-11.

One of the greatest advantages of the slab-off method is that a large amount of prism compensation may be made in comparison with other available methods. The completed lens grind produces a relatively inconspicuous line. This line overlaps the flat-top seg line already present on the lens and is partially obscured by it (Figure 21-12). Although any shaped seg, or even no seg at all, may be used in conjunction with bicentric grinding, the flat-top seg gives the best results cosmetically.

For the fused glass lens, the bicentric grind results in base-up prism. Therefore slab off will, by necessity, always be performed on *the most minus or least plus powered lens.*

Slab Off in Plastic Lenses

It is possible to use slab off on any plastic lens, including a progressive addition lens. With plastic the process somewhat resembles that of the glass lens, but is carried out as shown in Figure 21-13.

Slab Off for Progressive Addition Lenses. When slab-off prism is used on a progressive addition lens, the slab line will be on the back surface of the lens. The level of the slab-off line is normally positioned slightly above the near verification circle. The full amount of slab-off correction is usually calculated based on the distance from the prism reference point (*not* the fitting cross) to the center of the near verification circle.

Sheedy reports that slab-off prism on a progressive lens meets with just as much success as slab off on seg- mented multifocals. As with any slab-off correction, the critical aspect is selection of the candidate and as expected "presbyopia in the presence of anisometropia of greater than 2-3 D in the vertical meridian should trigger slab off consideration. However, we don't consider slab off if the patient is already a successful multifocal wearer with no near-vision complaints. We also tend to avoid slab off in the first-time multifocal wearer, because many aniso- metropic patients are able to successfully manage the vertical prism. We prefer to use slab off only when it becomes necessary. These patients also often benefit from aniseikonic lens designs—at least equal center thickness and base curves.[9]"

Precast Slab-Off Lenses (the Reverse Slab Lens)[10]

A high degree of skill is required to grind plastic slab-off lenses. The increased need for plastic slab-off lenses and the level of skill required offered an incentive for the development of a suitable precast slab off that could be surfaced in the normal manner. The first precast CR-39 slab-off lens, developed by Aire-o-Lite in 1973,[11] was for a 25-mm round seg. This was followed in 1983 by the Younger Optics Slab-Off lens series.

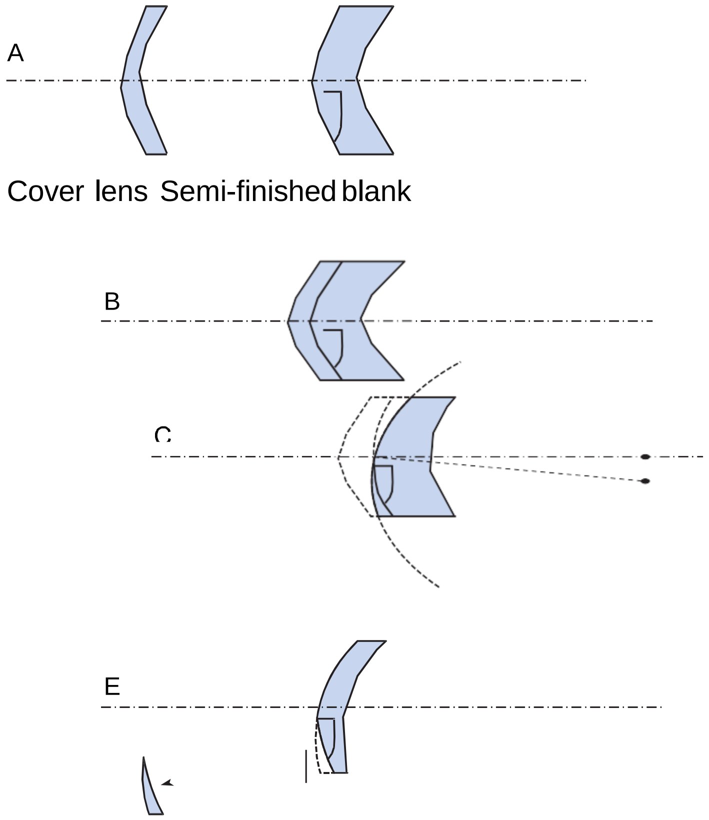
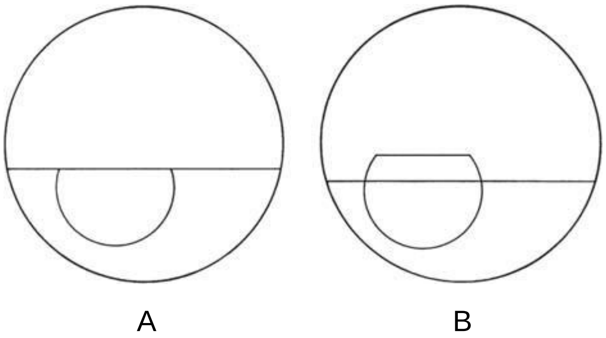


Figure 21-11. Slab-off prism manufacture. **A,** A cover lens is manufactured to have the same inside curve as the base curve of the required semifinished lens blank. **B,** This cover lens is cemented to the semifinished blank. (In actual practice, only one half of a cover lens is required, covering from the center of the lens on down. For instructional purposes, however, the complete cover lens is shown.) **C,** Base-down prism is ground on the front surface of the lens. Glass is surfaced off until only the lower half of the cover lens from the seg line down remains. The dioptric value of the prism is equal to the prescribed amount needed for compensation. **D,** The distance power is surfaced on and the prismatic effect removed during generating (surface grinding). Now the entire lens is once again without prism. **E,** Last, the remaining portion of the cover lens is removed. This wedge-shaped portion is a base-down prism whose value equals that surfaced, as was shown in **C**. The net effect is the addition of base-up prism to the lens from the seg downward.



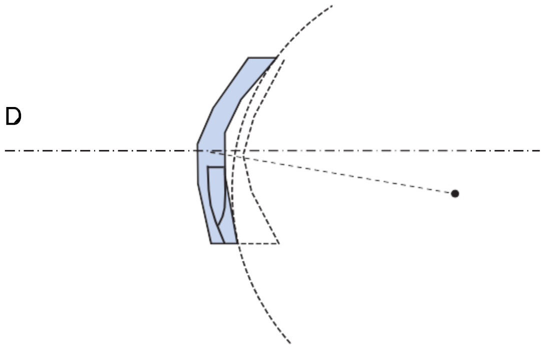


Figure 21-12. Slab-off prism produces a thin line easily concealed by a flat-top seg. The wider the seg is, the more inconspicuous the line will be. **A,** A bifocal lens is shown. **B,** Shows

The precast slab-off lens is made using a flat-top 28 lens. The lens blank is large and has the segment in the center so that it may be used for either a right or a left lens (Figure 21-14).

Slab-off prism starts at 1.50D and goes up to 6.00D in increments of ½D. In contrast to conventionally ground slab-off lenses, the precast lenses are a reverse slab. This means that instead of having base-up prism in the area below the slab line, the precast lenses have base-down prism. The slab-off prism is cast molded on the front of the lens so that the semifinished blank can be surfaced on the rear surface in the normal manner (Figure 21-15). In a number of cases, the end result will be a thinner lens.*

the correct position for slab-off prism on a flat-top trifocal.

The procedure for a trifocal bicentric grind is done from the back in a manner similar to that shown in Figure 21-13 for the plastic lens.

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*For equal plus powers, regular slab-off lenses will be thicker than reverse-slab lenses. Since regular slab off will be placed on the least plus lens, however, added thickness could help equalize left and right lens thicknesses and resulting magnification. For minus powers, the center thickness of both regular and reverse-slab lenses will be equal, but the lower edge of the reverse-slab lens will be thicker than the lower edge of the regular slab-off lens.

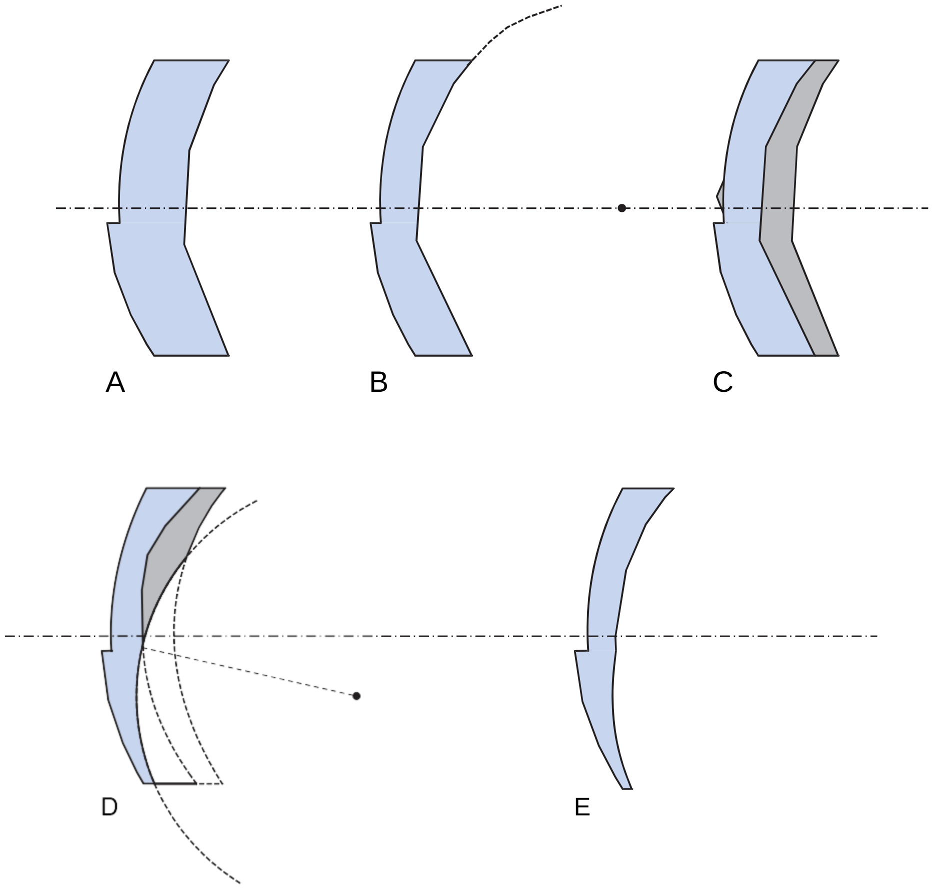


Figure 21-13. The process of bicentric grinding on a plastic lens must be carried out entirely on the rear surface because the front surface contains the one-piece construction bifocal segment area. The process begins with a semifinished lens **(A).** The semifinished lens is surfaced to the required prescription and is left thick enough for a second prism grind later **(B).** A liquid resin material is poured into the concave rear surface and allowed to dry. This resin **(C)** serves the same purpose as the cover lens served for the glass lens technique. The lens is then resurfaced at an angle **(D).** Surfacing a lens at an angle serves to grind on prism. The surfacing tools used are the same as were used in **(B)** so that correct power is maintained. The near portion now contains the proper amount of prism base up and the correct power. Last, the lens is chilled to cause the remaining resin to break away. The upper portion has not been changed since originally surfaced. **E,** The completed lens. It will be noted that with bicentrically ground plastic lenses, the slab line is on the rear surface instead of the front.

Slab line Centered segment

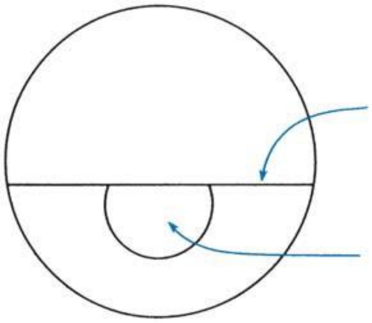


Figure 21-14. The Younger molded slab-off lens has the slab- off prism on the front. Prism is base down instead of the customary base up. The segment is centered so that the blank will work for either a right or a left lens.

With back-surface slab grinds, some segmented multifocal lens wearers experience the sensation of seeing two lines. They see the seg line on the front and the slab line on the back. With precast lenses, the slab line is on the front *with* the seg line. This eliminates the possibility of the wearer seeing two lines. Because reverse-slab lenses use base-down instead of base-up prism, the prism direction and the eye it is worn on is reversed. *The reverse slab is placed on the most plus or least minus, instead of the most minus or least plus*.

There appears to be no difficulty switching wearers from conventional slab off to precast slab off.[12] If a person has more than one pair of glasses, including sunglasses, however, then a possibility exists that all the pairs of Plastic lens

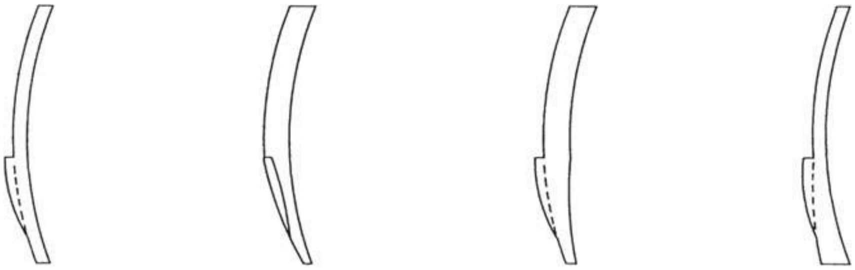
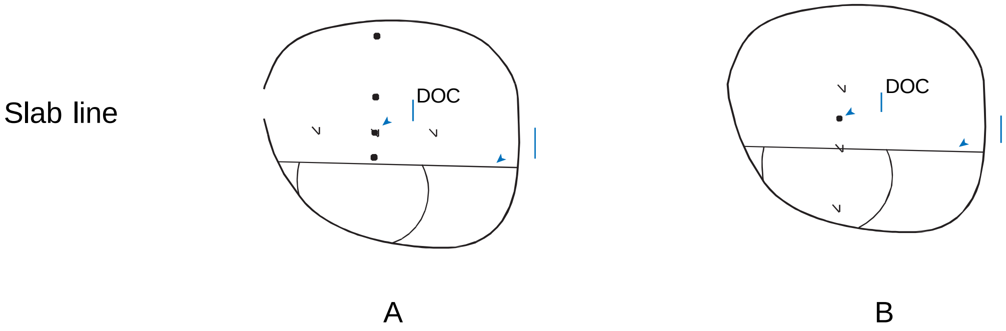


Figure 21 15. Slab off lenses of plano distance power are com- pared with one another and with a non–slab-off plastic lens. These cross-sectional drawings show the location of the slab-off grind and how that grind affects lens thickness for a plano lens. No slab-off Base up slab-off front surface Base up slab-off Back surface Base down Younger slab-off front surface

Figure 21-16. A, To verify the amount of slab-off prism present, the three contact points of a lens measure may first be oriented either at the position of the Xs or at the dots. **B,** The second position is shown. For regular index lenses the difference between these two readings indicates the amount of slab-off prism present.



Slab line glasses may have to be switched; otherwise, the wearer could have trouble because of the difference in object displacement between the prescriptions.

Slab-Off Verification

The amount of slab-off prism present may be verified by comparing the seg areas of the slab-off lens with its partner lens through a lensmeter. A simpler method, however, makes use of the lens clock. The lens clock is first used to find the base curve of the bicentrically ground lens by orienting the contact point horizontally across the lens center in the distance portion paralleling the slab-off line. After noting the base curve, the lens clock is then oriented with contact points perpendicular to the slab-off line. The central contact point of the lens clock is placed directly on the line. For regular index lenses the difference between these two readings indicates the amount of slab-off prism present (Figure 21-16).

Dissimilar Segs

One possible method of compensating for vertical imbalance in the reading area makes use of prismatic effect induced by the segment of a bifocal lens.

If the bifocal wearer looks through his or her bifocal segment, unless he or she is looking through the segment's OC, the segment (being itself a miniature lens) will produce a prismatic effect. This prismatic effect is separate from that produced by the distance lens.When both right and left bifocal segs are set at the same heights, having the same power addition, the vertical prismatic effect produced will be the same for both right and left eyes.

DETERMINING THE CORRECT AMOUNTOF COMPENSATION FOR VERTICAL IMBALANCE

The steps needed for determining the needed amount of vertical imbalance are as follows:

1. Select an appropriate frame and measure for bifocal height.
2. Determine the vertical location within the segment where reading will take place. That level is called
   the *reading level*. (The terms *reading level* and *reading depth* are used synonymously.)
3. Determine the prism amount that is to be used to correct the imbalance.

Bifocal height is determined as was explained in Chapter 5. Reading level may be determined subjectively, objectively, or by calculation.

Determining the Reading Level

Determining the Reading Level Objectively

Reading level may be objectively measured using the correctly sized sample frame. Place tape at the level of the proposed bifocal, occluding the distance portion so that the wearer looks *under* the tape. Then place reading material so as to simulate normal working or reading conditions. Position yourself below the wearer's eye level, almost in line with the reading material. Measure from the bottom edge of the tape to the estimated line of sight (which extends from the center of the pupil to the reading material). Add this value to the seg drop (MRP height minus seg height) to arrive at the reading level.

Determining the Reading Level Subjectively

To determine reading level subjectively, tape the sample frame as described above. This time have the wearer fixate a point at the near working distance. Lower a card from above past the level of the tape until it just barely occludes the fixation point. Note the distance the edge of the card overlaps the tape into the near portion and add this value to the seg drop.

imbalance will be "undercorrected." Thus the person doing the calculation can choose to undercorrect the imbalance a certain amount by choosing a higher reading level. In most instances, reading level will be 3 to 5 mm below the seg line. Reading depth will be the seg drop plus the estimated distance that the reading level is below the seg line.

METHODS FOR DETERMINING THE PRISM CORRECTION NEEDED

How the Prescriber Determines the Needed Amount of Imbalance Correction

Correcting for a vertical imbalance at near may not necessitate using the full amount of calculated compensation. (How the amount of vertical imbalance is calculated is covered later in this chapter in the section titled Correcting the Full Imbalance by Calculations.) Some individuals with a longstanding vertical imbalance become acclimated to it and through continuous use are able to overcome some of the prismatic effect by vertically diverging the eyes somewhat when reading or per-forming near tasks. Thus many spectacle lens wearers are able to compensate partially for an imbalance them- selves. For example, a person may show a need for 2.00D of slab-off prism when actual calculations indicate a need for 3.00D. It is possible to test and see how much imbalance is required. This is most easily done if the person is wearing glasses that contain a current, valid distance prescription.

With the individual wearing the correct distance pre- scription, place tape over the upper portions of the lenses at the actual or theoretical segment line location. This forces the wearer to look below the tape and through the lower area of the lenses at the level where he or she will be reading. A fixation disparity testing unit is held in the reading position and Polaroid filters placed over the glasses. Hold a hand-held vertical prism bar with prisms of increasing power over one of the wearer’s eyes. (If a prism bar is not available, loose trial prism lenses may be used.) Incrementally increase the prism amount by moving the prism bar until the fixation disparity target shows proper alignment. This is the correct amount of slab-off prism needed.

If a fixation disparity testing unit is not available, it is possible to position a pen light at the reading level and place a red Maddox rod over one eye. Incrementally increase the prism over one eye with the prism bar until the red line intersects with the white light. This method may yield a larger amount of vertical prism than the fixation disparity method. When imbalance is deter- mined using methods such as these, the prism amount becomes a part of the prescription.

Sometimes a prescription simply indicates the need for slab off, but does not state the amount, leaving it to the dispenser or laboratory to calculate. In many instances, even when the need for slab off exists, it is not part of the prescription. This does not preclude the dispenser from incorporating slab off in the wearer’s spectacles, however, since vertical imbalance is a spectacle lens-induced problem.

How to Use a Lensmeter to Determine the Amount of Imbalance

If the wearer's distance prescription has not changed, the amount of imbalance may be determined as follows:

1. Spot the MRPs of the lenses.
2. Having predetermined the reading position, locate the reading centers. This is done by measuring down from the MRPs to the reading level and in by the amount seg inset.
3. Spot the newly located reading centers. (These will correspond to the wearer's near interpupillary distance [near PD] at the reading level).
4. Center one reading center before the lensmeter aperture and read the amount of vertical prism present. Without moving the lensmeter table up or down, slide the glasses over so the second reading center is in front of the lensmeter aperture and measure the vertical prismatic amount at this point.
5. The vertical prism difference between these two vertical prism readings is the full amount of vertical prism imbalance experienced by the wearer.

If the distance prescription has changed, the old glasses cannot be used to measure vertical imbalance.

How an Optical Laboratory Determines the Amount of Imbalance

The optical laboratory determines the amount of slab- off prism by calculation. The chief advantage a laboratory may have is the possible availability of computer software containing the appropriate formula. The laboratory will compute the *full* amount of imbalance. If the dispenser does not specify a reading level, the laboratory will choose one.

CORRECTING THE FULL IMBALANCE BY CALCULATIONS

If the full correction for vertical imbalance is indicated, this may be calculated. There are several methods of calculation that may be used as will be described in the following sections. The methods do not always result in exactly the same answers. As with any decentration problem, difficulty in calculation increases with the complexity of the prescription—the easiest being spheres and the most difficult, spherocylinder combinations. Here are the steps normally used to find the amount of vertical imbalance.

1. Find the reading depth. The reading depth (or reading level) is the seg drop plus the distance from the segment top to the level at which the wearer is expected to read (usually 3 to 5 mm).
2. Find the power of each lens in the 90-degree meridian.
3. Find the prismatic effect at the reading depth of each lens.
4. Find the prismatic difference (vertical imbalance) between the right and left lenses.
5. When using slab-off, determine which lens will receive the imbalance correction.

Using Prentice's Rule to Calculate VerticalImbalance for Spheres

The traditional methods for calculating vertical imbalance use Prentice's rule. Here this traditional method will be explained, starting with an example of a prescription for spherical lenses.

Using Prentice's Rule to Calculate Vertical Imbalance for Spherocylinders

Spherocylinders at 90 Degrees or 180 Degrees Calculation of vertical imbalance at near for spherocylinders is fairly straightforward when the cylinder axes are at 90 or 180 degrees.

Planocylinders and Spherocylinders, Axes Oblique (Exact Calculations for the Traditional Method) Calculating imbalance for planocylinders whose axes are oblique requires considerably more calculations to achieve the best result. One way of doing this is to use the same calculations as outlined in Chapter 16 in the section on Decentration of Cylinders Oriented Obliquely and Horizontal and Vertical Decentration of Oblique Cylinders.

Calculating the prismatic effect of the distance lens at the reading center for spherocylinders is done by first calculating the prismatic effects caused by the sphere component, then calculating the prismatic effects caused by the cylinder component. The prismatic effects found in the two separate operations are then added together. The calculations required to use this method are feasible, but difficult, and are seldom used in clinical practice.

Prismatic Effect and Magnification Are Related Magnification is the result of a changing prismatic effect across a lens. The equation for spectacle magnification is employed when calculating magnification with aniseikonia. This equation takes both base curve and lens thickness into account. Changing either base curve or lens thickness causes a change in magnification. Remole uses spectacle magnification to more accurately find prismatic effect at a given point on a lens.

DESIGNING A LENS TO CHANGE THE APPEARANCE OF A BLIND EYE

Normally, lens power is used only to correct refractive error and prism power to alleviate problems with bin- ocular vision. Yet there is another use for power, prism, and even tint that has nothing to do with refractive error. It can also be used to improve the cosmetic appearance of a blind or prosthetic (artificial) eye.

A skilled ocularist will be able to match the color and appearance of the artificial eye's iris and sclera to that of the seeing eye. But because of a condition of the eye socket, an artificial eye may look abnormal, even when eye colors are well matched. If further cosmetic surgery will not help, cosmetics may be improved with spectacle lenses. Lenses used for cosmetic purposes are not part of the prescription. They may be determined by the dispenser at the time of frame selection.

Changing the Apparent Size of the Eye

Lenses have the optical effect of magnifying if they are plus or minifying if they are minus. When a plus lens magnifies, it not only causes the world to look larger to the wearer, but the wearer's eyes will also look bigger to everybody else. Normally, dispensers try to reduce this effect by using aspherics to flatten and thin the lens. Yet sometimes it may be advantageous to make a nonseeing eye look bigger *intentionally*.

*This magnification needs to be the dynamic spectacle magnification as calculated with reference to the eyes' centers of rotation, not the static spectacle magnification; the dynamic spectacle magnification is a greater magnification than the normally calculated (static) spectacle magnification.

Using Spheres

If a person has lost an eye and had it replaced with a prosthetic eye, the artificial eye may match the color of the seeing eye perfectly. The artificial eye may have a sunken appearance, however, making it look smaller. To correct this effect, hold up plus trial lenses in front of the prosthetic eye until it looks closer in size to the seeing eye. When a good match is achieved, use the experimentally found power. Likewise, if the nonseeing eye looks too big, minus power can be used to make it appear smaller.

Using Cylinders

Planocylinders may be used to change only the horizon- tal or only the vertical size of the eye. For instance, sometimes even when the horizontal dimension of the eye looks normal, the vertical depth of the palpebral fissure* of the nonseeing eye may be smaller than that of the seeing eye. To make the fissure look larger vertically, a plus cylinder, axis 180 may be used. To find the correct power, hold plus cylinders up in front of the eye until the desired cosmetic effect is achieved.

Tilting the Cylinder to Change Lid Slant

In some instances, the eyelids of the prosthetic eye may appear slanted. When a cylinder lens is rotated around its axis, it will cause a horizontal line to tilt. A plus cylinder will cause a straight line to tilt against the direction of rotation, whereas a minus cylinder will cause a line to tilt with the direction of rotation. When deciding whether to use plus or minus cylinder, the deciding factor is magnification.

To determine the optimal axis placement, hold the cylinder lens in front of the eye (preferably using a trial frame) and turn the axis until the slanted lids match the straight lids.[20]

Summary

1. The apparent overall size of the eye may be changed using plus or minus sphere lenses.
2. By using planocylinder lenses, the size of the eye may be increased or decreased in one meridian (the power meridian of the cylinder). The magnification in the meridian 90 degrees away (the axis meridian) will remain unaffected.
3. Rotating a planocylinder lens away from the horizontal or vertical meridian causes tilt. If eyelids look unnaturally tilted, place a cylinder lens in front of the nonseeing eye and rotate the cylinder axis until the eyelids look more like the normal eye.

*The palpebral fissure is the area between the upper and lower eyelids.

A

B

Figure 21-23. A, The artificial eye is this person's right eye. It appears low in comparison with the left eye. **B,** An attempt has been made to cosmetically alter the appearance of the eye. This has been done by placing 10D of base-down prism in the right lens. To help prevent a thick lower edge on the right lens, a frame should be chosen with a narrow vertical dimension. To help camouflage lens thickness, the lenses have been given an antireflection coating.

(Courtesy of Laurie Pierce, Tampa, Fla.)

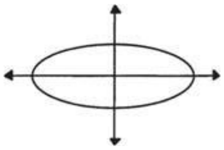
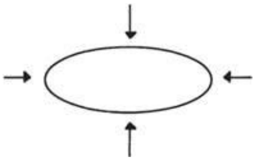
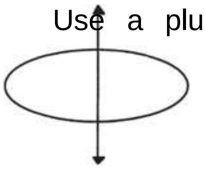
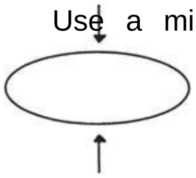
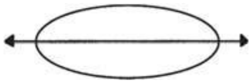
Using a Lens to Camouflage Scarsor Deformities

Sometimes a nonseeing eye is scarred or disfigured, but not to the point where a patch would be worn. In this case a lens should be selected that will decrease the visibility of the eye. Tinting may be applied to the lens as either a solid or a gradient tint. An antireflection coating should not be used. Keep in mind that tinting both lenses will decrease the wearer's vision at night. Cosmetic considerations should not rule over safety considerations.

Changing the Apparent Location of an Eye Trauma causing the loss of an eye can also cause the displacement of the socket. This makes the prosthetic eye appear higher or lower than the seeing eye. If the blind or prosthetic eye is lower or higher or appears to turn inward or outward compared with the seeing eye, its apparent location may be altered by using prism.

The base direction of the prism used will always be placed in the direction that the eye is physically displaced. In other words, if the eye appears too high, use base-up prism. If the eye turns in, use base in. If this is done, then to an observer, the wearer's eye will appear to be displaced toward the apex of the prism. Such prism is called *inverse prism* because it is opposite to what would normally be prescribed for a seeing eye.

Table 21-1 summarizes the use of lenses for cosmetic effects.

Problem	Desired Cosmetic Effect	Lens Solution
Eye looks small.	Make the eye look bigger. 	Use a plus sphere lens.
Eye looks large.	Make the eye look smaller. 	Use a minus sphere lens.
Eye not open as wide as the seeing eye. (Fissure looks too small vertically.)	Widen the fissure vertically. 	Use a plus cylinder, axis 180.
Eye open wider than the seeing eye. (Fissure looks too large vertically.)	Close the eye somewhat. 	Use a minus cylinder, axis 180.
Eye looks too small horizontally.	Widen the horizontal appearance of the eye. 	Use a plus cylinder, axis 90.

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Winn B, Ackerly RG, Brown CA et al: Reduced aniseiko- nia in axial anisometropia with contact lens correction, J

Sample Questions:

1. A man wearing D3.00 D lenses for both eyes (O.U.) turns his eyes to look at a distant object on his right. In so doing, he looks through a point on his lenses 1 cm to the right of the OCs (Figure 21-8). What is the resultant prismatic effect for each eye?

Using Prentice’s rule, it may be seen that:

$$D\ D\ cF$$

and in this case

D D (1)(3.00) D 3.00

2. Suppose a prescription of the following power is worn:

O.D. D7.00 D sphere
O.S. D3.00 D sphere

What prismatic effects are induced by the lenses for the points 1 cm to the right of the OCs when viewing a distant object located to the right (Figure 21-9)?

For the right eye, the prismatic effect is found (usingPrentice’s rule) as:

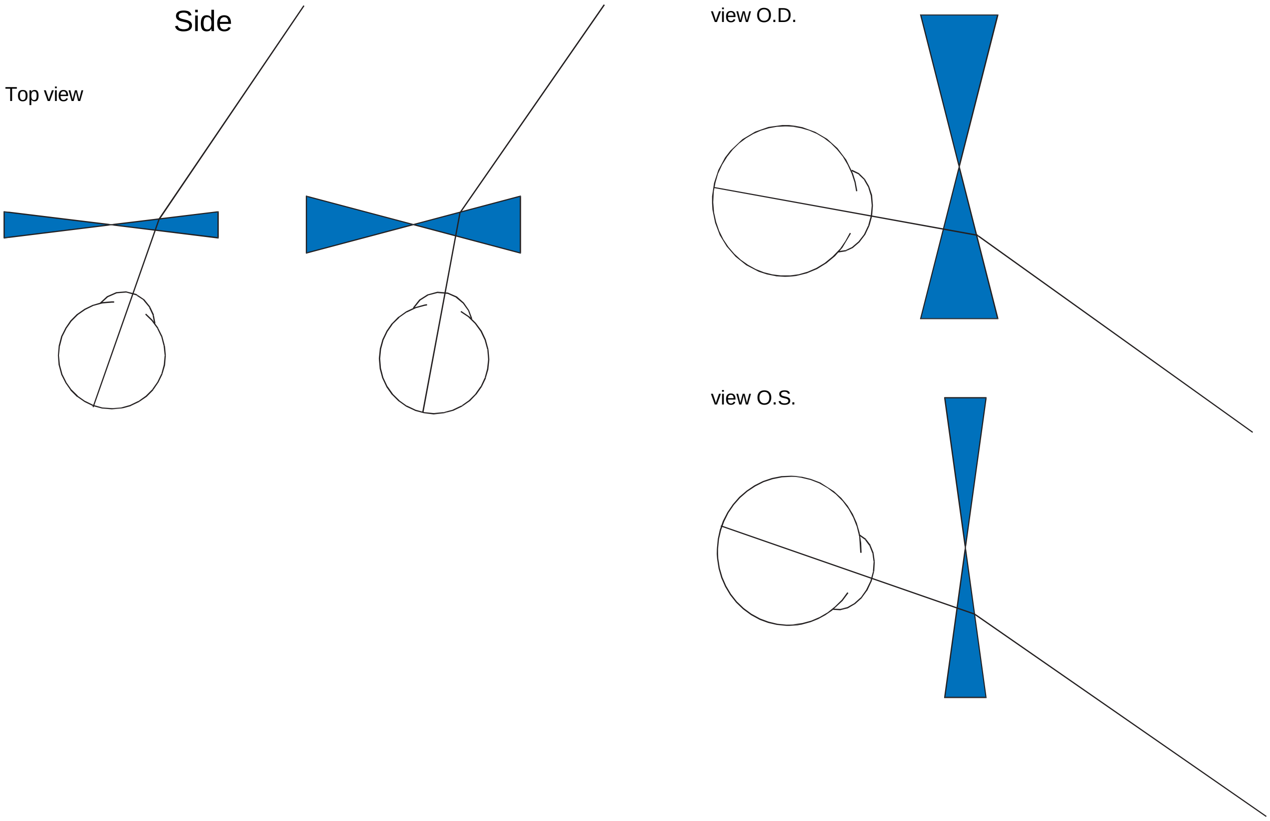


Figure 21-9. When parallel light from a peripherally viewed object at infinity strikes a pair of spectacle lenses whose powers are unequal, the prismatic effects created at these noncentral lens positions are unequal, causing more deviation for light entering through one lens than through the other. This in turn causes either a convergence or divergence of the eyes, depending on lens powers.

Side

D D *cF*
D D (1)(7.00) D 7.00D

For the left eye, the effect results in 3.00D of prism.

In Example 21-2, where both lenses were of identical power, there was no imbalance between the eyes. Both eyes continued to point in the same direction. In Example 21-3, however, the right eye is forced to turn 4.00D more than the left. Because the base-out effect overpowers the base-in effect, the net effect for the two eyes is 4.00D base out. The eye turns towards the apex of the prism, and the two eyes are forced to converge relative to one another.

Fortunately the eyes are not required to hold this position over long periods of time and quickly adapt to the variations of fixation.

3. Suppose a right prosthetic eye is physically displaced down-ward, *A*. How could the eye be made to look more normal?

Increasingly larger amounts of base-down prism are held in front of the prosthetic eye until, with 10D of base-down prism, the eye appears more evenly placed relative to the seeing eye. To prevent having the right lens appear thick at the bottom, use a frame with a small vertical size (small B dimension. To make the prism less obvious, an antireflec-tion coating should be used. It is possible to split the prism unevenly between the left and right eyes. If the prism is split, the *maximum* amount of vertical prism should not exceed 4D in front of the seeing eye. Exceeding 4D may cause postural changes and errors in the perceived location of objects. In this case one might use 7D base down before the right eye and 3D base up before the left eye.

4. Suppose vertical imbalance at near is to be corrected for the following prescription:

O.D. D3.00 D Sphere
O.S. D0.50 D Sphere Add D2.00 D
Frame B dimension D 46 mm Seg Height D 19 mm

Reading level is 4 mm below the seg line. What is the vertical imbalance at the reading level?

Begin by finding the reading level. In calculating imbalance, it is helpful to visualize the situation described. Because the B dimension is 46 mm,

seg drop D B / 2 D seg height
D 46 / 2 D 19
D 23 D 19

D 4

Because the reading level is 4 mm below the seg line, it will be 8 mm below the distance OCs. (This is shown in Figure 21-20.)

Use Prentice's rule to determine the vertical prismatic effect at the reading level. In the example problem, the reading level is 8 mm below the OC so the vertical prismatic effect for the right eye is:

D_V D cF
D 0.8 D D3.00D
D 2.40D

The base direction is up since the lens is plus. (Since we are only concerned with vertical prismatic imbalance, the horizontal prismatic effect is not needed and does not need to be calculated.)

The vertical prismatic effect at the left reading center is calculated in the same manner as for the right:

D_V D cF
D 0.8 D D0.50D
D 0.40D Base Up

Therefore the vertical imbalance is the difference between the left and right vertical components at the reading level.

2.40D base up O.D.
DD 0.40D base up O.S.
D 2.00D base up O.D.

The full correction for vertical imbalance must counteract 2.00D base up before the right eye at near. This may be done by:

1. Either placing 2.00D of base-up prism before the left eye at near, or
2. Placing 2.00D base-down prism before the right eye at near.

The choice depends on the method of compensation used. If the imbalance were corrected using conventional slab-off prism, the slab-off correction would be placed before the most minus or least plus lens. In this case the least plus is the left lens.

Unit 12:

Absorptive lenses

Learning Objective:

One of the most misunderstood areas in ophthalmic dispensing is absorptive or "tinted" lenses. Myths and folk tales about the harmful or therapeutic effects of certain hues persist. This may create confusion, even for the dispenser, who may develop a personal philosophy about absorptive lenses through a combination of learned facts and educated guesses or who may simply yield to the changing tides of fashion and let the wearer have whatever most pleases him or her.

Yet it is the responsibility of the person engaged in eye care to know as much as possible about the subject of absorptive lenses.

At the end of this chapter, participants will be able to learn:

1. Purpose of absorptive lenses.
2. Difference between different types of tints and filters.
3. Materials and methods to use tints in glasses.
4. What are different types of lenses used to avoid glare.

CLASSIFICATION

Absorptive lenses are classified by *two variables*. The first is *the tint of the lens* itself, and the second is *the lens trans- mission*. Tints of the same basic color are labeled by a variety of names, depending on the manufacturer or in the case of plastic lenses, the name of the dye used to tint the lens. Differences of shade are sometimes discernible when two manufacturer's products are held side by side. For this reason, a record of the lens source should be entered on the wearer's record so that a replacement lens will match the original.

The relative absorption of a lens is most often denoted as either percent transmission or percent absorption. (Twenty percent transmission is the same as 80% absorption.)

Absorption used to be denoted by a letter, such as A, B, C, or D, or by a number, such as 1, 2, or 3. The higher the number or the further down the alphabet, the darker the tint will be.

Because this system was developed for tinted glass lenses that change transmission with increasing thick- ness, specific transmission will vary for different powered lenses having the same number or letter designation. Because this system still has limited usage, the dispenser must be aware of these potential differences.

Problems of Uniform Transmission Inherent in Pretinted Glass Lenses

It should be noted that the specified transmission for a pretinted glass lens applies to a 2-mm thick plano lens.

Any departure from this thickness will give rise to changes in transmission. The individual who was previously wearing a C tint in a 02.00 D glass lens may therefore find the same tint irritatingly dark when the prescription is changed to 03.50 D.

Glass lenses that vary in thickness from one area to another will also show proportional changes in trans- mission. The high minus lens will have a lighter central portion, darkening rapidly towards the periphery (Figure 22-1, *A*); the plus lens shows a darkened central zone with the tint lightening to the normally expected shade at the periphery (Figure 22-1, *B*). Perhaps the most unusual is a high, near plano minus cylinder lens. In this case a lighter band runs across the lens corresponding to the location of the minus cylinder axis (Figure 22-1, *C*). Fortunately, few absorptive lenses require glass lens material, making the problem an infrequent occurrence.

THE EFFECT OF VISIBLE AND NONVISIBLE LIGHT ON THE EYE

Light is electromagnetic radiation found in the wave- length range that includes infrared (IR), visible, and ultraviolet (UV) radiation. Not all of these wavelengths cause an activation of photoreceptors that produce vision (Figure 22-2). Light is interpreted as color according to the length of the light wave that strikes the retina.

The visible spectrum is considered to be between 380 and 760 nm.[1] (However, light with a wavelength as short as 309 nm may be seen if it is of sufficient intensity. Light having sufficient intensity and a wavelength as short as 298 nm could be seen if it were not absorbed by the crystalline lens before reaching the retina.)[2]

Much of the “light” in the UV and IR regions of the spectrum that strikes the eye never reaches the retina. Instead it is absorbed by the cornea, aqueous humor, crystalline lens, or vitreous humor of the eye. If too much of this “light” is absorbed by the individual eye structure in sufficient quantity or over an excessively lengthy period, it can be potentially harmful.

The Effects of Ultraviolet Radiation

“Light,” or more properly, electromagnetic radiation with a wavelength shorter than 400 nm, is known as UVradiation. UV radiation can be further subdivided into four regions.

1. UVA 315 to 380 nm
2. UVB290 to 315 nm
3. UVC200 to 290 nm
4. UV Vacuum 100 to 200 nm

UVA radiation has the longest wavelength band and, relatively speaking, is the least harmful of the three radiation bands. It causes the skin to tan. UVB has shorter wavelengths and a higher energy than UVA. If present in sufficient quantity, long enough duration, or both, UVB causes sunburn, photokeratitis, cataracts, and retinal lesions. UVC is still higher in energy, but is effectively filtered out by the earth’s ozone layer. UV Vacuum is present outside the earth’s atmosphere, but is filtered by the atmosphere. The shorter the wavelength, the more biologically harmful the radiation will be.

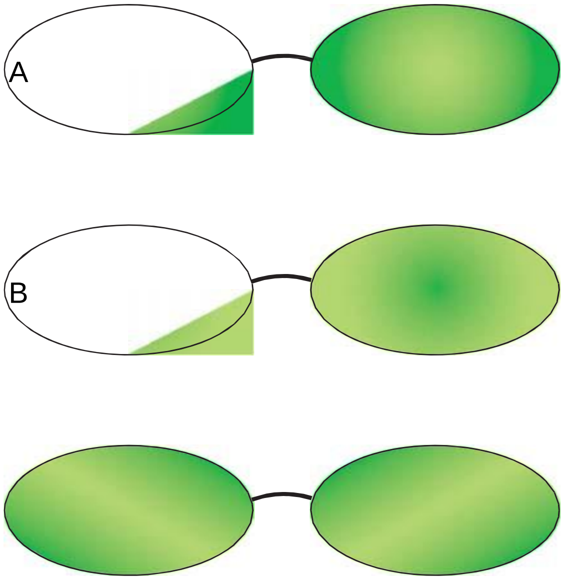


Figure 22-1. Glass lenses with the tint right in the material will vary in transmission as the thickness of the lens varies. **A,** A high minus prescription will be lightest in the middle and darken toward the edges. **B,** A high plus prescription will be darkest in the middle and lighten toward the edges. **C,** A plano, high minus cylinder will be lightest along the cylinder axis. Here the minus cylinder axis for the wearer's right eye is about 140; for the left eye it is about 40. This only occurs with high cylinders when the tint is within the glass itself.

There are a number of negative effects attributed to excessive exposure to ultraviolet radiation. The question becomes what constitutes "excessive exposure?" The answer is not simple. Single, high level amounts of UV can be damaging—but so can long-term, low-level amounts of UV exposure.

UV radiation is a normal component of sunlight, but the amount reaching the earth has been increasing with the thinning of the atmospheric ozone layer. The ozone layer normally filters out a large portion of shorter wave- length UV radiation.

UV radiation from sunlight is more intense between the hours of 10 AM and 2 PM with 60% of total UV radiation taking place during these hours.[1] The total annual amount of UV radiation is greater in geographic regions closer to the equator, and the amount of UV radiation increases in intensity at high altitudes.

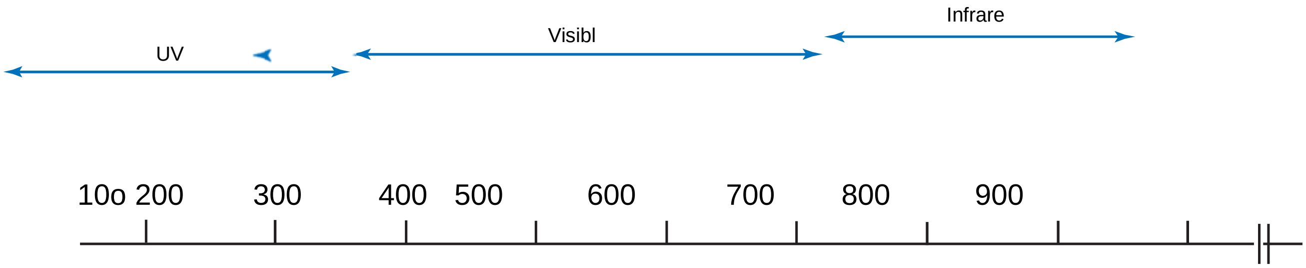
Sand and snow increase the amount of UV radiation an individual receives because sand reflects 20% to 30% of UV light. Fresh snow reflects 85% to 95% of the light that strikes it as compared with only 3% for grass.[4] This makes UV protection for skiers absolutely essential.

Other sources of UV radiation include UV-type lamps and welding.

Ocular Damage Caused by Ultraviolet Radiation

An example of ocular damage caused by a single dose of high-level UV radiation is a *welder’s burn*. In a welder’s burn, the cornea and conjunctiva absorb UV light between 210 and 320 nm.[1] The excessive exposure to these UV wavelengths results in inflammation of the cornea and conjunctiva known as *photokeratitis*. The same photokeratitis may result from exposure during snow- related activities and is referred to as “*snow blindness*.” It takes approximately 6 hours after a burn has occurred before the onset of pain. Fortunately, although the symptoms of grittiness, intense light sensitivity, excessive tearing, redness, and difficulty in opening the eyes are severe, in most cases the cornea heals, and symptoms are gone in 6 to 24 hours.

An example of ocular damage caused by long-term, cumulative, low doses of UV radiation is *the formation of cataracts*. People who live where UV radiation is high (at high altitudes or in desert or tropical areas) develop cata- racts earlier in life. As an example, those who live in an



UVA 315-380 nm
UVB 290-315 nm
UVC 200-290 nm
UVVacuum 100-200 nm

Visible from 380-760 nm
Visible down to 309 nm with sufficient intensity Visible down to 298 nm without crytalline lens

Figure 22-2. The light spectrum: ultraviolet, visible, and infrared.

area where the average amount of sunlight exposure is 12 hours have four times the amount of cataract formation compared with those who live in areas with a daily average of 7 hours.[5]

Welder's burn and cataracts are not the only eye-related problems induced by UV radiation. Another serious problem is retinal damage, particularly for the *aphake* (person without a crystalline lens) since the lens no longer absorbs light between 300 and 390 nm, but allows it to fall on the retina. This light is not only refracted somewhat differently, failing to produce as good an image, but now is absorbed by the retina, causing it to fluoresce.[6] This causes somewhat of a veiling glare effect. The glare effect is not the main problem since the sensitive, unprotected macular area of the retina can develop swelling from the UV and short blue spectrum (400 to 500 nm)[7] rays. In time this is followed by degeneration of the sensitive macular area. This degeneration is known as *age-related maculopathy* (ARM) or *macular degeneration*.

Though UV and short-wavelength retinal damage is normally associated with age, it should be noted that because children have more transparent crystalline lenses, their lenses allow some UV light to be transmitted to the retina.

Protecting the retina from UV light is imperative. For aphakes it is an absolute necessity. Today cataract surgery is followed by the implantation of an intraocular lens to replace the cataract-clouded crystalline lens. Individuals who have an intraocular lens implant are called *pseudophakes*. Although presently used intraocular lens implants are UV absorbing, UV protection is still advisable.

A *pterygium* is a growth of tissue that begins on the white of the eye and extends onto the cornea. With continued growth it can travel to the center of the cornea, blocking clear vision. There is a correlation between the incidence of pterygia and UV exposure. A similar condition known as a *pinguecula* may also be UV related. A pinguecula manifests itself as a yellowish thickening of the conjunctiva, usually on the nasal side of the cornea.

Drugs That Heighten Ultraviolet Damage

Certain drugs increase the amount of damage that can be done by UV radiation. These include, but are not limited to, sulfonamides, tetracyclines, certain diuretics, tranquilizers, and oral contraceptives. This means that in addition to those effects of UV radiation that have already been discussed, individuals taking these drugs are more prone to sunburn and skin cancer. Individuals known to be taking these medications should be advised to use UV protective eyewear and use sunscreen for skin protection when appropriate.

Who Should Have Ultraviolet Protection?

UV damage to the eye is known to be cumulative over time. Reduction in ozone layer levels means that exposure to UV radiation is higher than in years past. Because UV radiation affects everyone over time, the best way to reduce UV-related eye disease is to wear UV-absorbing spectacles and sunglasses early in life. Environmental and job-related factors place certain individuals at an even greater risk. For example, skiers in high mountainous areas are at particularly high risk because there is less atmospheric filtering of UV radiation at higher altitudes, and snow reflects about 85% of the UV light that strikes it. The eyebrows and even hats do not provide the protection that they normally would because of reflected light.

BOX 22-1

Individuals With a Greater Need for Ultraviolet (UV) Protection

THOSE WITH THE FOLLOWING CONDITIONS:

- Beginning cataracts
- Macular degeneration
- Pterygia
- Pinguecula
- Aphakia
- Pseudophakia

THOSE WHO ARE TAKING MEDICATIONS, INCLUDING:

- Sulfonamides
- Tetracyclines
- Diuretics
- Tranquilizers
- Drugs for hypoglycemia
- Oral contraceptives

(This list is only a sampling of drugs that may increase UV damage. It is by no means all inclusive.)

THOSE IN THE SUN UNDER THE FOLLOWING CONDITIONS:

- Outdoors between 10 AM-2 PM in summer
- Outdoors long hours (especially children at play)
- Snow skiing
- Sun bathing
- In high-altitude conditions
- Near the equator

Factors regarding protection from UV light are summarized in Box 22-

1Regardless of special factors that heighten the danger of UV light, studies conclude that “All sex and racial groups would benefit from simple methods to avoid ocular sun exposure.”

Eyewear That Blocks Ultraviolet Radiation

There are a number of lens options available to protect against UV radiation. Some require special ordering, bu

any lenses come with UV filtering as a basic part of the lens.

1. *Lenses with the UV filter directly in the lens material*—The first lenses that were developed specifically to block UV light had a yellowish cast. As manufacturing methods and chemistry improved, the yellow disappeared.
2. *Lenses with the UV filter in the coating*—Now many lenses come with a protective coating that have a secondary UV-blocking effect. These include all polycarbonates and many high-index plastic lenses.
3. *Lenses with a dyed-in UV filter*—Plastic lenses can be made UV inhibiting by immersion in a hot UV dye in the same manner as is used to tint a lens.
4. *Polarizing lenses*—Good quality polarizing lenses block UV radiation, though the polarization process has nothing to do with blocking UV light.
5. *Photochromic lenses also have UV-blocking properties*. In their darkened state, photochromic lenses are considered sufficiently protective against UV light.
6. *Lenses that go beyond UV protection*—There are lenses designed to go beyond simple UV protection. They also block out short wavelength (primarily blue) visible light. These are generally referred to as “glare control lenses” and are described later in this chapter.

Checking for Ultraviolet Absorption

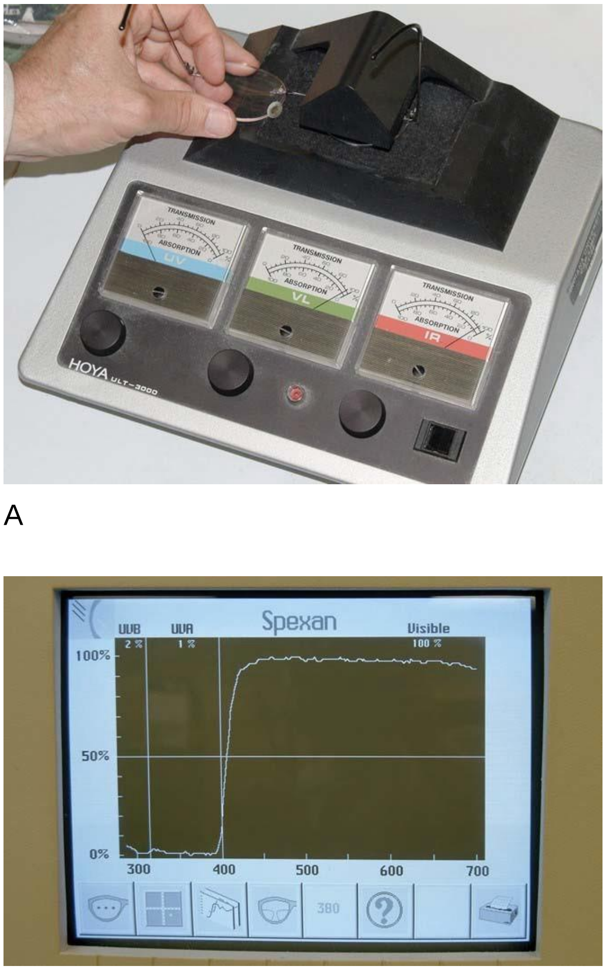
Lens transmissions are often checked using a photometer. Though photometers are helpful (Figure 22-3, *A*), at the time of this writing, they should not be totally relied upon for absolute UV measurements. As Torgersen[3] points out, photometers typically:

- Are not able to accurately determine absolute UV transmittance.
- Disproportionately weight the waveband of 360 to 400 nm.
- Do not cut off at the UVA limit of 380 nm, but measure on up through 400 nm.
- Are affected by the power of the lens.

It is therefore advisable for the practitioner to be very familiar with the absorptive properties of individual lens materials.

It should be remembered that the dyes used to make a regular plastic lens into a UV-blocking lens are only good for a finite number of applications before they must be replaced. Even when ordered, it is feasible that UV protection may be inadvertently overlooked in the laboratory. Photometers are still helpful to determine if dyes have been applied. Transmission may also be measured using a Humphrey automated lensmeter (Figure 22-3, *B*). If no UV meter is available, there is a crude test that can be performed to see if the lens is blocking UV light:

Place the lens in question on top of an unedged photochromic lens, such as a Transitions lens. (A plastic photochromic lens is more UV dependent than a glass photochromic lens.) Expose the two lenses to sunlight.



A

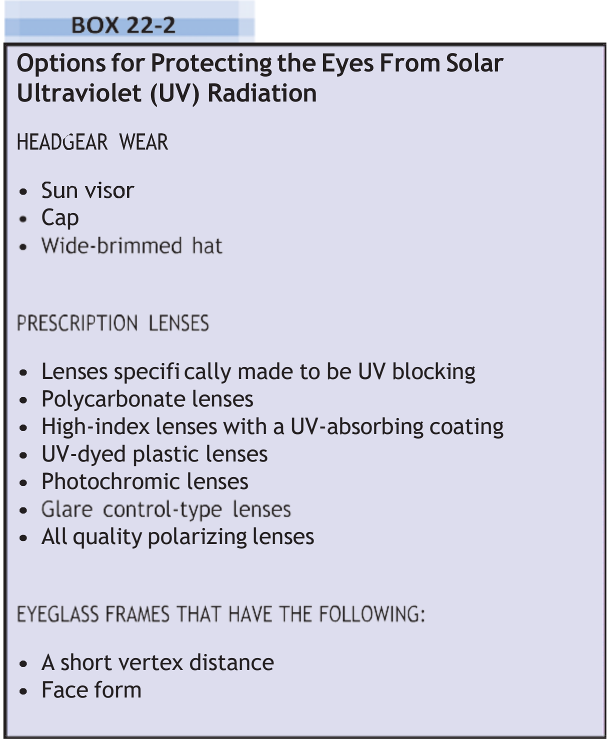
B

Figure 22-3. A, Lenses ordered with ultraviolet (UV) absorption should be checked using a UV meter. This light transmission meter measures UV, visible (VL), and infrared (IR) light. The lenses being measured are blocking all UV light and are transmitting most of the visible and infrared radiation. **B,** It is possible to check the transmission of a lens using a Humphrey Model LA360 Lens Analyzer. This autolensmeter allows both an on-screen display and a printout.

If the photochromic lens darkens under the lens that is supposed to be filtering UV light, the lens being tested is not filtering UV light adequately.

Selecting a Frame

Here is what to look for when selecting a frame for sunglasses or for serious protection against UV radiation. The frame should have a large lens area. It should be fit close to the face with minimum vertex distance. Wraparound frame styles are better still. Note: When wraparound styles are used for prescription eyewear, the prescription may need to be compensated for lens ti, see Box 22-2



BOX 22-2

Options for Protecting the Eyes From Solar Ultraviolet (UV) Radiation

HEADGEAR WEAR

- Sun visor
- Cap
- Wide-brimmed hat

PRESCRIPTION LENSES

- Lenses specifically made to be UV blocking
- Polycarbonate lenses
- High-index lenses with a UV-absorbing coating
- UV-dyed plastic lenses
- Photochromic lenses
- Glare control-type lenses
- All quality polarizing lenses

EYEGLASS FRAMES THAT HAVE THE FOLLOWING:

- A short vertex distance
- Face form

Ultraviolet Index

The UV Index is a measure of UV radiation. The U.S. Weather Service and the Environmental Protection Agency, along with the World Health Organization, use a UV index on a scale of 1 to 110 with intensities from low to very high. The index is categorized as follows:

UVI	**Exposure Level**
0 1 2	low
3 4 5	moderate
6 7	high
8 9 10	very high
11 and greater	extreme

Any UV index will vary from day to day and place to place. The intent of a UV index is to make the general public aware of UV radiation levels and encourage eye and skin protection.

The Effects of Infrared Radiation

At the present time, there is little conclusive evidence in the literature that would indicate any undesirable effects resulting from the IR component in sunlight in ordinary viewing.

Previously, it was thought that the solar retinitis caused by the intense exposure of looking directly at the sun for a long period of time was a result of the heat-producing IR component alone. Scientists at the Medical College of Virginia, however, found the eye to be 800 times more susceptible to damage from the blue end of the spectrum than from the near IR. It appears that solartinitis is due to a combination of photochemical damage from short wavelength (UV and blue) radiation and thermal damage from long wavelength IR.

IR radiation, when combined with UV radiation and blue light, can adversely affect the crystalline lens. Over a prolonged period of time, this will cause opacification. This lens opacification is commonly referred to as “glass blower’s” or “furnace men’s” cataract.

Common sources of IR are direct sunlight; molten substances, such as glass and metal; arc lamps; and IR lamps.

In looking at the transmission curve of a given lens, remember that simply because there is a drop in the transmission of IR in the region nearest the visible spectrum, there may not be this same absorption in the longer wavelength IR region. Many lenses that absorb strongly in the near IR transmit a great deal in the longer wavelengths. Therefore if a lens is to be chosen for IR absorption characteristics, a transmission curve showing the full range of the IR spectrum is needed.

The heat produced by IR radiation will cause the eye to be more easily damaged when exposed to UV radiation. Therefore though not scientifically verified, it would seem that a sun lens that practically eliminates UV radiation while also blocking IR to the same degree that it blocks visible light would be desirable. Examples of commercially available lenses that block IR are NoIR and IREX lenses.

REQUIRED AMOUNTS OF ABSORPTION ractitioners are continually asked how dark a tinted lens should be for best protection or how light a fashion tint must be to not adversely affect the wearer’s vision. The answer is considerably more complex than might be expected since much depends on the activities for which the lens is to be used.

If the only object is the comfort of the wearer, then the decision is often subjective and is fairly accurately determined through the wearer’s past experience. Other factors, however, must be considered as well. As far as actual improvement of vision, Miller[6] found that for high levels of illumination, sufficiently dark sunglasses will improve visual discrimination for certain types of targets, but not for others. In other words, for high illumination, a person’s ability to see clearly may be helped by dark lenses, and his or her visual comfort most certainly will improve.

How Much Tint Is Enough?

Normal transmission for sun lenses is generally between 15% and 30%. A sun lens that transmits more than 30% may not help the average wearer enough in full sunlight.[10] Sun lenses that transmit less than 15% may present problems because of reflected glare from the back surface. These problems can be eliminated by using a back-surface antireflection (AR) coating.According to ANSI Z80.3-2001 sunglass standards, general purpose sun lenses used for driving should not be darker than 8%, although for special purposes, such as skiing, mountain climbing, or use on the beach, trans-mission may go as low as 3%.[11]

At the lower end of the transmission spectrum, it was found that acuity increased with a 10% neutral density filter.* But for persons more than 40 years of age, vision worsened if the filter was any darker than 10%.[12]

It should be noted that people who are exposed to sunlight for long periods of time on a continual basis will require sun lenses that transmit 15% or less. Hecht, et al[10] found that a single exposure to ordinary bright sunlight for 2 or 3 hours caused dark adaptation to start 10 or more minutes later than usual and then slowed the process itself so that normal night vision was not reached until several hours later than usual.

For example, if a person (such as a lifeguard) is exposed to bright sunlight every day for long periods of time, his or her dark adaptation does not return to what it used to be even after a full night's darkness. If this continues for 10 days of unprotected high exposure to sunlight, it will impair dark adaptation to such an extent that 3 or more days of non exposure are required for dark adaptation to return to its previous level. This loss of dark adaptation can be prevented by wearing sunglasses that allow only a transmission of between 10% and 15%. For the person exposed to bright sunlight, wearing commercially available cosmetically tinted lenses that transmit 35% to 50% of the light will not prevent impairment of dark adaptation. In fact "it is strongly recommended that sunglasses transmitting 10% or less of visible light be used by all persons who, while working in bright sunlight during the day, will be expected to perform critical night duties soon afterward.[10]" In short anyone who has a job that requires seeing well at night must wear sunglasses if they are exposed to bright sunlight for 2 or more hours a day.

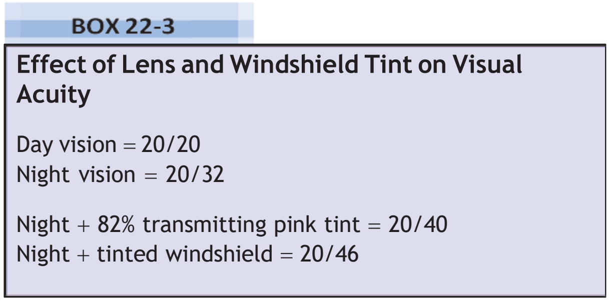
The Hazards of Too Much Tint

As just discussed, there are certain situations where a large amount of *absorption* is quite desirable. By the same token, there are also circumstances in which a maximum of light *transmission* is desirable. When considering darker fashion tints, wearers should be warned of the reduction in visual acuity in dimly lit conditions.

Tinted Lenses and Night Driving

A commonly occurring situation that demonstrates the hazards of too much tint for existing conditions is night driving. At night with eyes adapted to a light intensity of 1.1 mL through a clear glass windshield, the visual acuity of an individual who normally sees 20/20 will be reduced to 20/32. This is not because of looking through

*A neutral density filter is gray and absorbs light evenly across the visible s



BOX 22-3

Effect of Lens and Windshield Tint on Visual Acuity

Day vision = 20/20
Night vision = 20/32

Night + 82% transmitting pink tint = 20/40
Night + tinted windshield = 20/46

Data from Miles PW: Visual effects of pink glasses, green wind- shields, and glare under night driving conditions, Arch Ophthalmol 52:15-23, 1954.

the windshield, but rather is simply a result of reduced illumination. Any tinted material between the observer's eye and the object being viewed will further reduce acuity. Even an 82% transmitting pink tinted lens worn at night reduces acuity to 20/40. A green-tinted wind- shield by itself reduces acuity to 20/46. The combination of tinted windshield and tinted lens, however, reduces acuity to 20/60 (Box 22-3).[13] The level of tint desirable is therefore a function of the circumstances under which it is to be worn.

It should be obvious that a lens tinted only slightly more than the lightest available shade quickly becomes a potential hazard under circumstances, such as night driving, that may otherwise be considered normal. This was reinforced by a German study[14] that found wind- shield tinting to reduce night driving hazard detection distances by 10%. Allen[15] also found that a person wearing lenses having a 70% transmission at night ended up being much closer to an object on a highway before being able to see that object than when they were not wearing tinted lenses.

Another factor in the determination of the amount of tint permissible is age. As age increases, performance differences observed while wearing certain optical filters decreases. In other words, a person's ability to work effectively under a situation of reduced illumination decreases as he or she ages.

In spite of evidence to the contrary, some wearers insist that a light tint at night is helpful in reducing the glare of oncoming headlights. This is likely due to the ability of a tint to reduce some internal lens reflections. An antireflection coating is better at reducing internal lens reflections. Rather than using tinted lenses, an AR coating will reduce oncoming headlight annoyance and will increase the wearer's contrast sensitivity by increasing available light.

COLOR CHARACTERISTICS

During the past several years, there has been a phenomenal increase in available frame styles. Previously, certain types of frame styles went in and out of fashion. Now,

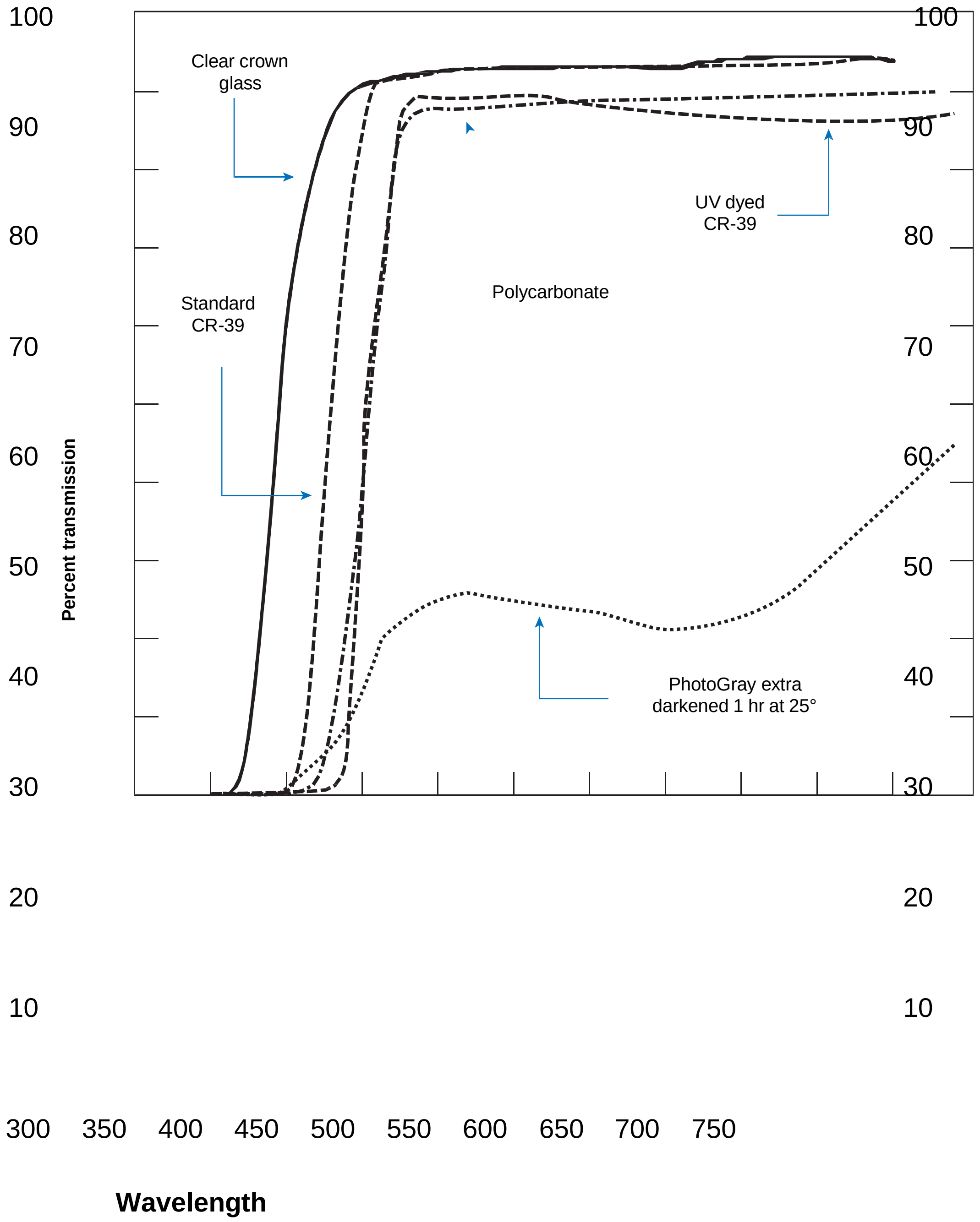


Figure 22-4. Transmission of ultraviolet radiation for standard ophthalmic lens materials. The polycarbonate lens material listed has an antiscratch coating standard for polycarbonate prescription lenses. Polycarbonate lens' UV blocking properties are a result of the coating on the material and not the material itself. (Transmission curves from: Spectral transmission of

common ophthalmic lens materials, St Cloud, Minn, 1984, Vision-Ease, pp 1, 16; from Photochromic ophthalmic lenses, technical information, Publication #OPO-232, Corning, NY, 1990, Corning Inc, p 5; and from Pitts DG and Kleinstein RN: Environmental vision, Boston, 1993 Butterworth-Heinemann.)

however, a full range of designs is being used. More recently this effect has also been seen regarding lens tints since there are many different shades and hues of lenses available. Because of this multiplicity of available colors, analysis of each one's merit becomes increasingly difficult. This section presents characteristics of the major lens colors in an attempt to address this problem.

Clear Crown Glass and CR-39 Plastic

Crown glass and CR-39 plastic both transmit approximately 92% of visible light. The 8% not transmitted is lost through reflection. All UV light below 290 nm is absorbed by crown glass (Figures 22-4 and 22-5).

Crown glass transmits IR in the same proportion as it does visible rays.
CR-39 plastic used in normal spectacle lens wear contains a UV inhibitor that does not block all UV light, but does block UV light below 350 nm.

Pink

Pink is a tint that has been widely used in the past and continues to be used, but in a limited amount. The lightest shades are referred to synonymously as pink, rose, or sometimes, flesh.* Pink tints have a uniform transmission across the visible spectrum (see Figure 22-5) and therefore do not cause any color distortion for the wearer.

Pink tints are occasionally used for unfavorable indoor lighting situations, such as bright fluorescent lighting or glare in the work area. The best solution to those problems is a change in lighting, rather than an indoor tint. Glare problems may be due to internal reflections within the lenses. This occurs most often in low minus corrections (see the section in this chapter on antireflection coatings). Light tints do reduce some of the reflections encountered, but not nearly as effectively as an antireflection coating. Many wearing light tints would be better helped with a simple antireflection coating. It is not advisable to use an indoor tint much darker than 80% because of interference with perception and reaction time when worn at night or under very dim illumination.
290 on up to the visible light that can be more disturbing.[6] Most UV light below 290 in the UVC and UV

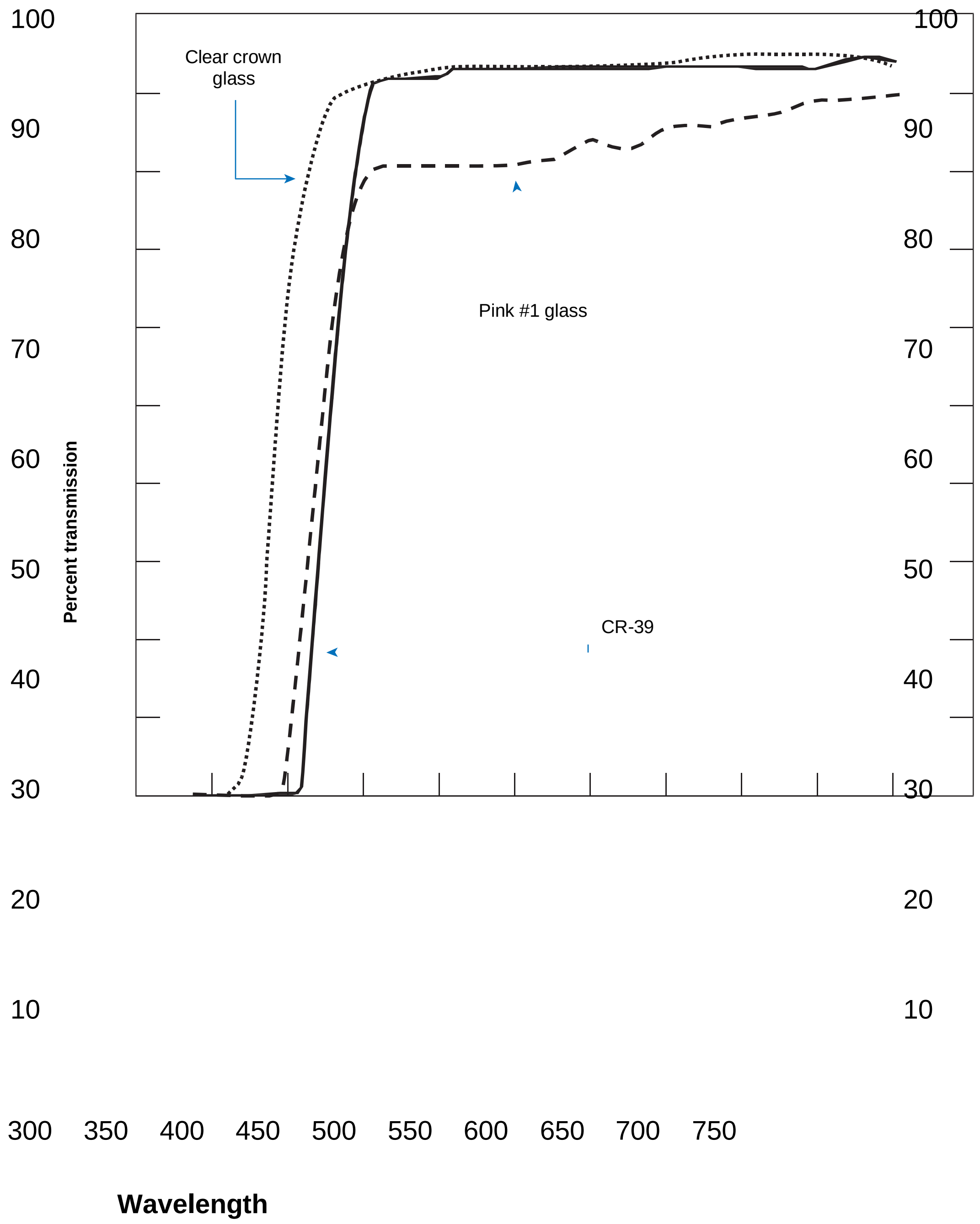


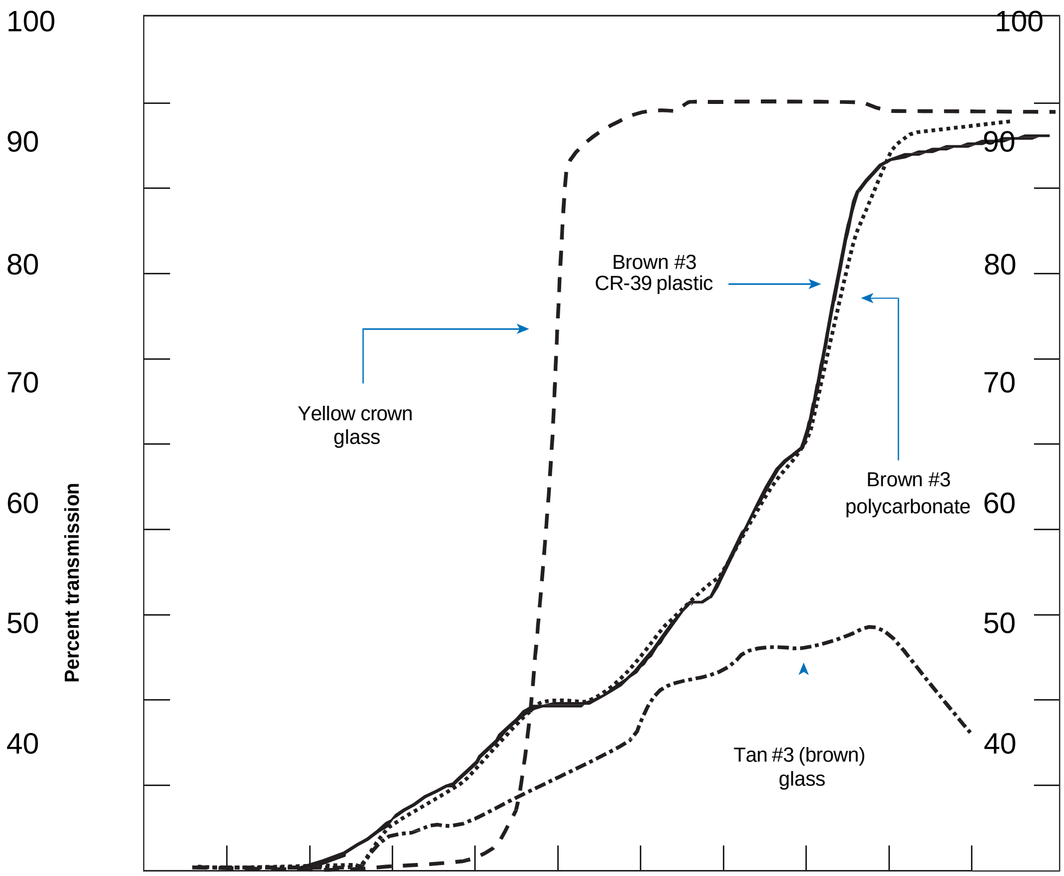
Figure 22-5. Transmission curves for clear crown glass, clear CR-39 plastic, and a #1 crown glass pink tint. Note how closely the transmission curve for the pink matches the curves for the clear. Because the pink has a relatively flat, horizontal curve across the visible spectrum, there should be no disturbance to relative color perception. (From: Spectral transmission of

common ophthalmic lens materials, St Cloud, Minn, 1984, Vision-Ease.)

Yellow

Yellow-tinted lenses (Figure 22-6) are especially subject to myth and speculation. Can people see better with yellow lenses? After reviewing the literature, Bradley states, ". . . probably not. Dozens of studies all report the same basic result: visual performance through yellow filters is approximately the same as vision through a spectrally neutral filter with the same absorption and this is generally slightly worse than with no filter at all. A select few studies have shown that vision through yellow filters is slightly better than vision through trans- mission-matched spectrally neutral filters, but these studies fail to show that vision through a yellow filter is superior to vision without any filter.[16]"

Yet in certain circumstances, if the background color surrounding a specific object, such as the blue sky, can be altered by a filter, then it is possible to increase contrast and make the object being viewed easier



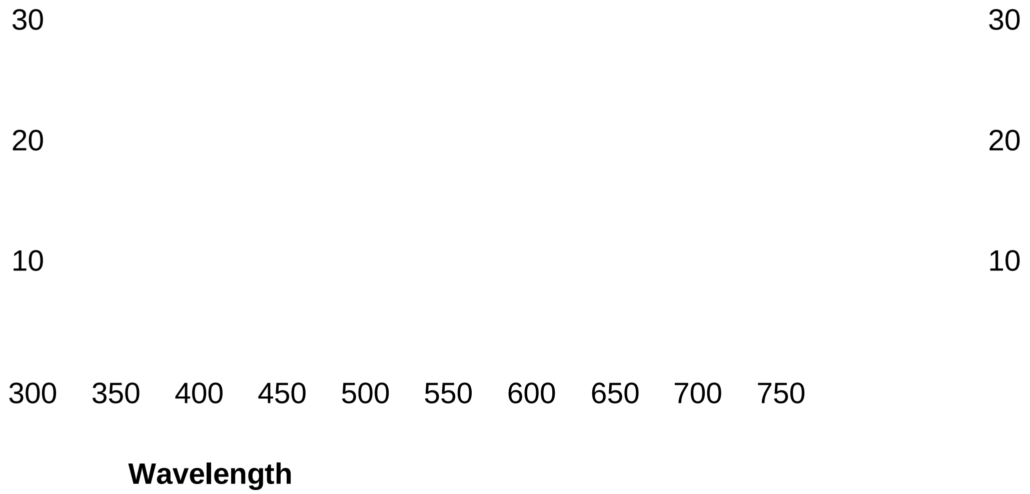


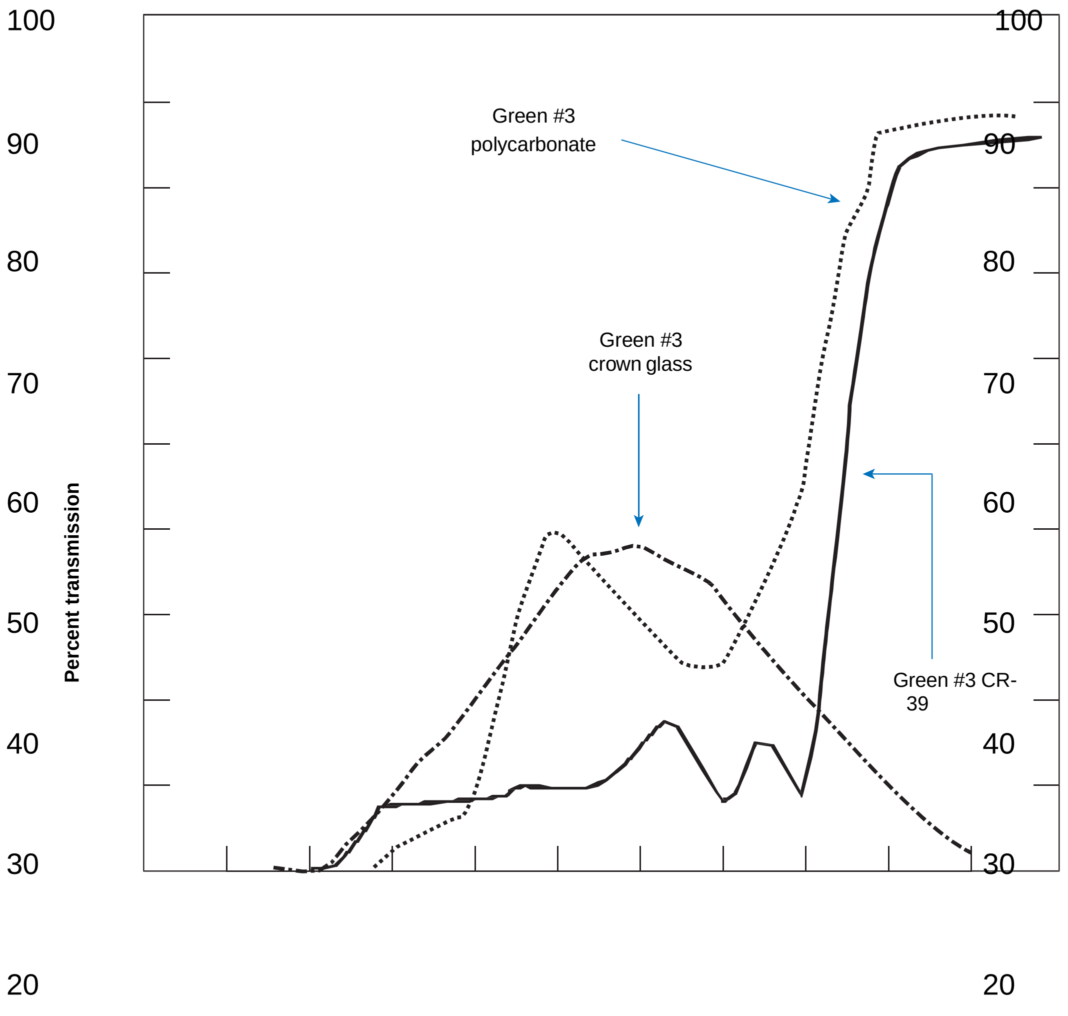
Figure 22-6. Transmission curves for yellow and brown tints. Yellow has a characteristic sudden drop in transmission between 500 and 450 nm. Brown also shows a drop, but that drop is spread over a larger part of the visible spectrum. Note how dyed plastic and polycarbonate lenses transmit the long end of the spectrum, including the infrared. It is possible to use lens dyes that absorb in the infrared region of the spectrum, if desired. (Yellow crown glass and tan #3 [brown] glass transmission curves are redrawn from: Spectral transmission of common ophthalmic lens materials, St Cloud, Minn, 1984, Vision-Ease, pp 9, 10. Brown #3 CR-39 and polycarbonate transmission curves from Pitts DG and Kleinstein RN: Environmental vision, Boston, 1993, Butterworth-Heinemann.)

perceive. “It has been argued that yellow lenses have the advantage that they selectively darken the bright blue sky without reducing the luminance of green, yellow, and red targets on the ground.[16]” For example, yellow lenses are traditionally used in competitive shooting. Many sportsmen believe their shooting ability is improved by a yellow tint. Even so, one of the earliest studies of 136 marksmen done in overcast daylight conditions found that only one individual showed a marked improvement. The author concluded that “the benefit of yellow lenses depends entirely upon the individual; some may be helped while others may be hindered.” More sophisticated variations of shooting lenses, such as Corning’s Serengeti Vector lenses, continue to be used for competition shooting.

Yellow lenses have been advocated for driving in haze or fog. Even though any lens, including a yellow lens, that absorbs light in the blue end of the spectrum can be helpful in reducing glare from light scattered by the atmosphere, this does not extend to fog situations. In contrast to atmospheric gases, fog is not as selective in the wavelength of light it scatters.

Yellow lenses have on occasion been suggested for use in night driving. This is not advisable and should not be encouraged. *Any* tint that cuts down on already dim illumination further reduces visual acuity, offsetting any reduction in headlight glare. The best solution for head- light glare at night is an AR-coated prescription that is up to date. Uncorrected refractive error will cause glare at night. This up-to-date lens prescription should be AR coated to further reduce glare caused by reflections within the spectacle lens itself.

Two brand names that have been traditionally associated with yellow lenses are Hazemaster (AO) and Kali- chrome H (B & L).



10 10

300 350 400 450 500 550 600 650 700 750

Wavelength

Figure 22-7. Green absorptive lenses have a transmission curve with a characteristic “hill” in the middle of the visible spectrum. Green glass lenses are good ultraviolet and infrared absorbers. Plastic and polycarbonate lenses, however, transmit light in the long visible end and infrared region of the spectrum. This is characteristic for dyed plastic materials in any color unless a specific infrared absorber has been added to the dye. (Transmission curves from Spectral transmission of common ophthalmic lens materials, St Cloud, Minn, 1984, Vision- Ease, and from Pitts DG and Kleinstein RN: Environmental vision, Boston, 1993, Butterworth-Heinmann.)

Brown

Brown or gray-brown lenses are most often used for sun lenses in Germany and other middle-European countries. Brown lenses have some of the same characteristics as yellow lenses in that there is a higher absorption of shorter visible wavelengths (see Figure 22-6). By reducing the transmission of the blue end of the spectrum, brown lenses, like their yellow counterparts, are also commonly thought to improve contrast on bright,hazy, or smoggy days. If this is the intent, a specialized lens may be more appropriate.

Green

Green sun lenses have a transmission curve that closely approximates the color sensitivity curve for the human eye. They were first made popular through use in the military, but have now been fairly well replaced by the neutral gray lens. The green-tinted glass lens obtains its color and characteristic transmission curve from ferrous (iron) oxide. There is good absorption for the green glass lens in both the IR and UV regions (Figure 22-7). When a lens is vacuum coated to a green tint, the IR absorption is acceptable, but not quite as good as the tinted glass lens.

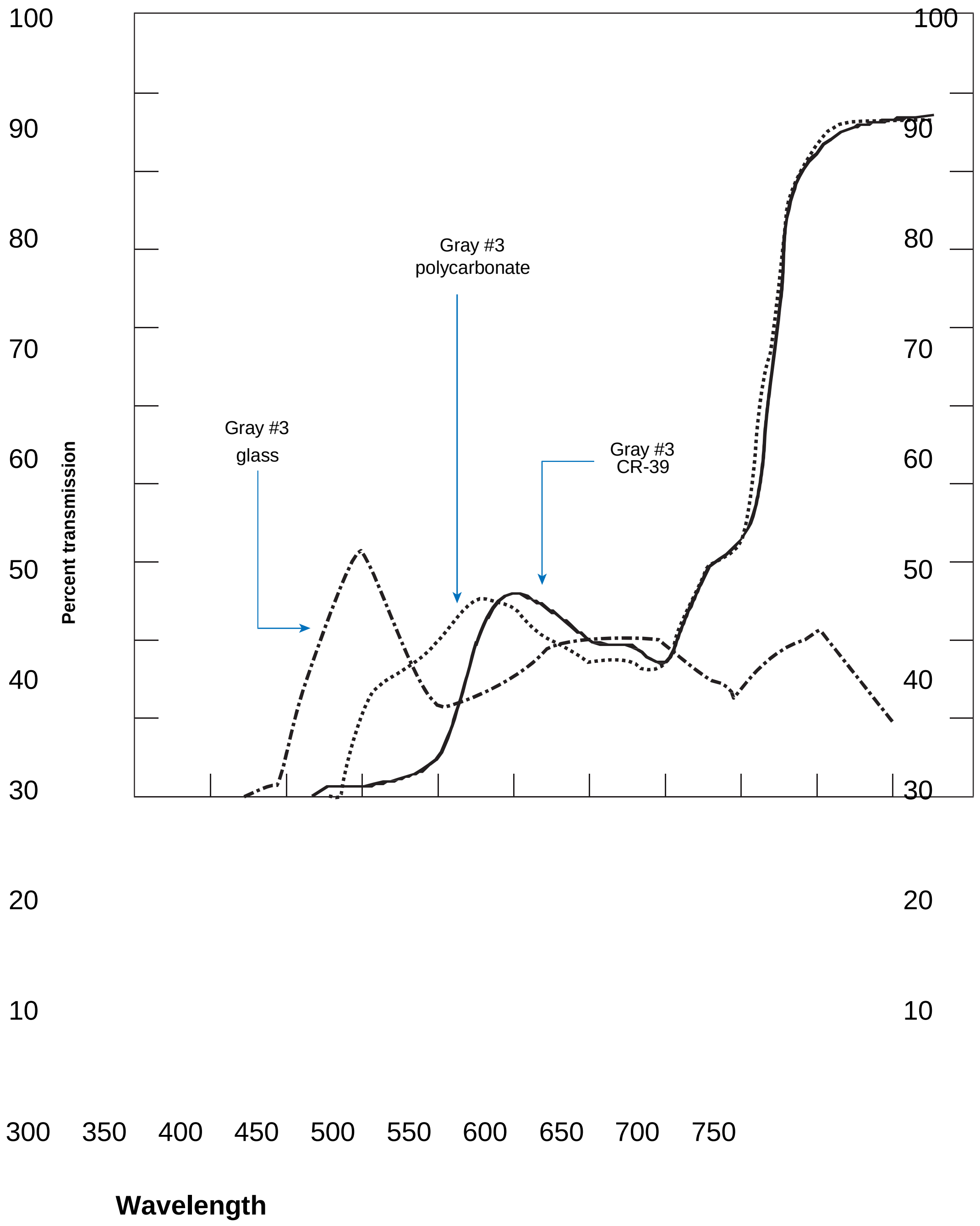


Figure 22-8. In the visible region from approximately 400 to 700 nm, the gray lens gives a fairly even transmission curve, making color perception closer to what would be perceived without absorptive lenses. (Transmission curves from: Spectral transmission of common ophthalmic lens materials, St Cloud, Minn, 1984, Vision-Ease, and from Pitts DG and Klein- stein RN: Environmental vision, Boston, 1993, Butterworth-Heinemann.)

A plastic lens dyed green to approximately the same shade as its glass counterpart exhibits poor absorption in the IR region. This characteristic is not atypical for dyed plastic lenses of other shades as well. Most dyed plastic lenses do not absorb well in the long wavelength, visible, and infrared regions of the spectrum.

Gray

Gray is a tint most popular for sun protection—and with good reason. Perhaps the best aspect of gray is its even- ness of transmission through the whole visible spectrum (Figure 22-8). This characteristic allows colors to be seen in their natural state relative to one another. For this reason, neutral gray is quite satisfactory for use by those with color vision deficiencies. Gray lenses will not

across the visible spectrum. Persons with normal color vision are able to adapt to most color changes caused by colored lenses, but color defectives do not have this adaptive ability. To the color defective, this may increase color-judgment errors or cause some objects to appear with unusual or unnatural colors when other than neutral gray lenses are worn.

Colored Filter Lenses for Color Defectives*

A color-defective individual lacks one of the three different types of retinal cones. So a person lacking in the cones that are sensitive to longer wavelength (red) light cannot differentiate red from green. Likewise a person lacking cones sensitive to the green area of the visible

help a color-defective individual in his or her perception of colors, but neither will it cause further misjudgment of colors as often happens to a color-defective individual when wearing lenses having a transmission that varies

*Much of the information in this section is taken from Bradley A: Special review: colored filters and vision care, Part I, Indian J Optom 6(1):13-17, 2003.

spectrum will have a similar red-green color discrimination problem.

Using a filter that selectively absorbs certain colors but not others will change the intensity of those colors, making it possible for a color defective to use light intensity cues to tell one color from another that may not have been previously distinguishable. These intensity differences are helpful when intensities can be compared with and without the specialized filter.

Factors Favoring the Use of Colored Filter Lenses for Color Defectives

As just stated, colored filters will allow a color-defective individual to use intensity cues to discriminate between two otherwise indistinguishable colors. A red filter will make a green object look dimmer than a red object. Selective filters for this purpose have been attempted with colored contact lenses, such as the red X-chrome lens worn on one eye or the ChromaGen contact lens available in different colors, depending upon defect type.* Filter contact lenses are placed on one eye only so that when closing first one eye, then the other, intensity variations are comparable. Some spectacle lens color filters are placed in only one sector of a spectacle lens so that a comparison of how the object appears can be made by moving the head. The object can be viewed first without, then with the filter.

Certain filters cause other colors to appear more vivid to a color defective because of the manner in which perceived colors shift in appearance when viewed through the filter.

Negative Effects of Using Colored Filter Lenses for Color Defectives

Colored filters worn over both eyes for the purpose of helping certain colors to be better distinguished by color defectives can cause problems. This is because colors that were distinguishable before may now be confused when viewed through the filter.

Even a colored filter, such as the X-Chrom contact lens, worn over one eye is not without a down side. One problem is that objects may appear to glisten. A second problem is that when there is a difference in intensity between the two eyes, moving objects may appear to be wrongly located as to how far away they appear.

SUNGLASSES

According to Pitts and Kleinstein, the ideal pair of sun- glasses should do the following:

1. Reduce the intensity of sunlight for optimum visual comfort and visual performance.
2. Eliminate parts of the optical spectrum that are not required for vision and are hazardous to the eyes.
3. Provide enough protection while being worn during the day so that the wearer’s dark adaptation and night vision are preserved at night.
4. Maintain normal color vision and allow the wearer to distinguish traffic signals quickly and correctly.
5. Resist impact and scratching and only require a minimum of care.

Sunglasses must meet the same impact-resistance requirements as any other spectacle lenses, whether they are for prescription or nonprescription use. The test for impact resistance is the ability to withstand the impact of a $^5/_8$-inch steel ball dropped from 50 inches.

There are four categories of sunglass lenses listed in the ANSI Z80.3-2001 sunglass and fashion eyewear standard. These are listed in Table 22-1.

The standard does not give specific examples of applications for the categories, but following are some basic descriptions:

- *A cosmetic lens*—Generally speaking this lens is more for fashion than function.
- *A general purpose lens*—This is the category used for sunglasses normally used by most individuals.
- *A very dark special purpose lens*—This lens is appropriate for situations of very intense light, such as for mountain climbing.

- *A strongly colored special purpose lens*—This type of lens might filter certain spectral colors more heavily than others.

Food and Drug Administration (FDA) guidelines for nonprescription sunglass lenses include requirements concerning color. These are based upon the American National Standards requirements for sunglass and fashion eyewear.* Color requirements are put in place because of traffic signal recognition needs. Since sun- glasses are sold over-the-counter to anyone, they must be made safe for anyone. (European and Australian standards allow some of these tints to be sold that would not be permitted in the United States, but require warning labels, such as "Not suitable for driving" and "Not suit- able for persons with defective color vision.[21]") Color defective individuals† can have their perception of color significantly altered by certain tints in a lens. Color does not properly represent the small improvement in real world performance."

A red-green color-defective individual (a protanomalous or deuter- anomalous person) may have some varying ability to discriminate red from green. A red-green "color blind" individual (a protanope or deuteranope) cannot tell red from green.

"Traffic Signal Recognition provisions contained in ANSI Z80.3 were developed with the color defective person in mind. Approximately 8% of the male popular tion and less than 3% of the female population have some type of color deficiency. Therefore, some of the requirements of this section of the standard may be overly stringent for color normal individuals."

This may be one reason why over-the-counter sunglass standards do not apply to prescription sunglass lenses. However, this places a larger burden of responsibility upon the prescriber and dispenser for dispensing prescription sunglass lenses.

For example, Bradley shows that both yellow and brown lenses fail to meet the ANSI Z80.3 (and FDA) standards for nonprescription sunglass lenses. Yet these tints are readily available in prescription eyewear, and brown is a commonly used prescription sunglass lens tint. So whereas such a tint may not make traffic signal colors unrecognizable for a color-normal individual, a color defective would not be able to discriminate a red from green traffic light signal adequately.

What does this mean? This means that the dispenser should not knowingly dispense sunglass or fashion lenses to a color-defective individual that would not conform to FDA standards for nonprescription sunglass and fashion eyewear.

DYEING PLASTIC LENSES

Plastic lenses offer great versatility in tinting since they may be dyed to almost any color and may also be made as light or dark as desired. The clear plastic lens is simply dipped in a dye solution of the desired color. The longer the lens is left in the dye, the darker the tint. As the dye is absorbed over the surface area of the lens, good- quality, well cured plastic lenses result in a tint of a uniform density independent of lens power and variation in lens thickness. The tint is not lighter in the thinner portions nor darker in the thicker, as when tinted glass is used.

However, a plastic lens that has not been properly cured when cast molded during manufacture may produce a certain amount of splotchy unevenness of color when they are dyed.

Gradient Lenses

Gradient lenses have a dark upper portion that gradually lightens toward the lower lens sections. Gradients are nicely produced in plastic (Figure 22-9). A gradient tint is accomplished by immersing the whole lens upside down in the dye. The lens is repeatedly immersed and removed from the solution, each time to a slightly different level on the lens. The bottom of the lens is in the tinting solution only occasionally, whereas the upper section remains longer, absorbing more of the color. A poor-quality gradient lens results when the lens is not dipped evenly and continuously. Poor-quality gradients show a fairly sharp demarcation line between upper and lower sections, whereas the better-quality lenses demonstrate no specific cutoff. Both lenses of a given pair must also lighten evenly from top to bottom to prevent differences in transmission between the two eyes at any one level on the lenses.

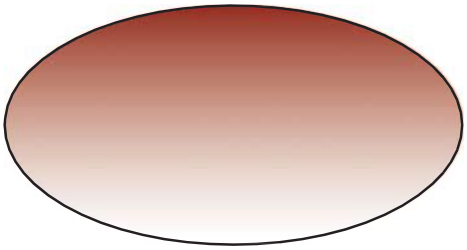


Figure 22-9. A gradient lens varies in transmission over the surface of the lens.

Changing and Matching Colors

Plastic lenses that have been tinted may be bleached out again and retinted if a tint has proven unsatisfactory as long as they have not been subsequently antireflection coated. Clear lenses may be tinted at any time. For example, when a person decides to change to a new frame, even though the prescription remains unchanged, the old pair may be tinted for fashion or sun wear.

When only one tinted lens is to be replaced, it is not always easy to match the previous tint of the other lens. One method used to create a match between two lenses is to bleach out the old lens and redye it with the new one. Even then an exact match can be difficult because the lens materials from the two lenses may not take dyes in the same manner.

Dyeing Polycarbonate and High-Index Lenses Polycarbonate lenses must be antiscratch coated to be usable for ophthalmic purposes. With polycarbonate lenses, dyeing of the lens occurs within the antiscratch
coating. Antiscratch coatings are not uniformly permeable to dyes. Dyeing some of the harder coatings dark enough to reach a sunglass tint may not be possible. A few polycarbonate suppliers have a selection of pretinted polycarbonate lenses. These lenses have the tint within the polycarbonate material itself. The lens can then be further darkened by additional tinting.

High-index plastic lenses dye more slowly than CR-39 lenses and may require special processing. Especially dark tints may not be easy to achieve, depending on the type of material used. It should also be noted that the resulting color of the tint may not be the same for high- index plastics as for a CR-39 sample lens. (Some high- index plastics cannot be dyed t all.)

LENS COATINGS

The practice of coating ophthalmic lenses varies widely from country to country. It is not at all uncommon for dispensers who edge their own lenses to maintain a stock of coated-lens blanks. In the United States, keeping a stock of plastic, AR-coated lenses is becoming more commonplace. In countries where hardening of glass lenses is not required, dispensers commonly stock AR- coated glass lenses.

Coatings represent an area that can greatly increase wearer satisfaction. Those who educate themselves in the area and can apply that information will find the benefits rewarding. Here are a few interesting possibilities.

Scratch-Resistant Coatings (SRCs)

Because of the tendency of plastic lenses to scratch more easily than glass lenses, manufacturers have developed processes of coating the plastic lens to develop more surface hardness and thus more resistance to scratching. SRC lenses are not specifically designed to reduce lens reflections. SRC plastic lenses, however, do exhibit some reduction of lens reflections. This means that they will have a higher light transmission compared with a non- SRC lens. An uncoated CR-39 plastic lens transmits about 92% of the incident light. By antiscratch coating the lens, transmission may increase to just short of 96%.

Scratch-resistant coatings are also called antiscratch coatings or hard coatings.

How Scratch-Resistant Coatings Are Applied Antiscratch coatings may be applied during manufacture or in the optical laboratory. The quality of available coatings varies. If the lens is to be antireflection coated, the quality of the hard coating is essential to the success of the antireflection coating.[24] Here are the two main ways that hard coatings are applied:

1. **Thermally Cured Hard Coatings.*** With this hard coating process, lenses are dipped in a “varnish” and removed from the varnish at a consistent rate to control thickness of the coating. The lenses are then thermally cured or “baked” over an extended period of time.[25] This method is commonly used by lens manufacturers.

2. **UV-Cured Hard Coatings.** Scratch-resistant coatings can be applied using a system that spins the coating on the lens. It then uses UV light to cure the coating.

*There is a similar, but certainly not equal, method that has been used at the retail level. It is not very satisfactory. In this process, the lens is mounted on a tool that spins the lens. A liquid material is dripped onto the lens, and the lens is either allowed to dry by itself, or is transferred to a small oven for curing. In some cases the finished product introduces problems with the stability of the coating that can outweigh the slight increase in scratch resistance that the process affords. Because most plastic lenses now come with a manufacturer-applied hard coating, this process is falling into disuse.The coating unit is normally enclosed in a positive pressure area to ensure a dust-free environment. The type of liquid coating material used will vary, depending upon lens material and whether or not the lens is to be tinted later. (There is a trade-off between coating hardness and tintability.) UV curing is done in seconds. This makes it considerably faster than the hours-long thermal curing process. At the time of this writing, UV curing is the method of choice for surfacing laboratories. A coating unit is essential for surfacing laboratories that process polycarbonate lenses.

Front Side Only or Both Sides?

Antiscratch coatings may be applied to only the front side of a lens or to both sides. SRC lenses that come factory finished (i.e., stock lenses) will usually be coated on both front and back surfaces. If a lens is semifinished and must be surfaced on the back side to obtain the needed power, however, it will be antiscratch-coated only on the front unless the laboratory applies a back- surface coating.

Since the front surface is most susceptible to scratching, one-side-only antiscratch coatings may be justifiable. If the wearer (and dispenser) is expecting front and back antiscratch protection on regular plastic lenses, however, it may be necessary to ask for it.

Care of Scratch-Resistant-Coated Lenses

Lenses with antiscratch coatings should not be exposed to excessive heat; approximately 200° F is a safe upper temperature limit. (Obviously the better quality coatings will do better under stressed conditions.) Therefore a certain amount of care should be taken when heating the frame for the insertion of lenses. It is not advisable to immerse coated plastic lenses in a hot salt bath. An air blower is the safer alternative to help prevent possible surface crazing. (In fact there are so many situations where a hot salt or hot beads frame warmer can damage lenses that dispensers should use hot air for frame warming exclusively.)

Damage to the coating of a lens may not appear immediately. At the time, the effect of mistreatment by exposure to intense heat in the dispensary may not make the lens appear any different. With use and exposure to sunlight, heat, and agents in the environment, however, the weakening initiated in the dispensary may cause the coating to fail at a later date. Most coating failure is reported by the wearer as an inability to clean the lens sufficiently. The wearer will report a film on the lens that no amount of cleaning will remove. On examination the surface of the lens is lightly crazed and may have an oily or lightly frosted appearance. As would be expected, cheaply applied coatings are most subject to failure.

Cleaning Lenses With Scratch-Resistant Coatings Cleaning instructions for SRC lenses are basically the same as for regular CR-39 lenses. Namely, rinse the front

and back surfaces with water to remove small particles. Dry the lenses with a soft, clean cloth or a tissue, such as Kleenex. Do not wipe the lenses when they are dry. If lenses are to be cleaned dry, the best solution is to use the same type of cleaning cloth as is used for antireflection-coated lenses.

Note: There is disagreement over whether or not to use tissues on plastic lenses. If the lens surface is dirty and dry, using a dry tissue may cause circular micro-scratches on a lens surface. If the lens surface has been washed or rinsed clean, drying the lens with a tissue will cause no harm.

Antifogging and antistatic agents are compatible with scratch-resistant coatings. As always it is best to keep the spectacles in a soft, lined case when not being worn.

Identifying Scratch-Resistant-Coated Lenses

It may be possible to identify an SRC lens by seeing if water beads on the surface as it does on a waxed car. Another test is to mark the surface with a water-soluble marking pen. An antiscratch coating can cause the mark to look streaky or blotchy.[26] These tests may detect most, but not all, antiscratch coatings successfully. It is almost unnecessary to check for the presence of a scratch-resistant coating since it may generally be presumed that most plastic lenses now come with such a coating.

Color Coatings

An absorptive coating may be added to a lens through the use of a metallic oxide applied to the lens in a vacuum. There are several advantages to these coatings.

Color coatings may be removed and the lens recoated to a new color or different transmission. This helps if the coating wears or if the existing color or darkness no longer meets the wearer’s changing needs.

A characteristic of the color-coated lens that should not be overlooked is the smoothness of its transmission curve. Transmission curves for color-coated lenses are generally more even across the visible spectrum than either internally tinted glass or dyed plastic. In addition, coatings continue to absorb the longer wavelengths in the near-IR region of the spectrum in roughly the same proportion as they do in the visible spectrum.

In the past, it has been said that color-coated lenses should not be wiped when dry, but rather washed or cleaned with a damp cloth and dried with a soft cloth.

Fortunately, color coatings are becoming more durable because the same advancing technology used for antireflection coatings are now beginning to be used for color coatings.

Color Coating of Glass Lenses

Color coatings are definitely advantageous for glass lenses since the coating is uniform in density, regardless of the lens prescription. Color-coated lenses have a predictable transmission, whereas lenses where the color is added to the molten glass exhibit a darker tint as the glass.thickens. As a result, a C tint could be considerably darker in a higher plus lens than in a plano sample. Color-coated glass lenses do not have this problem.

Because coated lenses are made from clear lenses, coated lenses are available in a wide range of colors and transmissions. This is especially advantageous for glass multifocals since multifocals that have the color directly within the glass are only available in limited tints and transmissions.

Color Coating of Plastic Lenses

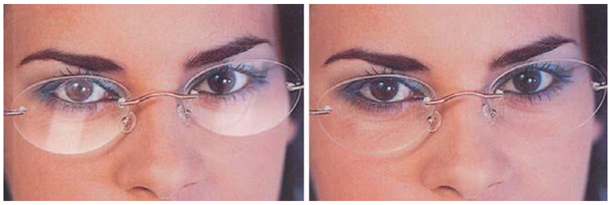
Because plastic lenses are normally dyed to achieve their tint, color coatings are not usually associated with plastic lenses. However, CR-39 plastic, high-index plastic, and polycarbonate lenses can also be color coated. Since dying high-index and polycarbonate lenses may have occasional limitations, color coatings offer a versatile alternative.

Antireflection Coatings

An AR coating is a thin, clear layer or layers applied to the surface of a lens. Its purpose is to: (1) reduce unwanted reflections from the lens surface and (2) increase the amount of light that actually passes through the lens to the eye.

Lens Reflections Vary According to Index of Refraction

When light strikes the front or back surface of a lens, a certain percentage of the light is reflected back from the



A B

Figure 22-10. AR coating removes the “window effect” by extinguishing reflections from the lenses, as seen here in photos comparing how rimless lenses look with **(A)** and without **(B)** an AR coating. (From Zeiss ET: Coatings-product facts, publication MI 9054-1198, Carl Zeiss.)

surface. This light is seen by an observer and could be described as a “window effect,” such as light seen reflecting from the surface of a window (Figure 22-10). The amount of light that is reflected is predictable and depends upon the index of refraction of the lens. (See the Absorptive Lens Calculations section at the end of this chapter for more on this subject.) The higher the index of refraction, the more light is reflected. For this reason, those who wear high-index lenses will like their lenses much better with an antireflection coating that removes these annoying reflections. As can be seen in Table 22-2, a low-index CR-39 plastic lens reflects 7.8% of incoming light, but a high-index plastic lens can reflect 14.1% or almost twice as much. This can have an effect not only on how the lenses look, but how they perform at night with only 85.9% of incoming light being transmitted.

Five Troublesome Lens Reflections

There are basically five reflections that present potentially disturbing reflected images to the wearer’s eye (Figure 22-11). These reflections are caused by light coming from an image that does not go directly into the eye, but is first reflected from one or more surfaces of the spectacle lens.

Under certain circumstances, a light or object from behind can be seen by the spectacle lens wearer. This situation is shown in Figure 22-11, *A* and *B*. In Figure 22-11, *A,* light is reflected from the back surface of the lens and enters the eye, whereas in Figure 22-11, *B,* light is reflected from the front surface of the lens. For normal spectacle-lens wearers, this is most noticeable at night when illumination is low, and there is a bright source of light from behind. For those wearing sunglasses, reflections from behind may even be visible during the day. This is because the image illustrated in Figure 22-11, *A* will not be attenuated by the dark sunglass lens as are objects viewed through the front of the lens.

The reflected images illustrated in Figure 22-11, *C* through *E* will appear as “ghosts” of objects viewed through the front of the lens. They are much less intense than the object itself, but under certain conditions, are readily noticeable. Ghost images can be most easily seen at night by looking at a source of light, such as a street

TABLE **22-2**

How Surface Reflections Vary According to Lens Refractive Index

Lens Material	**Refractive Index**	**% Reflection from Front Surface**	**% Reflection from Back Surface**	**Total % Reflected from Both Surfaces**	**Total % of Light Transmitted**
CR-39 plastic	1.498	3.98%	3.82%	7.8%	92.2%
Crown glass	1.52	4.30	4.11%	8.4%	91.6%

	3	%			
Polycarbonate	1.586	5.13%	4.87%	10.0%	90.0%
A high-index plastic lens	1.66	6.16%	5.78%	12.0%	88.0%
A higher-index plastic lens	1.74	7.29%	6.76%	14.1%	85.9%

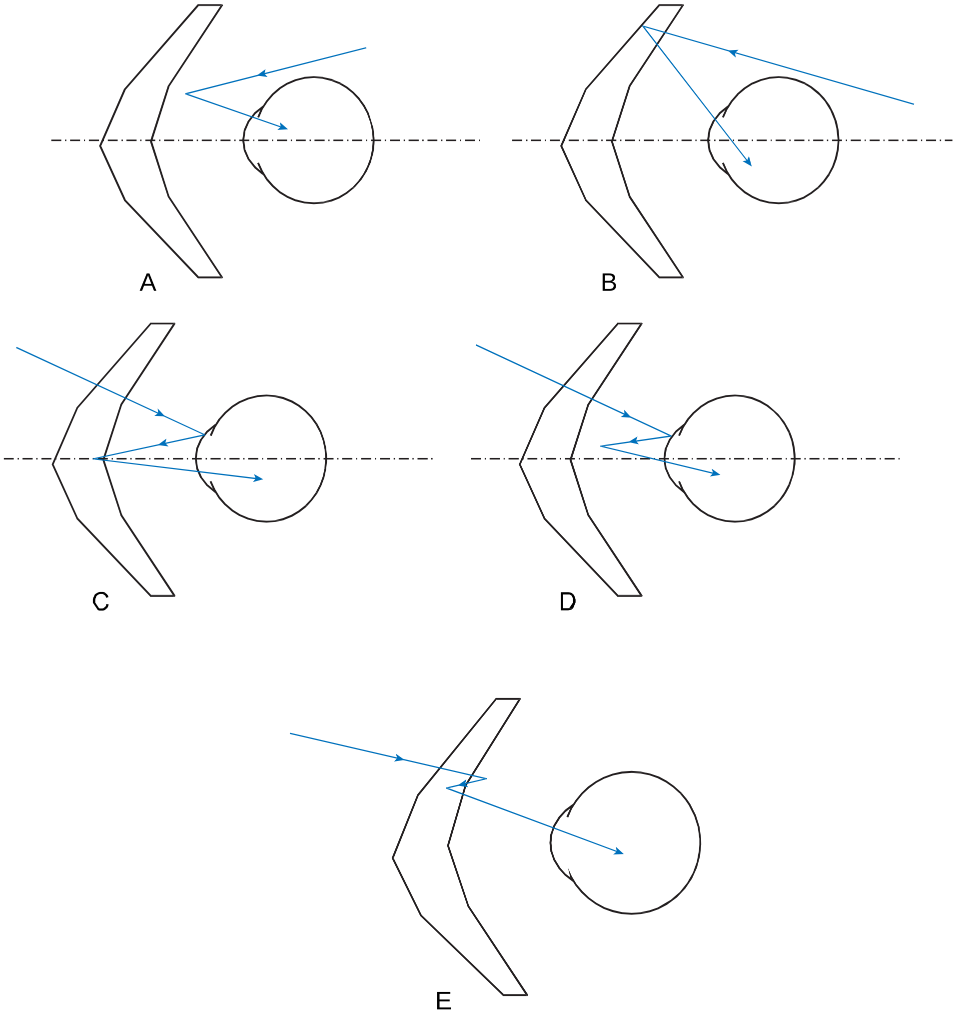


Figure 22-11. Five reflections of spectacle lenses that may prove troublesome to the wearer. It is possible to lessen the effect of reflections **(B)**, **(C)**, and **(E)** with a tinted lens. However, all reflections are virtually

eliminated using an antireflection lens coating. A coated lens is the method of choice for reducing lens reflections rather than the use of a light lens tint. (From Rayton WB: The reflected images in spectacle lenses, J Optical Soc Amer 1:148, 1917.)

light. By turning the head while still looking at the street light, it is often possible to see one or more "ghosts" of the light trailing off to one side. These ghost images are caused by the reflections illustrated in Figure 22-11, *C* through *E*.

In addition to reflections seen by the wearer, there are reflections of light sources and other objects seen on the lens surface by an observer. Regardless of source, all reflections are reduced considerably by AR coatings.

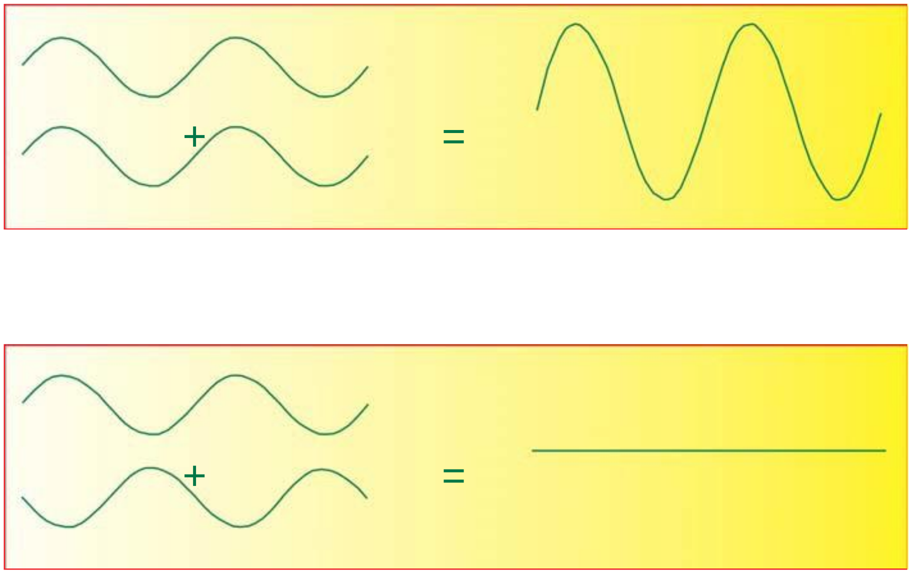
Often a person will request a tint for indoor glare conditions when he or she would be best helped by an AR coating. Although a tint may help somewhat, an AR coating is superior. It will be noted that in Figure 22-11 all but one of the troublesome reflections travel through the lens at least once. The reflected images are therefore reduced by a light tint within the lens. But they are not reduced as much as they would be if an AR coating was used.

Uncoated crown glass transmits 92% of the incident light. If even a single-layer AR coating is used, transmission jumps to approximately 98%.[27] If a multilayer antireflection coating is used, transmission is increased to more than 99%.[28] (It should be noted that these figures are for light entering the lens from the straight-ahead position. Light striking the lens at an angle will be reflected slightly more.)

The Theory of Antireflection Coatings

According to optical theory, for a single-layer AR coating to reduce reflections, an AR coating must meet two conditions: the *path condition* and the *amplitude condition*.

The Path Condition. Very simply stated, the path condition determines what the optical thickness of a single-layer coating film must be. To achieve the desired effect, the film must be either one fourth of a wavelength thick or odd multiples of one fourth of a wavelength (i.e., one fourth, three fourths, five fourths, and so forth). As light strikes the single layer–coated lens surface, some of the light will reflect from the coating surface and some from the lens surface (Figure 22-12). This causes the two reflected waves of light to be out of phase with each other, causing destructive interference and preventing reflection (Figure 22-13).



Constructive Interference

Destructive Interference

Figure 22-13. Two waves of light that are exactly in phase with each other, as seen at the top left, will constructively interfere with each other. The resulting amplitude of the combined light is enhanced as seen at the top right. Two waves of light which are out of phase, as seen on the lower left, will destructively interfere with each other and when added together are extinguished, as shown by the line on the right.

M***ultilayer-Coated Lenses***

From an optical point of view, using more than one layer helps to solve the problem of a single-layer coating that is ideal only for yellow light. Stated in oversimplified terms, if another layer of a different specifically deter- mined refractive index is added, more of the remaining

Why Single-Layer Antireflection Coatings Are Not 100% Effective. If both the amplitude and path conditions are exactly fulfilled for every wavelength, there would be minimal reflections from the lens with close to 100% of light passing through to the eye. This is not the case, however, because of limitations in available coating materials that are both hard enough and of the proper refractive index.

Another reason why single-layer AR coatings are not 100% effective is because the correct coating thickness for yellow light, which falls in the center of the visible spectrum, is not the correct thickness for blue and red light, which fall at either ends of the visible spectrum. This is the reason why, for certain angles of viewing, single-layer AR-coated lenses have a purplish cast. Since yellow light is found at the approximate midpoint of the visible spectrum and is also the color to which the eye is most sensitive, it has been chosen as the optimum wavelength for which the conditions should be fulfilled. For that reason red and blue, which have longer and shorter wavelengths than yellow, do not fulfill these conditions as well.* They are reflected more than the yellow. Red and blue reflections combine to give a bluish-purple cast to a single-layer AR-coated lens.

Initially, AR coatings were only available as single-layer coatings. This posed certain limitations on the effectiveness of the coating. Now that multilayer coatings are the norm, AR-coated lenses are more attractive, light that would otherwise be reflected is allowed to pass through; if a third layer is added, even more light would pass through. If a lens is coated properly, a large percentage of the reflected light is now allowed to pass through the lens. But the optical aspects of a multilayer coating are only a part of the purpose for multiple layers.

A typical multilayer-coated lens is not placed directly on the lens. The lens is first coated with a primer, then hard coated. This hard coating is basically an antiscratch coating. The next layer is chosen to provide maximal adhesion between the hard coating and the AR coating. The AR coating is applied as more than one layer; sometimes alternating layers of high and low refractive index.[29] Efficiency is not directly related to the number of layers used. The AR coating is then sealed in with a hydrophobic (water-repelling) top coat (Figure 22-14). Many newer coatings are so efficient in repelling smudges that the surface is slippery enough to require the depositing of a temporary “overlayer*” so that the lens will not slip during the edging process.[30]

The Relationship Between Antireflection and Scratch-Resistant Coatings. AR coatings will adhere to a lens *better* if the lens has a high-quality antiscratch coating. Antiscratch coatings are now considered essential for good adherence of the coating and reduction in damage to the coating.

Here is an analogy that describes how an antiscratch coating supports the AR coating: “AR coatings are hard and brittle. By comparison, plastic lenses are soft and spongy. Think of a single paper tissue (representing the AR coating) lying on a soft feather pillow (representing the lens). If you poke your finger at the tissue it easily rips. If you place a single tissue on a hard desk and try poking it with your finger, the tissue remains intact and undamaged. The analogy holds with AR coated lenses. The organic hard coat (over the lens and under the AR coating) supports the thin brittle AR coating much as the hard desk supports the paper tissue.” This explains why AR coatings were successful on glass lenses before they were on plastic lenses. Glass is a very hard substrate and an excellent support for the thin, brittle AR coating layers.

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*In addition to wavelength differences for incoming light, lens material will have different indices of refraction for each wavelength. (See the Chromatic Aberration section of the chapter titled Special Lens Designs.)

Matching the Antireflection Coating to theSubstrate. The best way to be sure that an AR Coating will perform well is to engineer it for the material upon

*This overlayer, called the Pad Control System, is used with the Crizal Alizé AR coating.

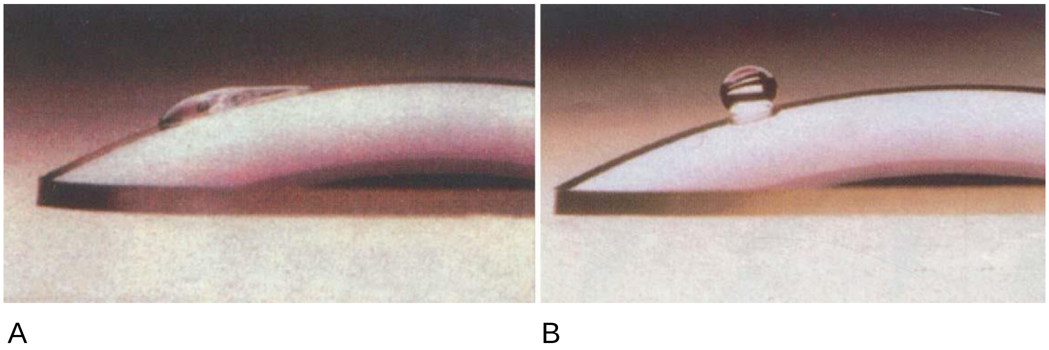


Figure 22-14. The lens on the left does not have a water-repelling top coat, and the water droplet spreads out on the lens. The lens on the right does. The hydrophobic coating causes water to bead up and slide off more easily, keeping the lens cleaner. (From Bruneni J: AR and other thin film coatings, Eyecare Business p 50, 2000.)

which it will be placed. A number of manufacturers are doing just that. The basic lens material is chosen, such as ordinary CR-39. Then a primer and hard coating selected that will work well with both the lens and the AR coating. The lens is sold with the coating already on it.

However, for other than single vision lenses, this may not be able to be controlled as well. There are a large number of variables. This is especially true in the U.S. market where there are a diversity of wholesale optical laboratories supplying different brands of lenses made from a variety of lens materials. A semifinished lens may come with one type of antiscratch coating already on the front surface. The optical laboratory applies another type of antiscratch coating to the back of the lens after surfacing. Now the coating laboratory must apply an AR coating to both surfaces, have it stick to both surfaces and perform well. Best results are possible if these variables are known. The AR Council recommends that if the lenses are being edged “in house” and sent out for coating, that the coating laboratory be informed of the type of lens material, the lens brand, and the type of hard coating being used.

To overcome the diversity of lens materials and hard coatings, manufacturers have addressed the problem by developing a special scratch coating that "can be applied to any nonglass lens, whether the lens is already scratch coated or not.[33]" This provides a known, uniform base upon which an AR coating can be applied so that inequities from chemical and physical differences in factory- applied and lab-applied coatings can be eliminated. Another approach is to totally strip the existing lens of the existing scratch coating and begin again on the base lens material. Others do not apply their coating to any lens that they have not manufactured themselves.

Impact Resistance and Antireflection Coating. When a plastic lens is coated, the impact resistance normally decreases. (For more on this topic, see Chapter 23.) However, by engineering the coating specially for the material, some high-index plastic lenses are able to be

made with 1.0-mm center thicknesses and still pass the FDA drop ball test because the lenses have a special "cushioned" scratch coating that absorbs shock.[33]

Reflex Colors

Multilayer AR coatings do not have the old purplish cast so characteristic of single-layer lens coatings. Instead most have a blue, green, or blue-green appearance. The reflex color itself is not an indication of the quality of the coating. However, if the lens has a reflex color that changes from one section of the lens to another, that is an indication of an unevenly applied coating. Reflected color "can be tuned by adjusting the layer thickness in the multilayer AR stack."

It is possible to cause a coating to have any one of a range of different reflex colors and still be an efficient coating. It is also possible to produce a coating with practically no color, resulting in a faint gray reflex,[35] which is not very pleasing visually and does not "announce" that the lens is an AR lens. In short the manufacturer's goal is to produce a lens with a faint reflex having an aesthetically pleasing color.

Antireflection Coating of Pretinted Lenses

Pretinted lenses, be they glass or plastic, may also be AR coated. This is quite advantageous in several situations. It should be remembered that once a dyed lens has been AR coated, it cannot be either bleached to a lighter color, or redyed to a darker color unless the AR coating is stripped from the lens.

Antireflection Coatings Make Lightly Tinted Lenses More Acceptable at Night. If a person desires a light tint in his or her lenses yet it is believed that night vision might be hindered, AR coating the lens can return the lens to its previous nontinted transmission. For example, a light tint may reduce lens transmission for a CR-39 lens from the normal uncoated 92% transmission to 88%. By eliminating front and back surface reflections, AR coating the lens will bring the transmission up to about 95% transmission—better than the transmission in the uncoated state. For night driving, any reduction in illumination will result in a loss of acuity.

If a Specific Tint Transmission Is Required. If a dyed plastic lens is to be AR coated, it must first be dyed 10% to 15% darker than the transmission desired, then bleached back to the intended tint. This ensures that lens color is buried deeper in the lens. Because of the intense cleaning process used in AR coating, some of the tint near the surface of the lens will be removed. Tinting the lens darker and then removing some of the tint near the surface with neutralizer ahead of time prevents the 5% to 7% lightening that will otherwise occur during the cleaning process.

Unfortunately, at present writing, the application of an AR coating may occasionally change the existing color of tints. The color may lighten, shift in hue, or become unmatched in the application process. These effects are unpredictable as to exactly how and when they will occur.[36]

Antireflection Coating of Sunglasses. AR coating of sun lenses reduces mirrorlike reflections from the back surface. Sun lenses may be AR coated to advantage. For example, the wearer may find reflections from the back surface of the sun lens disturbing. This is a genuine complaint because of the brightness of purely reflected light coming from behind, contrasted to the darkened image of the object being viewed through the sun lens. (See Figure 22-11, *A,* showing this reflection.) An AR coating allows the majority of light coming from behind the wearer to pass on through the lens without being reflected back into the eye.

Opinion on whether to AR coat the front of the lens is mixed. Some say that an AR coating on the front surface of the lens is not recommended because, when combined with the color of the sun lens, the AR coating leaves an objectionable residual color. However, when residual color can be controlled, then the recommendation is to coat both surfaces because "light is also reflected at a lower intensity at the back side of the front sur- face . . . [and] . . will give sunglass customers peak performance and the greatest comfort.[38]"

Antireflection Coating of Photochromics. A photo- chromic lens may be AR coated. AR coating of photochromics will increase both the maximum *and* the minimum transmission by a certain amount. The lens will transmit more light in both the lightened and the darkened state. *Color* coatings, however, should be applied only to the *rear surface* of a photochromic lens since the added tint cuts out many of the rays that activate the lens-darkening mechanism. The lens will not darken properly when color coated on the front.

A Side Comment on Tinted Contact Lenses

It has long been observed by contact lens fitters that the tint in a contact lens does not seem to have the same effect on light reduction for the wearer as does a tinted spectacle lens. The reason for this lies with the reduction of surface reflections when the contact lens is worn.

If a clear contact lens is measured for light transmission in air, it will transmit about 91.2% of the incident light. This is because about 7.8% of the light is reflected from the front and back surfaces, and 1% is absorbed by the contact itself. But if the same contact lens is placed on the eye, the back surface only reflects 0.2%

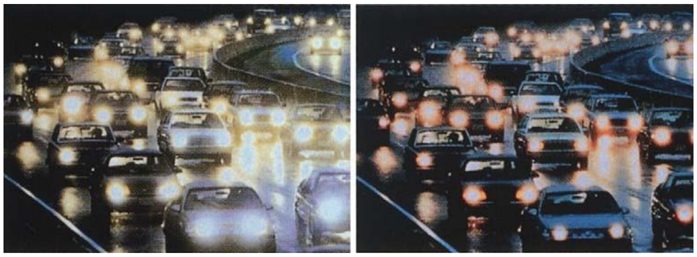
because of the tears, and the front surface only reflects 1.5% more than the front of the eye would without the contact lens. This combined with the 1% absorption of the lens material means that a clear contact lens transmits 97.3% of the incident light. In essence it is as if the contact lens had been AR coated. Therefore a lightly tinted contact lens will transmit more light than a non–AR-coated, clear spectacle lens.

Pros and Cons of Antireflection Coatings

The *pros* of an AR-coated lens are both subjective ones noticed by the wearer and objective ones seen by an observer.

Pros. Subjective advantages noticed by the wearer include better light transmission, decreased glare, and improved night vision. There is also a loss of the starlike flare from self-illuminated objects such as headlights, tail lights, and street lamps (Figure 22-15), resulting in better visual performance at night. For progressive addition lens wearers, the distracting "tails" that appear on illuminated digital dashboard accessories are also reduced. Objective advantages include the loss of surface lens reflections (the *window effect*). Without lens reflections, the wearer's eyes become more visible (see Figure 22-10). Because edge reflections are reduced and the lens appears less visible, AR coatings make thick lenses appear thinner. What used to be the biggest "con" for AR-coated lenses can now be a "pro." That has to do with cleaning of the lenses. Because the single or multilayer AR coating only works if it is the first thing that light strikes when entering the lens, any dirt, water, or skin oils will reduce the effectiveness of the coating. What this means is that a very small smudge on an AR-coated lens will be much more visible to the wearer. This is because the smudge will not only be visible in and of itself, but because the AR coating will not work there, reducing light transmission through the smudge by approximately 4%. Recognizing this AR developers have worked hard to make their lenses much more cleanable. They have accomplished this with the addition of a hydrophobic top coat that repels water and oils (see Figure 22-14). In fact these top coatings are so good at repelling liquids that they are not able to be marked with a normal marking pen. Instead they must be marked with either a china marker or a Staedtler permanent overhead transparency marker. "Permanent" marks are later removed using alcohol. Because of these hydrophobic properties, the newer types of AR coatings make the lenses much easier to clean than uncoated lenses.

Figure 22-15. Night driving is where many experience a notable difference between uncoated **(A)** and AR- coated **(B)** lenses. (From Zeiss ET: Coatings-product facts, publication MI 9054-1198, Carl Zeiss.)



A large "pro" for AR coatings are that, given the choice of a good coating or no coating, studies are showing that people are choosing the AR-coated lenses by a wide margin.

Cons. Smudges are more visible than with uncoated lenses. AR coatings exaggerate the contrast between clean and dirty areas.

Caring for an Antireflection-Coated Lens

AR coatings are much tougher than they used to be. They are not, however, as tough as the surface of a normal spectacle lens. Certain precautions need to be taken to keep them in good condition. They include the following:

1. Avoid using ultrasonic cleaners.
2. Avoid salt or bead frame warmers.
3. Avoid excessive heat. (This includes the interior of hot automobiles.)
4. Avoid caustic chemicals and sprays, such as acetone, ammonia, chlorine, hair spray, and other aerosols.
5. Avoid marking lenses with heavy inks.

Cleaning the Antireflection-Coated Lens

There are ways to correctly clean lenses and there are cleaning procedures that should be avoided. Lenses should be cleaned at least once a day.

Correct Ways to Clean Antireflection-Coated Lenses. Here is a simple sequence for cleaning AR- coated lenses without using a cleaner specifically made for AR-coated lenses[42]:

1. Rinse the lenses with lukewarm water.
2. Clean using a mild dishwashing liquid or hand soap. Soap should not contain a hand cream. That will cause the lenses to smear. Rub soap on both sides of the lens for about 5 seconds. (It is helpful to wash both lenses and frames at the same time.)
3. Rinse the soap off with tap water.
4. Dry with a soft, clean cloth, such as a cotton towel. Naturally a cleaner designed specifically for cleaning

AR-coated lenses will give excellent results. From time to time it is still worthwhile to use a soap or detergent on both frames and lenses, with lots of running water, to keep the frames clean, too. There are soft cloths specifically made for use with AR-coated lenses that allow the lens to be cleaned dry. These work very well for throughout the day and are especially handy when there is no soap and water available. These cleaning cloths should be washed periodically with laundry soap and water, but do not use fabric softener.

Things to Avoid When Cleaning Antireflection- Coated Lenses. There are certain treatments and cleaners that should not be used on the AR-coated lens. Antistatic and antifog agents put a layer of coating on the lens. Some regular lens cleaners also leave a coating on the surface. Any layer on top of the coating reduces its effectiveness. The safest policy is to use a cleaner specifically designed for AR-coated lenses.

The newer the type of AR coating, the more it may be treated like an ordinary lens.

As with any lens, AR-coated lenses should not be exposed to household spray cleaners, chemicals, ammonia, chlorine, and hair spray.

Antifog Coating

Antifog coatings are used for individuals who are constantly going into and out of changing temperature environments or who are exposed to other environmental conditions that would fog lenses. Wearers who may appreciate antifog coatings include cooks, ice skaters, and skiers. Antifog coatings can be made as permanent coatings applied directly to the lens during manufacture. To produce the antifogging properties, the lens is coated with a resin film that absorbs moisture. "When the absorption reaches the saturation point, the interfacial activator [within the resin] changes water droplets into a thin outer layer of water.[44]" It is much more common to find permanently applied antifog coatings in sport eyewear, such as swimming goggles. Prescription lenses with an antifog coating are not always available. When available they are limited to single vision lenses.

Fortunately, there are sprays and drops that can be applied to ordinary spectacle lenses to reduce fogging, such as Zero-Fog lens treatment by OMS Opto Chemicals. Although Zero-Fog claims to be compatible with AR coatings, not all antifog sprays or drops are.

Mirror Coating

A mirror coating can be applied by a vacuum process to the front surface of the lens, causing the lens to have the same properties as a two-way mirror. When applied as a full-mirror coating, the observer is unable to see the wearer's eyes and sees his or her own image reflected from the lens. The wearer is able to look through the lens normally. There is, of course, a reduction in the transmission of the lens simply because of the high per- centage of light reflected.

Mirror coatings alone do not reduce the amount of light coming through the lens to the level of regular sunglasses. Mirror coatings may be used in combination with a tinted lens to provide more protection from intense sunlight than the mirror coating alone can provide.

Metallized and Dielectric Mirror Coatings[45]

Mirror coating can be applied as a metallized or a dielectric coating.

Metallized coatings apply a thin layer of metal on the front of the lens. They both absorb and reflect light. Each metal used has its own coloration that is transferred to the lens. Some metals allow more color variation by controlling the thickness of the coating. Metallized coating can be applied as:

1. Full-mirror coatings that hide the wearer's eyes.
2. Gradient mirrors that are highly reflective at the top and decrease in reflectance toward the bottom.
3. Double gradient mirrors that have maximum reflectance at top and bottom, with less along the midline. These are often used for snow and water sports.
4. Flash coatings that may have only a hint of reflectance.

ielectric coatings reflect certain wavelengths selectively. They transmit more light through to the wearer than metallized coatings. Dielectric coating can reflect just one color or be applied in a way that causes the lens to change color when seen from different angles.

Edge Coating

Lenses may be edge coated to reduce the concentric rings visible to the observer. The idea of edge coating is to apply a color to the bevel area of a lens that matches the frame, camouflaging the edge. Many times edge coatings look "funny." This is because they are usually applied with a small brush, then hardened in an oven. If the job is not done well, if an inappropriate frame is chosen, or if the color match is poor, the net effect can be worse than no coating at all.

There are many suitable alternatives to edge coatings.

These include the following:

- Polishing the edge of the lens
- Rolling the edge of the lens
- AR coating the lens
- Using a lens of higher refractive index to reduce edge thickness
- Using any combination of the above

THE PHOTOCHROMICS

A major breakthrough in the area of absorptive lenses took place in 1964[46] with the invention of Corning's Photo Gray photochromic lens. A photochromic lens changes in its transmission when exposed to light.

Glass Photochromic Lenses

For glass lenses, the darkening process occurs as a result of silver halide crystals within the glass that are activated by UV and short visible radiation of wavelengths between 300 and 400 nm.

The photochromic process is similar to that which takes place when light strikes photographic film emulsions, also containing silver halide crystals. With the crystals "trapped" in the glass, however, the darkening process is reversible. The glass photochromic lens will not wear out with repeated darkening and lightening cycles, although over time the lenses do not lighten indoors like they do when new. "Within a year indoor light transmission percentage is in the low 70s."

In the United States the most generally used ***glass*** photochromic lens is the PhotoGray Extra lens. This lens has a range from 85% to 22% transmission, allowing it to double as a sunglass lens for most purposes. (It should be kept in mind, however, that under fluorescent lighting, a photochromic lens will not always lighten to its lightest transmission. Neither do lenses darken as well when driving.)

Plastic Photochromic Lenses

Photochromic lenses are now preponderantly plastic. Plastic photochromics are available in a variety of brands and colors. Instead of using an inorganic material, such as the silver halide crystals used for glass lenses, plastic photochromics use organic dyes.

How Plastic Photochromics Are Made

Plastic photochromics can be made in a variety of ways. These include, (but are not limited to):

- Imbibition
- In Mass
- Multimatrix
- Dip Coating
- Front Surface Coating
- Transbonding

At the time of this writing, the first two methods are the most commonly used.

Imbibition Surface Technology. The primary example of the lens type made using imbibition surface technology is the Transitions photochromic lens. Transitions lenses are made by starting with a clear plastic lens. It can be plastic material very much like CR-39 or other organic lenses. Each lens manufacturer is responsible for making their own lens using compatible lens materials. These lenses are then sent to a facility where their surfaces are infused (imbibed) with photochromic material using a proprietary manufacturing process.

The evenly distributed photochromic material results in an even color density over the entire lens as it darkens. **In-Mass Technology.** In-mass technology mixes the photochromic dyes into the liquid lens material before the lens has been formed. This has been the standard technology for the manufacture of glass lenses. The

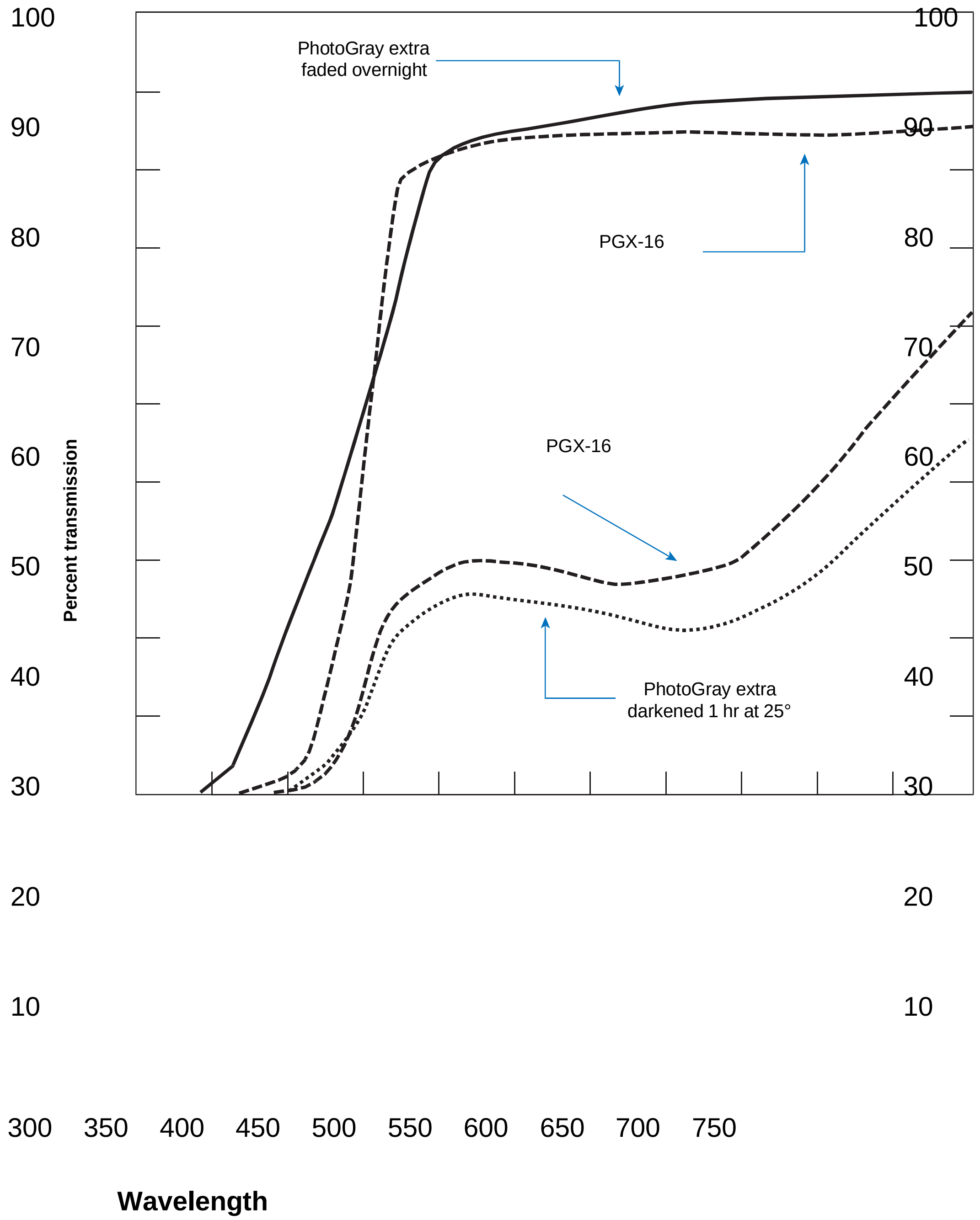


Figure 22-16. PhotoGray Extra, like crown glass, has an index of refraction of 1.523. The PGX-16 is the equivalent of PhotoGray Extra in a 1.6 index glass material. As can be seen, their transmission curves are very similar, with the PGX-16 having a somewhat

smaller faded or darkened range compared with the standard PhotoGray Extra material. (From: 1.6 index photochromic lenses, preliminary technical information, Publication #OPO-245, Corning, NY, 1991, Corning Inc. and Photochromic ophthalmic enses, technical information, Publica- tion #OPO-232, Corning, NY, 1990, Corning Inc.**)**

disadvantage in glass is that the photochromic material reacts throughout the lens. This causes the thicker edges of a minus lens to darken more than the thinner center does. But with plastic material, primarily only the photochromic material positioned near the surface of the lens reacts. A high-minus glass photochromic lens may give a very slight "bull's-eye" effect. A high-minus plastic photochromic lens does not produce the same effect. In fact proponents of in-mass technology point out that as the organic dyes wear out near the surface and do not darken as fully, the dye slightly deeper in the lens is then activated by the now entering UV rays. The deeper dyes take over the darkening function, thus extending the photochromic life of the lens. Corning SunSensors and Rodenstock ColorMatic lenses are examples of a lens made with this type of manufacturing technology.

Dip Coating, Front-Surface Coating, and Transbonding. Although imbibition and in-mass technologies are preponderant, photochromic plastic lenses can be made in other manners. A lens may be *dip coated* and then cured with a heat process. Another method is to *coat the front surface of the lens*. A third process called *transbonding* is used with polycarbonate and high-index lenses. This process uses surface treatments in combination with a series of ophthalmic grade layers.[48]

Multimatrix.[49] Kodak Insta-Shades photochromic lenses use a process they refer to as *Multimatrix*. This process begins with a clear lens that has a 1-mm layer bonded to it. The bonded layer contains the photochromic dye.

Advantages and Disadvantages of Photochromic Lenses

Over time plastic photochromics wear out and glass photochromics fail to fully lighten in their faded state. The amount of time that it takes to wear the lens out depends on the cumulative number of hours that the lens is exposed to UV radiation. In other words, the more the lens is worn outdoors, especially during high sunlight conditions, the faster it will wear out. This causes problems when only one lens needs to be replaced. It is not advisable to replace one lens even if the other lens is less than 1 year old because the two lenses will age differently.

Although photochromics are becoming more able to perform like a sun lens in their darkened state, they still are not able to replace sunglass lenses. The primary example of why they do not function as efficiently as a sun lens is the way they are unable to darken well behind the windshield of a car. Although a full-range photo- chromic lens responds to both UV and visible light, because a person driving a car is shaded from direct sunlight and shielded from much UV radiation by the windshield, the lens will not fully darken in normal driving conditions. Glass windshields have a plastic laminate between front and back glass layers that helps retain fragments of glass during an accident. The plastic layer has UV absorbers to keep the plastic from being degraded by UV light. Those wanting photochromic lenses of any type should be informed that the lens will not darken as deeply when driving. The upside to all of this is that since photochromic lenses use UV light in their activation process they are good UV absorbers and furnish UV protection to the eyes.

Factors Influencing Photochromic Performance There are several variables that influence photochromic transmission and darkening speed. Some affect only glass photochromics and others both glass and plastic:

1. Light intensity (both glass and plastic)
2. Temperature (both glass and plastic)
3. Previous exposures (exposure memory) (glass)
4. Lens thickness (glass)

It may be noted that the glass lens hardening process can also affect glass photochromic lens performance. The method of choice for hardening of photochromic glass lenses is chemical tempering.*

Light Intensity

most, several other factors contribute to lightening and darkening. A photochromic lens is made to return to its lighter state by exposure to red light or IR radiation. This is referred to as *optical bleaching*.

Temperature

Heat will also bleach the lens. This is referred to as *thermal bleaching*. As a consequence, photochromic lenses do not darken as much on hot days as they do on cold days.

Taking advantage of this characteristic makes it possible to make photochromic lenses fade faster indoors by running warm tap water over them for 30 seconds. This is likely only necessary in certain rare circumstances (e.g., when the wearer is having photographs taken).

Exposure Memory

Glass photochromics achieve their full changing range and speed only after a “breaking-in” period. This is a consequence of the cumulative effect that takes place; the lenses have *exposure memory,* meaning they respond to light in proportion to accumulated total recent exposures. Put away unused for long periods of time, a glass photochromic lens will lose its exposure memory and have to be broken in again to obtain rapid, complete cycling. For this reason, a well-used glass photochromic lens will darken at a faster rate than an identical, new lens. When only one lens is being replaced in a pair of glasses, this can present a rather curious effect.

Glass photochromic lenses rarely return to their maximum transmission during ordinary wear. There- fore another problem with replacing only one lens is that the older lens will be darker in its lightened state than the new lens.

Lens Thickness

Transmission of glass photochromics is also influenced by *lens thickness*. A PhotoGray Extra lens will darken down to 22% transmission if 2 mm thick, but can get as dark as 11% if 4 mm thick.[51] Even though the transmission varies with thickness, the noticeable variation from edge to center found in high-plus or high-minus tinted glass sun lenses is not present.

Although exposure to UV and visible light is the condition that influences photochromic lens transmission

Because of federal requirements, glass photochromic lenses must be hardened by some method. There are two primary methods for hardening a glass lens. Fortunately, heat hardening of lenses has practically fallen into disuse. Heat hardening a photochromic lens causes it to lighten slower and reduces its transmission in the indoor lightened state. It also reduces transmission of the lens in the darkened state at higher outside temperatures. The amount of this reduction depends on the color and type of lens, but can be significant enough to be visibly noticeable. This causes the heat- tempered lens to be darker for night activities than the chemical- tempered lens. Chemical tempering is the method of choice for photochromics.

[†]To cause both old and new glass photochromic lenses to have the same shade and behave in a more nearly identical manner, an old glass photochromic lens may be returned closer to its original state in one of two ways.

1. When the new lens is hardened, the old lens may be rehardened as well. The temperature change cycle helps equalize their differences. This proves to be the most effective method and is the one recommended by the manufacturer.
2. If retempering the old lens with the new is not feasible, the old lens may be boiled in water for 2 hours. This boiling process thermally bleaches the lens, returning it closer to the condition of the newer one. The same bleaching effect may also be produced by placing the lens in an oven set for 212° F (again the boiling point of water) for an equal time. A heat lamp may also be used.

Most plastic photochromics are not influenced by thickness.

Photochromic lenses now come in a wide variety of materials including polycarbonate, trivex, and high index. They are also available with polarization.

Photochromic Ultraviolet Absorbing Properties Photochromic lenses are good absorbers of UV radiation. In their darkened state, glass photochromic lenses generally absorb 100% of UVB radiation and 98% of UVA radiation. The darkened state is the normal situation where UV protection would be needed.

Plastic photochromics have effective UV absorption properties as well.

Coating a Photochromic Lens

In the past, AR coatings used to interfere with the performance of plastic photochromic lenses. With changes in both coatings and lenses, this is not the problem it used to be. AR coatings will not reduce the range of the photochromic cycles. As with any lens, it will increase the transmission in both the lightened and darkened states. In the lightened state, this may be significant. In the darkened state, because of the light absorbed going through the lens, the difference will only amount to a little more than a 1% decrease in darkening—hardly noticeable to the wearer.

Colors for Photochromic Lenses

Photochromic lenses can be made in a variety of colors. Most photochromic lenses begin with one color and change to a darker shade of that same color. It is also possible to make a photochromic lens that starts with one color in the lightened state and darkens to a different color. These lenses have been available in the past and may reappear in the future.

POLARIZING LENSES

Glare from reflecting surfaces is one problem that is only partially alleviated by regular absorptive lenses. Glare is commonly caused by reflections from water, snow, highways, and metallic surfaces. A normal absorptive lens reduces the intensity of light evenly, which also reduces reflected glare. Yet a normal absorptive lens leaves the glare at the same level relative to the surroundings as it was before. Light reflected from a smooth, non diffusing surface is peculiar in that for the most part it has been *polarized* through the reflection process.

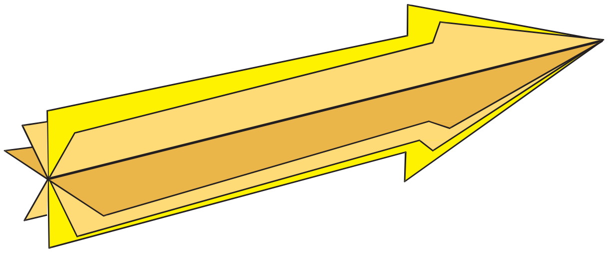


Figure 22-17. Light waves are not restricted to one direction of vibration. Light from a single source can vibrate in the vertical plane, in the horizontal plane, and in any plane in between simultaneously.

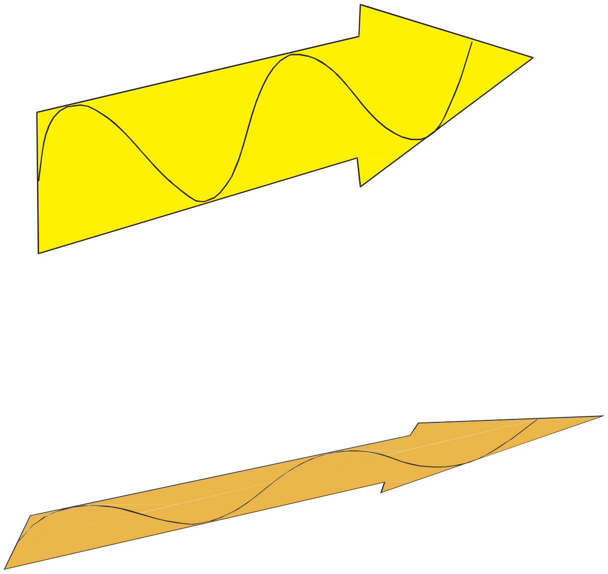


Figure 22-18. Polarized light vibrates in only one plane. The light at the top is vibrating vertically; the light at the bottom, horizontally. Polarized reflected light from water, sand, or snow is horizontally vibrating light.

How Polarizing Lenses Work

Ocean waves vibrate up and down as they travel, as is evidenced by the up-and-down motion of a floating cork. A light wave is not so restricted and is free to vibrate up and down, sideways, or obliquely. In other words, in their nonpolarized state, light waves vibrate perpendicular to the direction in which the light is traveling, but with no particular degree orientation (Figure 22-17). The process of polarization, however, causes the vibration direction to be restricted. Instead of vibrating in just any direction, polarized light will be vibrating only in one plane (Figure 22-18).

When light strikes a horizontal *reflecting* surface, it becomes partially polarized with the major direction of vibration being in the horizontal plane (Figure 22-19).

If light strikes the surface of a *refracting* material, such as water or glass, most of the light will be refracted as it strikes the surface of the water and go on into the water. The rest of the light will be reflected. There is an angle of incidence of the light striking a surface where not just some, but all of the reflected light will be polarized. This angle is called Brewster's angle (Figures 22-19 and 22- 20). See Box 22-4 for more on Brewster's angle.

To reduce the intensity of reflective glare more than that of surrounding objects, a filter that absorbs the horizontally vibrating components of light would be useful. Such a filter is available for ophthalmic use and is made from a sheet of polyvinyl acetate (PVA). The PVA is first stretched to five times its normal length in one direction. Then it is dipped in iodine. The iodine is absorbed into the chains of molecules in the PVA. These darkened lines create the polarizing filter. This filter may be "sandwiched" between two layers of cellulose acetate butyrate (CAB) (Figure

22-21).[52] This is how thin, plano polarizing lenses are made. For prescription lenses, the polarizing sheet is mounted between hard resin or poly- carbonate material. Alternately, it can be mounted on one layer of CAB material and molded directly into a plastic lens during the lens casting process.

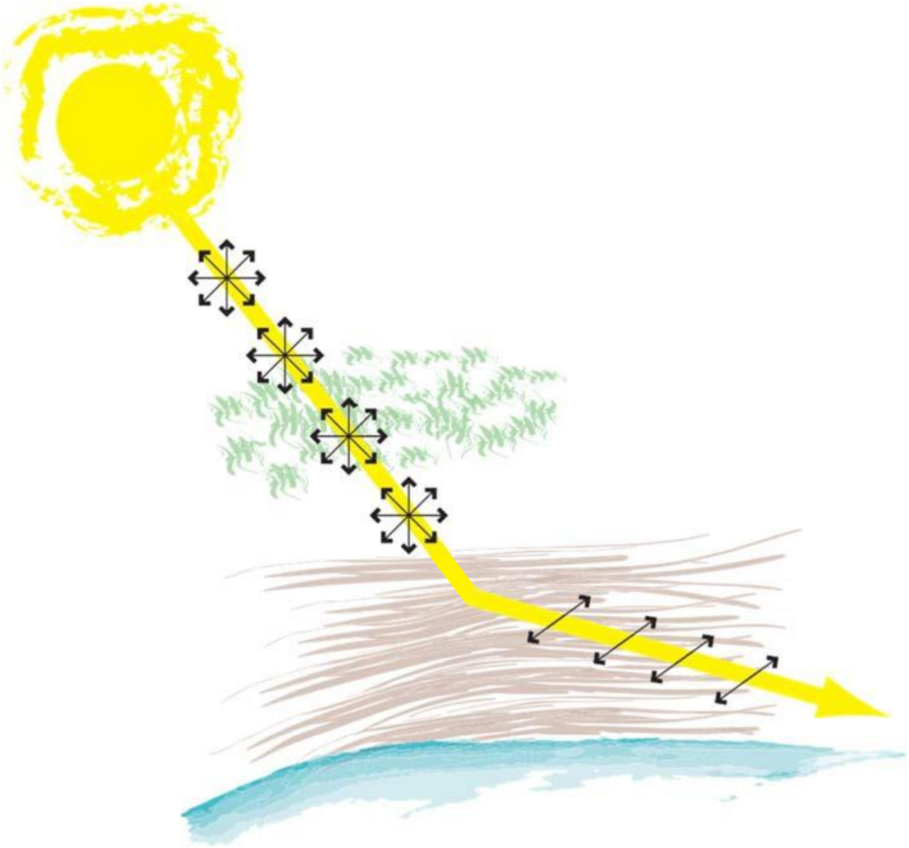


Figure 22-19. When light strikes a horizontal reflecting surface, such as water or sand, it becomes partially polarized with the major direction of vibration being in the horizontal plane.

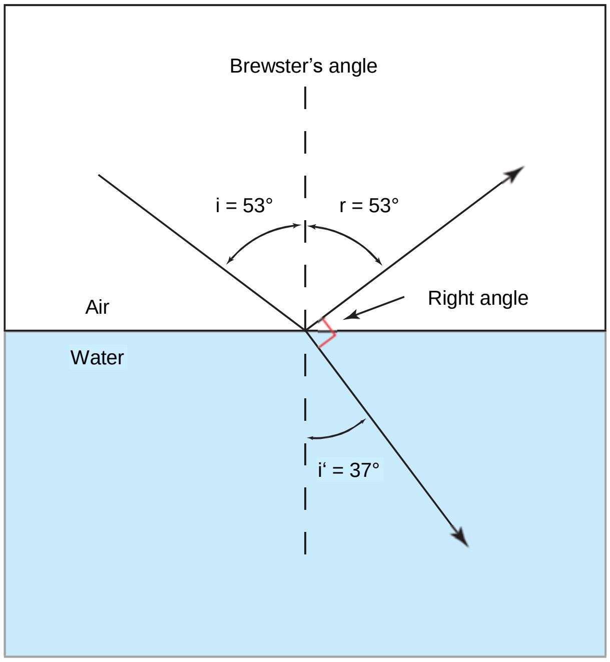


Figure 22-20. Brewster’s angle is the angle where complete polarization of reflected light occurs. At Brewster’s angle, the reflected and refracted rays are 90 degrees away from one another.

Polarized ophthalmic lenses are oriented so as to extinguish the horizontally vibrating component of light, hence reducing the intensity of light reflected from horizontal surfaces. Although reflected glare is not eliminated, it is much reduced in comparison with other objects in the visual field.

Because the polarizing element in the lens must be oriented to extinguish horizontally vibrating light, the lens blank may not be rotated (Figure 22-22). This necessitates custom grinding the rear surface of the lens so that both the direction of polarization and the cylinder axis are correct. In other words, all nonplano lenses must be individually surfaced, including single vision lenses.

If an ideal polarizing filter is oriented properly and all incoming light is horizontally polarized, then all of the light would be extinguished. However, if the filter is tilted, then some light will get through. When the filter is 90 degrees away from where it should be, all of the horizontally polarized light will come through the filter. The amount of light that comes through depends upon the orientation of the polarizing filter. This amount is predictable and may be found using Malus' law. (For more on Malus' law, see Box 22-5.) If the polarizing lens is not oriented along the 180-degree meridian, not all horizontally polarized light will be absorbed. And if a person is wearing a polarizing filter and tilts his head to one side, the filter will not absorb as much of the horizontally polarized light. The more the head is tilted, the less horizontally polarized light is absorbed.

When Should Polarizing Lenses Be Used? Polarizing lenses offer advantages in a number of different situations and can be recommended for the following reasons:

1. *To decrease driving fatigue and increase driving safety*— Because much of the light reflected from large pavement areas is polarized, those who do a lot of daytime driving will benefit from polarizing lenses. There is also polarized light that reflects off the inside of the windshield from the dashboard or from objects on the dashboard. This is an intensely distracting glare that will be almost totally eliminated with polarizing sunglasses.
2. *For fishing and for boating on the water*—Reflected light from the surface of water makes it hard to see below the surface. Wearing polarizing lenses not only removes the discomfort of reflected glare, but makes it easier to see below the surface.
3. *For more visual comfort at the beach*—Sand and water are both sources of polarized glare. Polarizing lenses are especially helpful here.
4. *So that colors are not bleached out*—Reflected polarized light produces a veiling glare. This veiling glare causes colors to appear less vivid. When glare disappears, colors return.
5. *So that bright, snowy days are not as blinding*—Snow is highly reflective. It is also polarizing. Those who are out working or driving in the snow will benefit from using polarizing lenses. (Note: Polarizing lenses may not be as advantageous for skiers as one might think. Skiers' heads tilt far to the left and right when skiers turn and lean. This makes the polarizing filter less effective when the frame front is no longer oriented parallel to the ground and causes changes in brightness.)
6. *To block UV radiation*—Virtually all prescription polarizing lenses, both glass and plastic, are made to block UV radiation. This is not a function of the polarizing filter, but rather foresight on the part of the manufacturers. UV filtering is a big advantage, since the same surfaces that normally reflect light in a polarized manner also reflect a high percentage of UV light.
7. *Polarizing lenses are good sunglasses*—Polarizing lenses should be considered for ordinary sun lens wear.

BOX 22-5

Malus’ Law

A polarizing filter has an absorption axis and a transmission axis. If an ideal polarizing filter is oriented with its absorption axis along the 180, it will extinguish all horizontally polarized light. This means that the transmission axis of this same filter will be at 90 and will allow all vertically polarized light to pass through. When the filter is tilted somewhere between these two positions, only a certain percentage of horizontally polarized light comes through the filter.

Malus’ law is a predictor of how much polarized light will be transmitted by an obliquely oriented polarizing filter. It is expressed by the equation:

$$I_X = I_O \cos^2 q$$

I_X is the intensity of the light transmitted through the filter, I_O is the original intensity of the entering light, and q is the angle of tilt with *reference to the transmission axis*. The equation for the traditional form of Malus’ law is based on the transmission axis, not the absorption axis. For polarizing ophthalmic lenses the absorption axis is oriented at 180. The transmission axis is at 90.

EXAMPLE

A polarizing filter used in a lens has its absorption axis oriented along the 180-degree meridian. We will assume that it is an ideal filter and will absorb all horizontally polarized light. The polarizing lens is being worn by a person who tilts his head 30 degrees. What percent of horizontally polarized light will now be allowed to pass through the tilted filter?

SOLUTION

Assuming that we have 100% of incoming horizontally polarized light striking the filter, then the intensity of the irradiating (incoming) horizontally polarized light (I_O) is 1. Remember that Malus’ law is based on the transmission axis. When the wearer tilts his head 30 degrees the transmission axis of the lens is 60 degrees away from the horizontally polarized light. Therefore using Malus’ law:

There are many cases of polarizing glare that occur routinely during outdoor activities. A surprising number of individuals would benefit.

Polarizing lenses are made in most lens styles—not just single vision lenses, but bifocals, trifocals, and progressive addition lenses as well. They are available in glass, photochromic glass, plastic, photochromic plastic, polycarbonate, and high-index plastic. Colors and tints are available, including mirrored and iridescent. Polarizing lenses may also be AR coated.

Precautions With Polarizing Lenses

There are some instances where polarizing lenses create unique situations. Here are a few:

1. Since windshields are tempered, the tempering process induces intentional stress into the material. This stress may be visible through polarizing lenses in much the same way the stress is visible through the crossed polarizing filters of a polariscope (colmascope) used to check for impact resistance of glass lenses (see Chapter 23).
2. Some skiers believe polarizing lenses make snow conditions harder to judge. In addition, as the skier tilts from side to side, the polarizing lens tilts. The percentage of horizontally polarized light reflected from the surface of the snow and absorbed by the polarized lenses will vary, depending upon the angle of tilt. This will cause an ongoing change in the intensity of the reflected light.
3. Golfers also sometimes find polarizing lenses make judging the condition of the course more difficult since the smooth grass surface causes a certain amount of polarization of reflected light.
4. The instrument panels in some cars use LCDs (liquid crystal displays) to display information. An LCD display is polarized. If the LCD is horizontally polarized, polarizing sunglasses will extinguish the display. To see how this works when wearing polarizing lenses, turn the display of an LCD display watch 90 degrees. The time display will disappear. Or when pumping gas while viewing the display on the gas pump, tilt your head sideways and see the numbers fade out.
5. Pilots experience a number of adverse situations when wearing polarizing lenses, some of which can be dangerous.
   a. Polycarbonate windshields in many aircraft have stress patterns. These patterns become visible and may be distracting when wearing polarizing lenses.
   b. Some airplane cockpits, like some car instrument panels, may have polarized numbers or images that can disappear when viewed through polarizing lenses.
   c. Much of the light from an oncoming aircraft that makes it visible is reflected light from the metallic surfaces of the plane. Much of this reflected light is horizontally polarized. When this reflected light is eliminated by horizontally polarizing sunglasses, the oncoming aircraft may not been seen as soon as it would otherwise have been.

Two Methods for DemonstratingPolarizing Lenses

It is helpful to explain how polarizing lenses work to a prospective buyer. But it is much better to show them with a first-hand demonstration. Here are two methods that show how polarizing lenses affect light. (There are also commercially available demonstration units.)

It is possible to take two plano polarizing lenses and, by holding one before the other with their polarizing axes crossed at 90 degrees, eliminate all incoming visible light rays. What one polarizing lens does not extinguish the other will. To demonstrate how polarizing lenses work with this method, hold one lens still, then rotate the other lens back and forth 90 degrees. Watch objects viewed through the lenses dim out completely, then brighten up as the lens is rotated back.

(*Caution*: When crossed sheets of polarizing material or lenses are not quite 90 degrees apart, only a small portion of the light is admitted. Herein lies a potentially dangerous problem. Some wearers may be inclined to use your demonstration system with one polarizing lens and one sheet polarizer, or two pairs of polarizing glasses, for viewing an eclipse of the sun. Unfortunately, Clark reports that plastic sheet polarizers are inefficient polarizers of IR radiation—as are most spectacle lenses. Therefore an inordinate amount of heat-producing IR reaches the retina and, especially when combined with UV or short wavelength blue light could be damaging. Direct viewing of an eclipse, even with highly absorptive lenses, is *never* advisable.)

A second method for demonstrating how polarizing lenses work uses a pair of glasses with polarizing lenses and a glossy magazine.[54] Place the magazine on a flat surface with a light source in the background. With the glossy magazine between you and the light source, the magazine will show a reflecting glare. Move around until the glare is maximal. Now turn the glasses 90 degrees so that the lenses are vertically aligned, instead of horizontally as when worn. View the magazine through one of the lenses. Now slowly rotate the glasses until they are horizontal again. As the glasses are rotated, the glare on the magazine will decrease.

GLARE CONTROL LENSES

Polarizing lenses correct reflective glare. There are othertypes of glare that polarizing lenses alone cannot eliminate, however. Glare problems are corrected by addressing the type of glare experienced. For our purposes, we will divide glare into two types:

(1) discomfort glare and

(2) disability glare. These two types of glare are similar in cause, but different in their effect upon vision. *Dis- comfort glare* is a “glare which produces discomfort, but does not necessarily interfere with visual performance or ability.” *Disability glare* “reduces visual performances and visibility [and] may be accompanied by discomfort.”

Discomfort Glare

Discomfort glare may occur when the eyes try to cope with high and low light intensities in a relatively small viewing area. The eyes have difficulty adjusting to both lighting situations simultaneously. Discomfort glare is best corrected by a change in environmental factors. Individuals working at a computer screen placed in front of a bright window experience discomfort glare from the surrounding area. The problem is corrected by repositioning the computer or shading the window. Discomfort glare is also experienced when viewing a television in a dark room. When an individual must look back and forth between vastly different illuminations, discomfort is experienced. Put another way, stray light that reduces visual comfort but does not interfere with resolution is called discomfort glare.

Disability Glare

Disability glare occurs when stray light interferes with contrast, making it difficult to resolve an image. Stray light washes out the image on the retina in the same manner that strong overhead lighting degrades the image of a slide on a projector screen.

If the stray light causing glare were made up of just polarized light, it could be eliminated using a polarizing filter. If the stray light causing problems were to originate from a light source of only one color, a selectively absorptive lens capable of filtering out only that one color would be able to screen out the offending light, restoring the quality of the image.

Factors That Cause Disability Glare

There are many situations that cause disability glare. For example, dazzlingly bright oncoming headlights can obscure a dark road, making it nearly impossible to see someone in dark clothing walking along the side of the road. In addition, there are factors that can cause or increase disability glare. One such factor is the presence of a cataract. If the crystalline lens begins to cloud and fog up like a dirty windshield, disability glare can increase. Oncoming headlights at night are bad enough when viewing the scene through normal eyes. When those same intense headlights are passing through a cloudy, light-scattering cataract, the effect is considerably magnified.

Another cause of increased glare may be related to the absorption of UV light by the crystalline lens. As the crystalline lens of the eye absorbs UV and short wavelength visible light between the range of 310 and 410 nm, it fluoresces, giving off light with a wavelength near 530 nm. Contact lens practitioners will see the pupil giving off a greenish-yellow cast when viewing the eye with a UV lamp. This is really fluorescence of the crystalline lens as seen through the pupil.

Additional Protection from Glare Using Side Shields

The person who is especially sensitive to glare, such as someone with corneal scarring, may benefit from the use of side shields. These shields may be tinted and attached to prescription spectacles.

A wraparound frame is like a frame with built-in side shields. Wraparound frames are available in regular sun- glasses or in specialty filters, such as NoIRs or Solar Shields. Many of these specialty filters are made to be worn by themselves or over conventional eyeglasses.

Using Absorptive Filters That Block Short Wavelengths

The effects of UV radiation on the retina are known and have been discussed in an earlier section of the chapter. In addition to UV light, there are some damaging effects of blue light reported. However, the amount of light needed to cause such retinal damage is not found in the natural environment. There is enough short wavelength light generated by ophthalmic instruments to cause ocular damage with sufficient exposure. However, there are normally filters used in these instruments to prevent such damage.

In an attempt to slow the development of certain degenerative diseases, such as macular degeneration and retinitis pigmentosa, practitioners sometimes use lenses that block both UV and blue light.

Another rationale for using a lens that blocks short wavelength light is to try to increase contrast. When a blue object is viewed through a lens that filters blue, the object does not disappear but looks darker. A darker object against the same background will have a higher border contrast. For this reason, lenses that filter out short wavelength light are said to increase contrast.

Lenses Made to Block Short Wavelengths andControl Glare

Several lenses made their appearance in the 1980s that have been used in an attempt to control glare. Some of these lenses have been used heavily by low-vision practitioners and by those who see a large proportion of older wearers.

Glare Control CPF Lenses

Corning developed a series of photochromic lenses referred to as Glare Control CPF lenses. This line of lenses has since been acquired by and is sold through Winchester Optical.* They are specialty photochromic lenses made using a unique manufacturing process.

CPF lenses begin with photochromic material that is surfaced for the prescription and edged for the frame. Afterwards the lens is “fired” by heating the lens in a hydrogen atmosphere. This reduces the silver halide crystals near the surface of the photochromic lens to critical for causing the photochromic change would be blocked, and the lens will not darken. Therefore the front surface of the lens must be reground to remove the altered layer. The altered back layer that gives the lens its unique spectral absorbing properties remains in place.

There are several series of these lenses, each with a coded name, such as the CPF

527. The letters “CPF” stand for “Corning protective filter.” The number indicates the wavelength below which light is absorbed. (For the CPF 527 lens, all UV and visible light up to 527 nm is absorbed by the lens.)

CPF lenses are described and compared in Table 22-3. Some of their transmission curves in lightened and darkened states are shown in Figure 22-23.

None of these Glare Control lenses are to be worn for night driving.

Glare Control Dyes

There are some glare control “colors” available in lens dyes. This is a less expensive option, whereby clear plastic lenses may be tinted to the desired absorptive characteristics. To work as anticipated, the tint should not just match an expected lens color. The absorptive properties of the dyed lens should also fulfill the desired transmission requirements.

Nonprescription Options for Controlling Glare

Well-known nonprescription filters available for con-trolling glare are available from NoIR Medical Technologies. These are wraparound glasses that come in sizes allowing them to be used alone or on top of pre- scription eyewear. There are many options available. NoIRs vary in the amount of light absorbed, the selectivity of that absorption across the spectrum, and the resulting physical color of the lens. However, according to one study that reviewed 318 patients from three low- vision centers, when NoIRs were used, 89% of low- vision patients chose either the #101 or #102 NoIR filters.

Disadvantages of Glare Control-Type Lenses There are certain disadvantages associated with lenses that block the short-wavelength visible spectrum. One of the greatest disadvantages of these lenses is their effect on color vision. The amount and type of color confusion will vary, depending upon the lens. The more of the visible spectrum that is absorbed by the lens, the greater will be the effect on color vision.

For the color-normal individual, there may be no color confusion induced for lenses that absorb moderately in the blue end of the spectrum. There may be mild confusion for lenses, such as the BluBlocker, that absorb more of the visible spectrum.

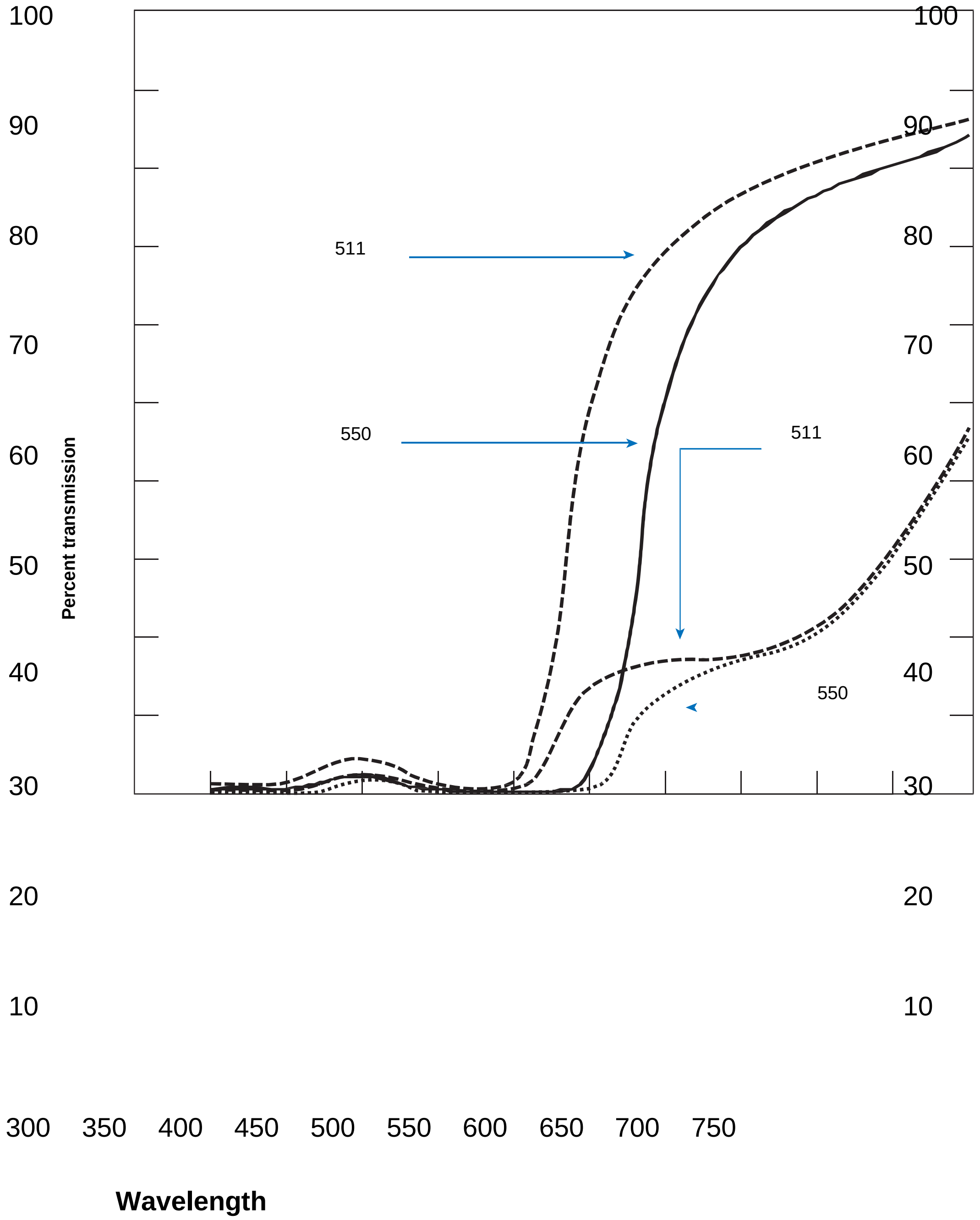


Figure 22-23. Transmission curves for two of the standard series CPF Glare Control lenses. Note that CPF lenses block all wavelengths below the identifying number for the lens (i.e., for the 550 lens, no light with a wavelength shorter than 550 nm is transmitted through the lens). Spectral transmission curves for the CPF 527 lens (not shown in the figure) fall between the transmission curves for the 511 and

550 lenses. (From: Corning Glare Control lens manual,
OPM 190, Corning, NY, 1991, Corning Inc.)

Color discrimination will be more noticeably affected for individuals who already have a color deficiency. Scores on standardized color testing decreased notably for color defectives. In some cases, this can affect the color defective's ability to identify traffic signals quickly.

The expectation with glare control lenses is that visual performance will improve. However, improvements in visual performance by individuals who would be considered candidates for these type of lenses is not a given. In fact there may be no statistically significant difference in visual acuity or contrast sensitivity with the glare control- type lens compared with a neutral density filter of the same transmission.[64,65] Reported improvement in vision is more of a subjective assessment on the part of the wearer. Therefore decisions on which lenses to use are usually made by the individual subjectively comparing two or more appropriate lens types.

Clinically, glare control lenses continue to enjoy popularity, especially in practices specializing in low vision. Although not everyone with glare problems or degenerative eye disorders may find the lenses beneficial, those who do wear them report a subjective improvement in vision and satisfaction.

SPECIALTY ABSORPTIVE LENSES

Glass Blower's Lenses

Glass blowers prefer an absorptive lens that filters out the yellow band of the spectrum so that they may more clearly see what is happening to the color of the heated glass without it being marked by the yellow flame. This function is fulfilled with a glass *didymium filter* lens. Didymium lenses are dichroic, meaning the lens will appear rose colored in natural and incandescent lighting, but aqua under fluorescent lighting. Didymium lenses used in glass blowing *are not welding glasses,* even though there are some welding glasses that contain didymium.

X-Ray Lenses

Lenses used for x-ray protection are made from a 1.80 index, heavy glass material. This particular glass is softer than regular glass and is prone to scratching. (Note: Just because a lens may have an index of refraction of 1.8 does not mean that it protects against x-rays.) X-ray protective lenses are not capable of being chemically hardened. They cannot be heat tempered using normal ophthalmic air hardening equipment. X-ray protective lenses can be heat tempered at a lower temperature. But since most air

Therefore reflected light from the front surface of the lens will be:

$$R_F 0\,100(0.0398)\,0\,3.98\%$$

To determine how much light is reflected from the second surface, we run through the equation again. This time the value of the incident light is not 100% or 1. Instead it is:

$$I\ 0\ 1\ 0\ 0.0398\ 0\ 0.9602$$

Therefore

$$0\ \underline{n00n}\ 0^2$$

Sample Questions:

1. **How Index of Refraction Affects theTransmission of a Spectacle Lens (the Fresnel Equation)**

The amount of light that is reflected when light goes from one media to another is determined using the Fresnel equation. The Fresnel equation is:

$$|I_R\ 0\ \frac{0\ n00n\ 0}{0\ n0\ 0\ n\ 0}\ 0\ I$$

where *n'* is the index of refraction of the second media, *n* is the index of refraction of the first media, I is the amount of incident light, and I_R is the amount of incident light that is reflected.

2. ***Why Coating Fused Glass Multifocals Help to Reduce Segment Visibility***

Fused glass multifocal segments are made from a glass material having a higher refractive index than the distance portion of the lens. This means that the segment will reflect more light than the distance portion, increasing its visibility. By applying an AR coating, both parts of the lens transmit close to 100%. The difference in percent transmission between the distance lens and the segment is less, making the lens segment less noticeable.

3. **Why a Tinted Glass Lens Becomes Darker When Its Plus Power Increases (Lambert's Lawof Absorption)**

When a lens material contains its tint in the melt or resin, the amount of light transmitted will change with squaring the transmission factor for the original thickness. If the thickness triples, the effect is cubed, and so on.

4. What would the ideal refractive index be for a single-layer antireflection coating applied to a high-index lens if the lens has an index of refraction of 1.6?

Since the lens has an index of refraction of 1.6, the ideal index of the single-layer AR coating would be the square root of 1.6.

$$n_F \ 0 \ \sqrt{n_L}$$
$$0 \ \sqrt{1.6}$$
$$0 \ 1.265$$

Therefore the ideal single-layer antireflection coating would have an index of refraction of 1.265.

Unit 13:

Lens Material, Classification, Safety and Sports Eyewear

Learning Objective:

At the end of this chapter, students will be able to learn:

1. What is refractive index, what are different lens materials.
2. What are safety goggles, indications to use these lenses.

Lens material and eye safety in the workplace and for sports or recreational activities are all inter-related. In this chapter the characteristics of lens materials are considered. This leads logically to a discussion of appropriate frames and lens materials in eye protection.

LENS MATERIALS

The variety of materials that can be used for lenses has increased substantially during the past few years and promises to continue to expand. With choices abounding, the practitioner needs to know the unique characteristics of each lens material so that a proper match between the needs of the wearer and the best possible material occurs. Ophthalmic lenses are made from glass and plastic. Glass lenses are often referred to as *mineral* lenses, whereas if a lens is made from plastic, it is said to be from *organic* material.

Crown Glass

The material traditionally used for spectacle lens wear for several hundred years has been glass. Glass works well for ophthalmic materials because it resists scratching and is not easily affected by environmental factors. The main disadvantages of glass are weight and impact resistance. To pass United States requirements for impact resistance, glass must be hardened.

The most commonly used clear glass lens material is made from a type of *crown glass* having an index of refraction of 1.523. This material is low in chromatic aberration.

High-Index Glass

There are higher index glass lens materials available that will reduce lens thickness for higher powered prescriptions. Index 1.60 lenses are readily available in spherical and aspheric designs and in segmented and progressive multifocals. *Corning Clear 16* is able to be surfaced to a 1.5-mm center thickness and, after hardening, is impact resistant enough to pass Food and Drug Administration (FDA) standards.

There are fused flat-top bifocals available in indexes up to 1.70, and single vision lenses in still higher indexes. Even though there is a 1.90 index glass available, it is generally not used in the United States because it cannot be hardened and thus will not meet impact resistance standards.

Unfortunately, high-index glass lenses are composed of materials with a higher specific gravity, making them heavier. In countries where there are not impact resistance requirements, this is not a problem since they can be ground very thin anyway. But with the thicknesses needed to achieve a sufficient impact resistance, a pre- scription must be fairly strong in order for high-index glass lenses to be both thinner and lighter than crown glass. What the dioptric value should be for a high-index glass lens to exhibit the expected advantages of both thickness *and* weight will depend upon the specific gravity of the material used. When glass was the main material used, the rule of thumb was that high index became lighter than crown glass for lenses more than

07.00 D.

High-index glass lens materials generally have Abbé values close to that of polycarbonate. Chromatic aberration is measured in terms of an Abbé value. The lower the Abbé value, the higher the chromatic aberration. Chromatic aberration can result in color fringes being visible at high-contrast borders. An example of a high- contrast border would be the black and white keys of a piano. Fortunately, when lenses are fit properly, most problems with chromatic aberration can be minimized so that they do not pose a problem.

Plastic Lenses

CR-39

For years the most commonly used plastic lens material was CR-39. CR-39 was developed by PPG Industries. “CR” stands for Columbia Resin, and the number 39 denotes the type of Columbia Resin used. CR-39 lens material processes well in the laboratory. For years CR- 39 was used without antiscratch coating. Now, however, most CR-39 lenses come with an antiscratch coating, making the material much more scratch resistant. CR-39 lenses that must be surfaced are less likely to have an antiscratch coating on the back side unless one is ordered. (Segmented multifocals and progressive addition lenses are examples of lenses that must be surfaced.)

Plastic lenses are roughly half the weight of crown glass lenses. For low velocity, large mass objects, such as a softball, chemically tempered lenses perform somewhat better than CR-39 lenses in their impact resistance ratings. For smaller, high velocity, sharply pointed objects, CR-39 lenses perform better than chemically tempered glass. (It should be noted that glass is weakened more by scratching than is CR-39 plastic.) Keep in mind, however, that for impact resistance there are a number of other plastic lens materials that outperform both chemically tempered glass and CR-39 plastic. Impact resistance will vary according to the type of plastic used.

CR-39 plastic lenses do not fog up as easily as glass lenses. Whereas welding or grinding spatter will pit or

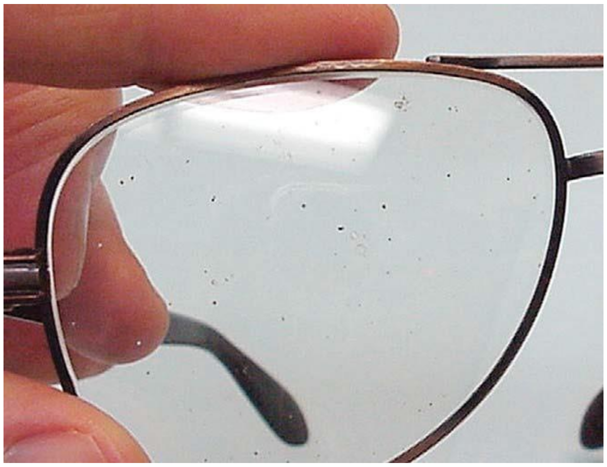


Figure 23-1. Welding or grinding spatter will pit or permanently stick to glass lenses, as shown here. It does not adhere to plastic lens material.

permanently stick to glass lenses, it does not adhere to plastic lens material (Figure 23-1).

High-Index Plastics

CR-39 plastic lenses have an index of refraction of approximately 1.498. This is the lowest refractive index material used for spectacle lenses. For minus lenses of equal powers and center thicknesses, the higher the index of refraction of a lens material, the thinner the lens edge can be made. Therefore high-index plastic lens materials will have both a weight and a thickness advantage over CR-39. They are an attractive alternative.

High-index plastic comes in a variety of materials. When considering the virtues of a high-index lens, the materials should not only be compared on the basis of index of refraction alone, but also on the basis of weight, impact resistance, finished lens thickness, Abbé value (chromatic aberration), and ease of production. Table 23-1 gives a comparison of some of these characteristics for a few representative materials.

Table 23-2 gives a summary of the impact-resistance characteristics for many of the currently available lens materials.

Polycarbonate

Polycarbonate lens material is soft and requires an anti-scratch coating. However, the very softness of the mate- rial contributes to its high-impact resistance. Instead of breaking on impact, the softer polycarbonate material is more likely to absorb a blow and just dent. When safety is the primary concern, polycarbonate has traditionally been the number one choice.

TABLE **23-1**
A Representative Comparison of Lens Materials

Lens Material	**Refractive Index (n)***	**Density †**	**Thickness† (Minus Lens Center Thickness)**	**Abbé Value§**
CR-39 plastic	1.498	1.32	2.0	58
Crown glass	1.523	2.54	2.0-2.2	59
Trivex	1.532	1.11	1.0-1.3	43-35
Spectralite	1.537	1.21	1.5	47
Polycarbonate	1.586	1.22	1.0-1.5	29
Polyurethane	1.595	1.34	1.5	36
Corning Clears 16 (glass)	1.60	2.63	1.5	42
High-Index plastic	1.66	1.35	1.0-1.7‖	32
	1.71	1.4		36
Thin & Lite 1.74 High-Index plastic	1.74	1.46	1.1	33
High-Index glass[30]	1.7	2.97	2.0-2.2	31
	1.80	3.37		25
	1.90¶	4.02		30.4

*The higher the refractive index, the thinner the edge of a minus lens.

†The lower the density, the lighter the lens.

TABLE **23-2**
Relative Impact Resistance of Various Ophthalmic Materials

Lens Material	**Comments**
Untreated crown glass	Because of Food and Drug Administration regulations, untreated crown glass is not used for ophthalmic eyewear in the United States.
Heat-Treated crown glass	Heat-treated glass loses much impact resistance when it is scratched. In fact against the impact of small,

	high-velocity objects, a badly scratched untreated glass lens is more impact resistant than a badly scratched, heat-treated lens.
Chemically tempered crown glass	Against the impact of large, slow moving objects, such as a softball, chemically tempered lenses are more impact resistant than CR-39 plastic. Against the impact of small, high velocity objects, however, the CR-39 plastic lens is the more impact resistant.
CR-39 plastic	An uncoated CR-39 lens ranks as shown here. If this lens is coated, however, the impact resistance tends to be reduced. Just how much depends on the type of coating that is used.
High-Index plastic	High-index plastics are made from a variety of materials and, although they vary in their impact resistance, have been classed as only being as strong as CR-39.[23] Keep in mind that there are subgroups in this category. Many of the newer high-index plastics perform well enough to be thinned to 1.0 or 1.5 mm thickness. As with CR-39, impact resistance of high-index lenses is decreased with the addition of antireflection coatings. Polyurethane lenses appear to perform fairly well in impact resistance.
Polycarbonate, Trivex, and NXT materials	Impact resistance for polycarbonate, Trivex, and NXT lens materials exceeds other commonly used prescription lens materials. Antireflection coating does reduce impact resistance of these lenses by varying degrees, depending upon the type of missile impacting it. Eye care practitioners should be attentive to new information on these lenses before assuming that they are equal in all situations.

Because polycarbonate lenses are so much safer than conventional lenses, the eyewear purchaser should be informed of the availability of safer lens materials and given the opportunity to choose a lens that affords better protection.

Trivex Lenses

Trivex lens material is a very impact-resistant lens material. It was developed by PPG Industries, the developers of CR-39 material. Trivex processes fairly easily and takes a lens tint easily. The lens material was originally for military use as a plastic material to provide excellent safety characteristics for windows in combat vehicles and good optics.[1] PPG Industries promotional materials attribute the "tri" in Trivex to a triperformance lens material; meaning it offers a triple combination of supererior optics, impact resistance, and ultra light weight.

Trivex rivals polycarbonate in impact resistance. It is the lens of choice for drill-mounted lenses because it does not crack or split at the drilled hole. Some laboratories will warrant no other material than Trivex for drill-mounted lenses.

The lens is very light weight, having a density of 1.11. Even though the index of 1.53 is just a bit higher than crown glass, it may be thinned to 1 mm so that thickness and weight are seldom an issue. The Abbé value of 43 to 45 is less than CR-39, but higher than its rival, polycarbonate. It maintains a good resistance to damage from chemicals.

NXT Material

There are other lens materials that continue to be developed that will add much to the ophthalmic lens market in the coming years. An example of one such material with some potential for more ophthalmic use is called NXT. NXT was developed in the early 1990s under a

U.S. government contract to develop a new bullet-proof material. The resulting lens is a light-weight material that is extremely strong and also compatible with photochromic pigments and with polarization. It has already been used in sun and sport eyewear, helmet visors for motorcycles, airline cockpit door view ports, ballistic police shields, and vehicle door armor.

NXT has an index of refraction of 1.53, a density of 1.11, an Abbé value of 45, and is highly flexible. It is reported to be compatible with low-powered sphere and cylinder prescription lens powers.

Laminated Lenses

Lenses that are made from two or more layers of material are called *laminated lenses*. Lamination can be used for several purposes. Before dyed plastic lenses, clear glass lenses were sometimes laminated with a thin layer of tinted glass to give an even tint across the lens. Polarizing lenses have a stretched polarizing film sandwiched between two layers of regular lens material to cut out reflected glare. Lamination can also be used to increase impact resistance.

Effect of Lens Coatings on Impact Resistance When a plastic lens is either scratch resistance coated or antireflection (AR) coated, the impact resistance of the lens decreases. This seems opposite to what would be expected.

Both scratch resistance and antireflection coatings are harder than the plastic lens material to which they adhere. When a lens breaks, the break starts at the weakest point. If a plastic lens is hit by an object, the lens may flex, but may not break. If the coating is harder than the lens, however, as the lens flexes, the harder (more brittle) coating cracks before the uncoated lens. When the coating is strongly bonded to the lens, the energy that is concentrated in the first crack is released. The released energy travels through the lens and may cause it to break.

Corzine et al[3] used a static load form of testing* and compared uncoated CR-39

lenses with (1) scratch resistance-coated lenses, (2) five-layer AR-coated lenses, and
lenses that had been prepared for antireflection coating but not coated. The mean fracture loads required to break the lenses in each category were as follows:

Lens Type	**Fracture Load**
Uncoated CR-39	587
Scratch resistance coated CR-39	505
AR coated CR-39	465
AR prepped but not coated CR-39	609

As can be seen from the results, the weakening of the lens is due to the coating itself, not by the process the lens is subjected to in preparation for coating.

In another study, Chou and Hovis tested coated CR- 39 *industrial* lenses for impact resistance using the Canadian Standards Association ballistic test protocol. They concluded that AR coating produced such poor impact resistance that they were "unsuitable for use in spectacles that are intended to provide even minimal impact protection in industrial, sports, or other environments."[4] They also concluded that CR-39 lenses with just scratch resistance coatings do produce adequate protection for these environments.

The weakening of a plastic lens by an AR-coated lens is not limited to CR-39 material. Weakening would be expected to occur in some degree with other lens materials that are softer than the more brittle AR coating.

Effect of Surface Scratches on Impact Resistance

A scratched lens surface reduces impact resistance. The scratch introduces a weak spot on the lens and creates a sort of "fault line." The scratch provides an easy area for stress to build during impact, making breakage more likely. To better imagine how this works, think about how panes of glass are "scored" with a diamond so that they may be broken along the scored line. Contrary to intuition, scratches on the back surface of a lens will reduce lens impact resistance *more* than front surface scratches. Glass or CR-39 lenses with front surface scratches were reduced in impact resistance by 20%, whereas CR-39 lenses with back surface scratches were reduced in impact resistance by 80%.

GENERAL EYEWEAR CATEGORIES

We can divide eyewear into three broad categories:

- *Dress Eyewear*
  Dress eyewear is eyewear that is designed for everyday use.
- *Safety Eyewear*
  Safety eyewear is designed to meet higher standards of impact resistance since

it will be worn in situations that could be potentially hazardous to the eyes.

- *Sports Eyewear*
  Sports eyewear is designed to protect the eyes and/ or enhance vision in specific sports situations. What is appropriate will vary dramatically, depending upon the sport.

REQUIREMENTS FOR DRESS EYEWEAR*

There are a number of industry and government agencies that have a direct impact on the business of eyewear. All are important to the dispenser in ensuring that the wearer is receiving a product that is within the expectations of the ophthalmic industry and government regulatory agencies. The following sections list the agencies involved and how they affect the dispensing of eyewear.

Food and Drug Administration

There did not used to be any impact resistance requirements for dress ophthalmic lenses. In most places in the world, there still are not. It is possible to surface glass lenses as thin as 0.3 mm and still have the lenses be wearable. The lenses look wonderfully thin and are still optically excellent. But they afford little protection for the eyes and in many situations end up becoming a hazard to the wearer.

For that very reason, the United States Food and Drug Administration (FDA) began mandating impact resistance for dress ophthalmic lenses in 1971. Since then all eyeglass and sunglass lenses must be impact resistant, except when the optometrist or physician finds that they will not otherwise fulfill the patient’s visual requirements. If the lens cannot be rendered impact resistant, this must be recorded in the patient’s record, and the patient must also be notified in writing.

*Static load testing is where an increasing amount of pressure is applied to the lens until the lens finally breaks.*Much of the material from this section and the following section on Safety Eyewear is from Brooks CW: Essentials for ophthalmic lens finishing, St.Louis, 2003, Butterworth-Heinemann.

Must Dress Ophthalmic Lenses HaveMinimum Thickness?

Formerly, dress ophthalmic lenses had a minimum thick- ness requirement of 2.0 mm. Now there is no thickness requirement, regardless of lens material. Impact resistance requirements are performance based, and the lens must be capable of withstanding a predetermined amount of impact. If that requirement can be met with lenses that are thinner than 2.0 mm, the lens is acceptable. Today there are many lenses that can meet current impact resistance requirements and still be below 2.0 mm, including some types of glass lenses.

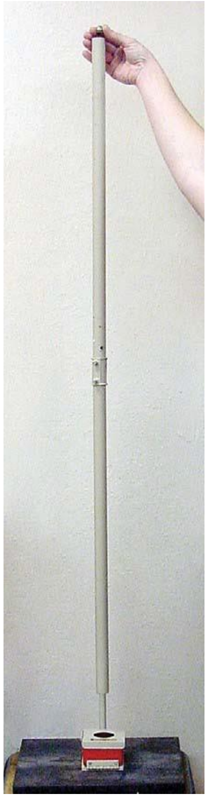


Figure 23-2. A drop-ball tester drops a steel ball on the front surface of a lens from 50 inches.

Impact Resistance Test Requirements

The standard “referee test” for determining impact resistance suitability for dress ophthalmic lenses is the drop ball test. This test is very specific in how it should be administered. However, the FDA states that this does not inhibit the lens manufacturer from using equal or superior test methods to test for impact resistance.

The Drop Ball Test

To be judged acceptable, a lens is first placed front side up on a neoprene gasket. It must be capable of withstanding the impact of a five-eighth-inch steel ball weighing 0.56 oz, dropped from a height of 50 inches (Figure 23-2).

When Should the Drop Ball Test be Performed?

Glass lenses must be tested after the lens has been edged and hardened and before it is placed in the frame. Plastic lenses may be tested in the “uncut-finished” stage before they have been edged.

Drop-Ball Testing of Glass Lenses

With few exceptions, all glass lenses must be hardened *and* individually subjected to the drop ball test. Only lenses that could be damaged by the test are exempt. These lenses must still be hardened, but do not need to be tested. Glass lenses that are exempt from testing are:

1. Raised multifocal lenses (These are lenses that have a ledge area on the lens, such as an Executive lens.)
2. Prism segment multifocals
3. Slab-off lenses
4. Lenticular cataract lenses
5. Iseikonic (size) lenses
6. Depressed-segment one-piece multifocals
7. Biconcave, myodisc, and minus lenticular lenses
8. Custom laminate lenses (such as polarizing lenses)
9. Cement assembly lenses

Individual Versus Batch Testing

Batch testing is the practice of selectively testing a statistically significant number of lenses in a manufactured group. This avoids having to individually test lenses that could sustain damage by the test itself. The practice of batch testing is permitted for:

1. Plastic lenses.
2. Nonprescription lenses, such as mass-produced sunglass lenses.

Glass, plano-powered sunglass lenses that are individually produced in a finishing laboratory must still be individually drop-ball tested.

Who Does Batch Testing?

The lens manufacturer normally does batch testing. When this is done, plastic lenses that are edged in a finishing laboratory do not have to be individually tested or batch tested in the finishing laboratory. Batch testing for semifinished lenses is done for a certain minimum thickness. If these lenses are surfaced to *less* than what was considered minimum thickness, they are no longer within the batch. They would need to be individually tested.

If the lens is altered after having been received from the manufacturer, as when it is sent out for AR coating, then the lens is no longer warranted by the original lens manufacturer. There are a great many types of coatings that could be applied to the lens. Each of these coatings will affect the impact resistance of the lens differently. Typically the AR coating laboratory will batch test lenses being coated in their laboratory. To do this, they will use lenses of the same material and minimum thickness as those being sent to them for coating. It is the responsibility of the finishing laboratory to be in communication with the company that applies the coating to determine that testing requirements have been fulfilled.

Defining "Manufacturer"

There are a large number of participants involved in the process of making a pair of glasses. One company makes the lenses, another may surface the lenses, a third may edge the lenses, and someone else could coat the lenses. Who then is the manufacturer of the finished eyeglasses? Although in a lawsuit, each participating party is likely to be named, final responsibility lies heavily with the unit that performed the final process on that lens. Here is how the FDA responds to the question.

Q. In terms of the regulation, who is the manufacturer?

A. The manufacturer is the person who puts the lens in the form ready for its intended use or who alters the physical or chemical characteristics of the lens by such acts as grinding, heat treating, beveling, or cutting. For the purpose of this regulation the term "manufacturer" includes a company that imports eyeglasses for resale.[6]

In this chain of manufacturing events, the question of record keeping may arise. Here is how the FDA poses and answers this question.

Q. What are the record keeping requirements on partially finished lenses furnished by one manufacturer for completion by another?

A. Records must be kept to show how lenses were rendered impact resistant, when and how they were tested for impact resistance, and by whom in the processing chain these actions were accomplished.[6] This means that if the retailer is the manufacturer,

then the record keeping requirements of the manufacturer apply. Retailers also have a 3-year requirement of keeping the names and addresses of persons buying prescription eyewear.

The Dispenser's Role in Record Keeping

To ensure that all regulations have been met and that ophthalmic lenses are safe, the FDA requires that records be kept for 3 years after the purchase of eyeglasses. Records that must be kept consist of records of the sale or distribution of prescription eyewear, including the names and addresses of people buying prescription eyewear. (Records do not have to be kept for individuals buying nonprescription eyewear.)

If the dispenser has an in-house laboratory, record keeping requirements for a manufacturer apply. These requirements include:

1. Copies of invoice(s), shipping document(s), and records of sale or distribution.
2. Results of impact-resistance testing (drop-ball test results).
3. A description of the test method and of the test apparatus used.

Federal Trade Commission

The Federal Trade Commission (FTC) was established to prevent unfair business practices, such as deceptive advertising and monopolies. In the 1980s the FTC began to look at the ophthalmic industry. After two series of investigative studies known as Eyeglasses I and Eyeglasses II, prescription release rules were formulated for spectacle and contact lenses. The spectacle lens aspects of these rules will be considered here.

Eyeglasses I

In 1978 the FTC concluded their Eyeglasses I investigative study with a spectacle lens prescription release rule.

This rule requires that patients be given a copy of their spectacle lens prescription so that they may fill that prescription wherever they desire. The prescription is to be given immediately after the eye examination is completed, whether or not the patient asks for the prescription. A new written prescription is also to be given even if the change is too small to require a change in eyeglasses or if there is no change at all since the previous eye examination. The Eyeglasses I prescription release rule listed minimal information to be included in the prescription: sphere power, cylinder power and axis (if any), prism (if any), and the signature of the prescribing optometrist or physician.[7]

Eyeglasses II

In 1989 the FTC did a more complex investigative study that was primarily concerned with restrictions on practice ownership by people who were not optometrists, ophthalmologists, or opticians.

Eyeglasses II rules no longer list minimal information needed for a spectacle lens prescription. Therefore prescribers are at liberty to include whatever they consider important for the patient's visual welfare on the prescription. This could include lens material, specific lens styles, and instructions for wear. For example, suppose a patient has one eye with normal vision and one with very little usable vision. In this instance in which eye protection is important, including polycarbonate lens material on the prescription may reduce the possibility of pre- scriber liability in the event of eye injury.

An expiration date is usually a part of the prescription. (Although duplication of an existing pair of glasses may be done without restrictions, the dispenser has an ethical obligation to inform such a person of the importance of regular eye examinations. Eye disorders and diseases are not always accompanied by pain and so may not be readily apparent. Contrary to what is often believed, state laws do not set a time limit, such as 2 years, on the length of time an eyeglass prescription may still be filled. "Most states do not have a requirement for an expiration date on spectacle Rx's, although they do not prohibit a doctor from indicating one. Where states do have laws, the concern has been primarily to regulate how short the time limit should be, not how long. In states where this subject is not regulated, it is left to the discretion of the doctor.[8]")

Like Eyeglasses I, Eyeglasses II continues to prohibit disclaimers written on the prescription, such as "Not responsible for accuracy of ophthalmic prescription materials obtained from third-party dispensers."

American National Standards InstituteRecommendations for Prescription Ophthalmic Lenses

The main points of the American National Standards Institute (ANSI) Z80.1 recommendations for prescription ophthalmic lenses are summarized in Appendix A.

The ways in which many of these standards are verified are found in Chapter 6.

It must be kept in mind that in the case of prescription lenses, these parameters are recommendations only—not requirements. Practitioners may choose to allow more latitude than the standard requires in some instances, or they may request more accuracy in a given area in other instances. The document itself summarizes it best:

"The standard remains a recommendation. Therefore it is the specific intent of the Z80 Committee that this standard not be used as a regulatory instrument.[9]"

SAFETY EYEWEAR

Safety eyewear has been an extremely important factor in reducing eye injuries. Now that safety eyewear is a must in industry, eye injuries most often occur because of a failure to wear eye protection at the time of the accident or because the wrong kind of eye protection was worn. Today the most likely eye injury situation occurs when workers are wearing safety eyewear without sideshields.[10]

ANSI Establishes Safety Eyewear Standards The standards used for safety lenses and frames are agreed to and put forth by the ANSI. The ANSI Z80.1 standards for prescription eyewear are not a regulatory instrument. However, the ANSI Z87.1 standard for safety eyewear has become just that. Here is how it happened.

OSHA Regulates Safety Eyewear Standards

The Occupational Safety and Health Administration (OSHA) is the federal agency charged with regulating safety practices in the workplace and in educational settings. OSHA rulings have the same power as law. Visits to a workplace are often unannounced, and violations of OSHA regulations discovered at the time of the inspection can result in both mandates to correct the violation and substantial fines.

Rather than beginning anew with a set of eye and face protection requirements OSHA has chosen to adopt the Z87.1 standards already set forth by ANSI as their standards. Therefore the ANSI Z87.1 standards are a federal requirement.

Because it would be difficult to list every situation in which eye protection must be worn, OSHA has instead chosen to place the burden on education and industry by simply stating that "protective eye and face equipment shall be required where there is a reasonable probability of injury that can be prevented by such equipment."

Impact Requirements for Safety Eyewear

At the time of the writing, the most recent ANSI Z87.1 requirements for safety eyewear were published in August 2003. The previous 1998 standard had a single set of requirements for all safety eyewear. The 2003 standard has two levels of safety standards. One level is called *basic impact;* the other, *high impact*. The Z87.1 1998 standard is identical to the basic impact level for the 2003 standard.

Basic Impact Requirements for Safety Eyewear Because there are two levels of safety eyewear, why would anyone want to wear a basic-impact lens when high-impact lenses are available?

In a number of work situations, workers are cleaning their glasses constantly (e.g., places with a lot of dust and places in which liquids or mists are present). In these situations, plastic and polycarbonate lenses may scratch. Glass lenses withstand scratching better and will not have to be replaced constantly. Badly scratched lenses are irritating to wear and, if vision is impaired, may create a safety hazard. So even though glass lenses are not able to pass the high impact requirement, in the absence of a material that has the same scratch resistance, basic- impact glass lenses may be the more appropriate lens.

Basic Impact Thickness Requirements

For a number of years, thickness requirements for pre- scription safety lenses have been a minimum of 3.0 mm. The exception has been for plus lenses that have a power of 03.00 D or higher in the most plus meridian of the distance portion of the lens. The reason for the excep-tion is because high plus lenses are much thicker in the center. Therefore these lenses may be thinned to a 2.5- mm minimum edge thickness and still remain strong because of their overall thickness. These standards remain as thickness requirements for the 2003 basic- impact category of Z87 safety eyewear.

Basic Impact Testing Requirements

The testing requirements for basic-impact safety lenses are similar to those for dress ophthalmic lenses. Dress lenses are required to withstand the impact of a five-eighth-inch steel ball dropped from 50 inches. Basic- impact safety lenses must withstand the impact of a 1-inch steel ball dropped from 50 inches.

Basic Impact Marking Requirements

Basic-impact safety lenses must be marked with the manufacturer's logo or identifying mark. The markings are applied after edging. In-house laboratories that do their own edging of safety lenses must mark the lenses. Marks on the surface of the lens should be out of the line of sight. They usually appear at the center of the top of the lens or in the upper, outer corner. If the lens is other than a clear lens, it may require an additional marking (Figure 23-3). A summary of these marking require- ments are found in Table 23-3. Remember, a lens that is thick enough to be classed as a safety lens and strong enough to pass safety lens impact testing is not accept- able as a safety lens until it is marked with the required manufacturer's identification.

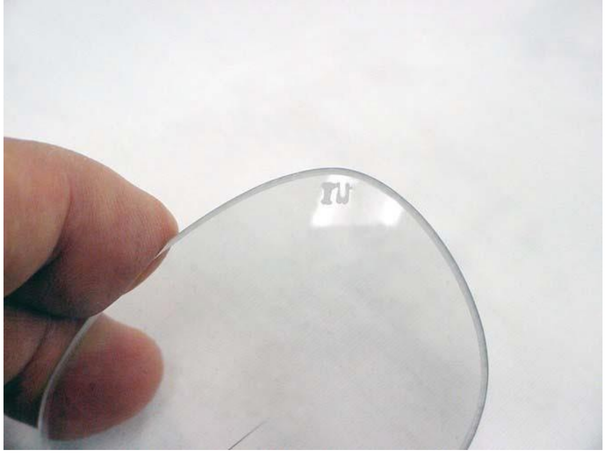


Figure 23-3. The marking identifying a lens as a safety lens.

Warning Labels for Basic-Impact Lenses

Basic-impact safety glasses are not as impact resistant as high-impact safety glasses. The person wearing the lenses needs to know this. Therefore a warning must accompany basic-impact eyewear. That warning is in the form of a notice included with the basic-impact eyewear and is intended for the wearer. The notice must say that the lenses meet the basic impact requirements, but should not be relied upon for protection from high-impact exposure.

High Impact Requirements for Safety Eyewear Though it may seem opposite to the expected, high impact requirements allow the lenses to be made thinner than basic-impact lenses. However, the tests that high-impact lenses must withstand are more stringent than those for basic-impact lenses.

High Impact Thickness Requirements

The thickness requirement for high-impact safety lenses is a minimum of 2.0 mm. This includes both prescription and nonprescription (plano) safety lenses.

High Impact Testing Requirements

High-impact safety lenses must pass a high velocity impact test. In this test, the lens is mounted on a special holder and must be capable of withstanding the force of a one-fourth-inch steel ball traveling at 150 feet/sec.

High Impact Marking Requirements

High-impact safety lenses are marked in the same manner as basic-impact lenses, except that they are to be additionally marked with a plus (0) symbol, not just the manufacturer's logo (Table 23-4).

Comments on Multilayer Antireflection Coating and Safety Lenses

As previously mentioned, AR coatings generally reduce impact resistance of a lens compared with the impact

TABLE **23-3**
ANSI Z87.1 Lens Marking Requirements

Lens Type	Requirement* Example	Basic Impact High Impact Example
Clear lenses	Manufacturer's	monogram

	and JO JO + sometimes 0
Tinted (absorptive) lenses except for 2.5 lenses	Manufacturer’s monogram, JO JO+2.5 special purpose shade number, and sometimes 0
Photochromic lenses	Manufacturer’s monogram, “V” JO V JO+ V for variable shade, and sometimes 0
Special purpose lenses “S” provide eye protection while performing visual tasks that require unusual filtering of light. Examples include didymium-containing lenses, cobalt-containing lenses, uniformly tinted lenses, and lenses prescribed by an eye specialist for particular vision problems.)	Manufacturer’s monogram, JO S JO+S (Special purpose lenses for special purpose, and sometimes 0

*All markings must be legible and permanent and placed so that interference with the vision of the wearer is minimal.

TABLE **23-4**
Safety Lens Requirements

	Basic Impact	High Impact
Thickness	3.0 mm 2.5 mm if power is +3.00 D or greater	2.0 mm
Marking (See also Table 23-3)	Manufacturer's logo	Manufacturer's logo +
Impact testing	1-inch steel ball dropped from 50 inches	1-inch steel ball dropped from 50 inches and ¼-inch steel ball traveling at 150 feet/sec

resistance of that same lens in an uncoated state. The amount of reduction will depend upon the lens material and the type of AR coating used. This is an important factor with safety lenses.

Chou and Hovis[12] tested 2- and 3-mm thick polycarbonate lenses for penetration with an industrial sewing machine needle mounted in a cylindric aluminum carrier. The lenses were tested with and without a multilayer AR coating. (All lenses had scratch-resistant coatings.) They confirmed that polycarbonate lenses are more susceptible to penetration by sharp, high-speed missiles than blunt missiles. They also found that reducing lens center thickness and applying a multilayer AR coating further reduces penetration resistance. Their conclusion was that 2-mm thick polycarbonate lenses and the use of multilayer AR coating on polycarbonate lenses should be discouraged for industrial eye protectors where sharp missile hazards are possible.

In a second article, Chou and Hovis[13] tested the Hoya Phoenix brand of Trivex lenses using a pneumatic gun to propel a 6.35-mm steel ball at the center of 2- and 3-

thicknesses. They concluded that when multilayer AR coated, these lenses should not be used in industrial or sports eye protectors, particularly at 2-mm center thickness where there is a high risk of exposure to high-energy impacts.

Safety Frames

In 1989 the ANSI standards for safety frames dropped specific design requirements, including groove design. Instead requirements are performance based. Safety frames must withstand certain specific impact tests that are not required of normal dress frames. Frames are placed on a head model. When impact occurs, the frame cannot break. Nor can the frame or lens come into contact with the eye.

The first test used to test safety frames is the *high velocity impact test*. This test simulates a high velocity, low mass object. In the high velocity impact test, a series of one-fourth-inch steel balls traveling at 150 feet/sec are directed at 20 different parts of the glazed frame* (Figure 23-4). A new frame is used for each impact. Neither the

mm thick lenses, with and without multilayer AR coatings. They found that multilayer AR coatings significantly reduce the impact resistance at both dress and industrial

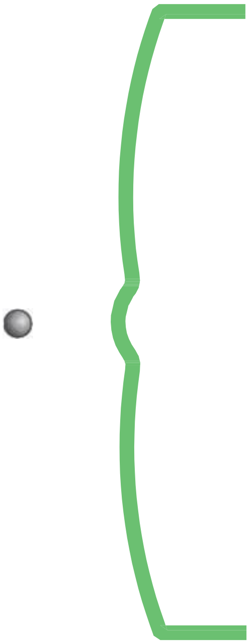


Figure 23-4. The high velocity impact test fires a one-fourth-inch steel ball at 150 feet/sec at a frame or lens.

frame nor the lens can break, nor can the lens come out of the frame.

The second test simulates the impact of a large, pointed, slow moving object. In this *high mass impact test,* a pointed, conical-tipped projectile, 1 inch in diameter, weighing 17.6 oz is dropped 51.2 inches through a tube and onto the eyeglasses (Figure 23-5). When the projectile strikes the frame, the lens must not break, nor come out of the frame.

Marking Safety Frames

With safety requirements, a clear distinction between “dress” frames and safety frames must be kept in mind. *Dress* frames are those worn for everyday purposes.

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*A glazed frame is a frame with lenses. In this case the lenses are plano in power.

No matter how sturdy the construction of a dress frame, it is still not a safety frame unless it passes the required tests and is specifically marked as being a safety frame. Without these markings, the frames are not safety frames. These markings are size, the manufacturer’s trademark, and the all-important Z87 or Z87-2 marking on both temples and front, indicating compliance with ANSI Z87 standards.

Safety frames intended for use with 2.0-mm thick high-impact lenses must be tested for 2.0-mm thick lenses. When successfully designed and tested, these frames are marked “Z87-2,” instead of just “Z87.” The “2” signifies that the frame is suitable for 2-mm lenses (Box 23-1). All frames that are marked Z87-2 must be capable of retaining both basic-impact 3.0 lenses and high-impact 2.0 lenses. Thus all new safety frames can be expected to bear the Z87-2 markings.

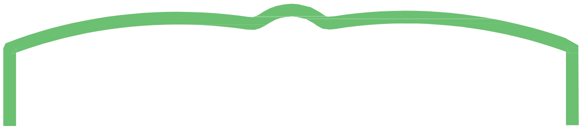


Figure 23-5. The high mass impact test drops a pointed, 1- inch diameter projectile onto safety eyeglass frames from 51.2 inches to test their suitability for use as Z87 safety frames.

BOX 23-1

Safety Frame Marking Requirements

FRONTS
1. A-dimension (eye size)
2. DBL (Distance between lenses)
3. “Z87” to indicate frame compliance with basic-impact standards or Z87-2 to indicate frame compliance with high-impact standards (Z87-2 frames may be used for both basic- and high-impact lenses.)
4. Manufacturer’s identifying trademark

TEMPLES
1. Overall length
2. “Z87” to indicate frame compliance with basic-impact standards or Z87-2 to indicate frame compliance with high-impact standards
3. Manufacturer’s identifying trademark

Defining Safety Glasses

Safety frames should only be used with safety lenses. Some safety frames are less expensive than regular dress frames. However, *regular lenses must not be put into a safety frame,* even to save the wearer money. A pair of regular

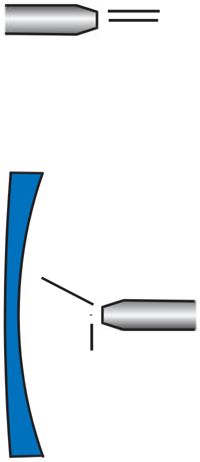


Figure 23-6. Side shields provide protection from flying frag- ments coming from a different work area and from the imme- diate area when the wearer turns his or her head.

Figure 23-7. When air strikes front and back surfaces of a lens that has been heated just below the softening point, it “freezes” the outside, setting up a controlled internal stress that makes the lens more impact resistant.

“dress” lenses placed in a safety frame may give the wearer the impression that they are wearing safety glasses. A safety frame with dress-thickness lenses is no more safety eyewear than a dress frame with safety lenses. Eyeglasses are not safety glasses until both the frame and lenses are in compliance.

Lenses that are made thicker for added safety should not be placed in a pair of regular frames. If safety is important enough to warrant thick lenses, it is important enough to warrant safety or sports-type frames. “Safety” lenses in regular frames can give the wearer a false sense of security and the mistaken impression that this is a “safe” prescription. *Under no circumstances should a pair of lenses be marked as safety and placed in a nonsafety frame*.

Side Shields

Now that eye protection is required and used in many settings, eye injuries that happen to people wearing safety glasses often occur from the side. There is special attention called to this in the preface to the ANSI Z87.1 2003 safety eyewear standards with the statement, “This standard recognizes the Bureau of Labor Statistics study that revealed the need for angular protection, in addition to frontal protection, in eye and face protectors worn in the occupational setting.

Side shields may be removable or permanent (Figure 23-6). Most people would rather not wear side shields if given the choice. If side shields are constantly required, then permanent side shields are logical. Removable side shields have the advantage of being able to be taken off when working in a nonhazardous situation. The drawback is that removable side shields often end up not being worn. Side shields are not universally interchangeable. A removable side shield designed for one particular type of frame cannot be expected to provide the ANSI-standard-approved protection required if used on a different type of frame.

Hardening of Glass Lenses

Glass lenses are not impact resistant enough to pass the FDA-mandated impact test unless they are hardened. There are currently two methods of hardening glass

lenses. One uses a heat-treating process and the second a chemical-tempering process. Not all types of glass are capable of being tempered. Glass lenses that are not capable of being hardened may only be used in the United States if no other type of lens material is accept- able for the visual needs of the wearer.

Scratched lenses are more likely to break than unscratched lenses, regardless of the method used to harden a lens. Scratches introduce weak points on the lens. A scratched heat-tempered lens looses more of its impact resistance than a scratched chemically tempered (or *chemtempered*) lens. For maximal safety, scratched lenses should be replaced.

Heat-Treating Process

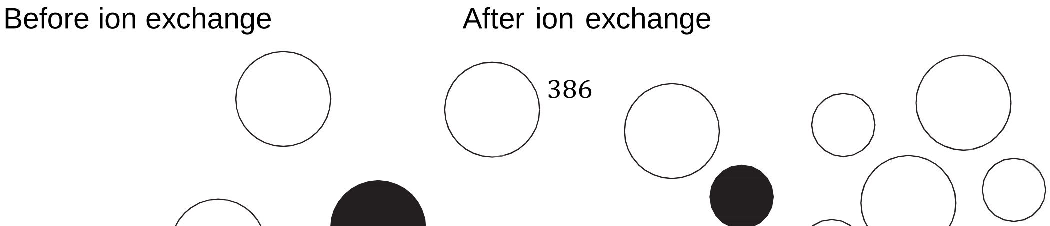
Heat treating is done by placing the edged glass lens into a small kiln where the temperature is high enough to almost bring the glass to the softening point. The lens is left in the kiln for about 2 or 3 minutes. The exact amount of time depends upon:

1. Lens thickness.
2. Type of glass.
3. Lens tint.

To help determine a still more accurate length of time a lens is left in the kiln, lens weight may also be considered.

The lens is removed from the heat and cooled rapidly by blowing forced air against both front and back sur- faces (Figure 23-7).

To understand how this process could cause an increase in impact resistance, remember that as glass heats, it expands and becomes more like a liquid. When the hot lens is struck by cool air against its outer sur- faces, the outer surfaces "freeze." The inner part of the lens cools more slowly. As it is cooling, it is trying to contract. But the outer part of the lens is already "frozen" and refuses to shrink further. This creates an inner pull on the lens, inducing stress. Part of the stress is surface compaction or squeezing called *maximum compressive stress*. Another part of the stress is called *maximum tensile stress*. This stress creates strength in the same way that



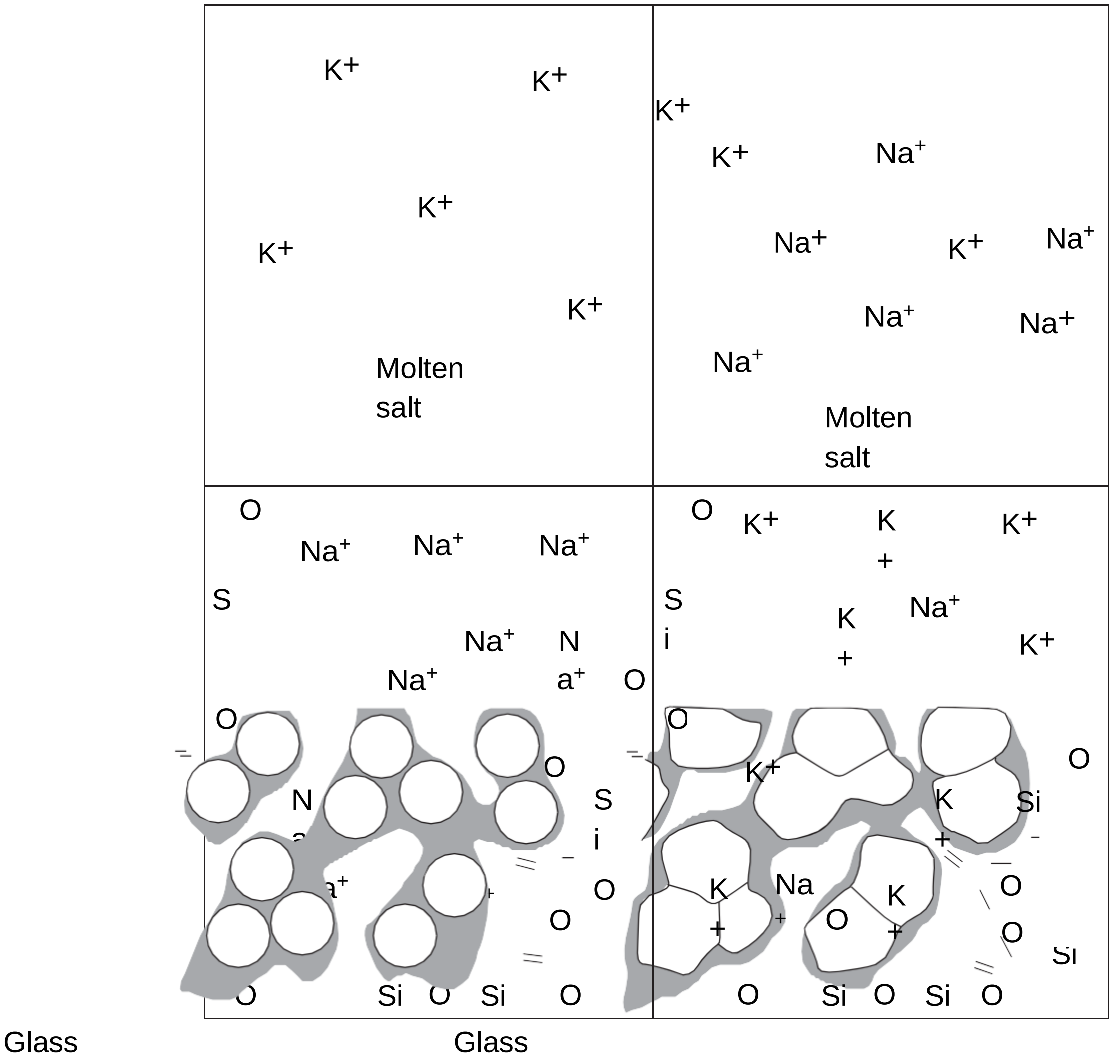


Figure 23-8. In chemtempering, smaller sodium (Na) or lithium (Li) ions from the glass are replaced by larger potassium (K) ions from the molten salt.

the tightened spokes on a bicycle wheel add strength to the rim. These forces result in a compression of the lens surface. The depth from the outside surface of the lens where compressive stress and tensile stress meet is called the *depth of compression*.

The advantage to heat treating is that it is fast. The disadvantage is that the heat-tempered lens is not as impact resistant as a lens that is chemically tempered.

Chemical Tempering

Glass lenses are chemically hardened by immersing them in molten salt. The salt used for clear crown glass and tinted crown glass lenses is potassium nitrate (KNO_3). During the process of chemical tempering, smaller sodium (Na) or lithium (Li) ions from the glass are drawn out of the lens surface and replaced by larger potassium (K) ions from the salt (Figure 23-8). This crowds the surface, setting up a surface tension that "squeezes" the lens. This surface tension increases impact resistance by creating compressive stresses. The actual amount of compressive stress is 28 to 50 kg/mm^2, com- pared with 6 to 14 kg/mm^2 for heat-tempered glass.[15]

The salt used to temper a photochromic lens is different from the salt used for crown glass lenses. Salt used for photochromic lenses is a mixture of 40% sodium nitrate ($NaNO_3$) and 60% potassium nitrate (KNO_3). Both of these salts are hazardous in dry or molten states.

If the proportion between salts is incorrect or if the salt is contaminated or has been used too long, the lenses will have problems. Lenses may break in the bath, come out hazy, or show hairline cracks. Processing a crown glass lens in a salt bath intended for photochromic lenses will cause the lens to craze, showing a meshwork of hairline surface cracks (Figure 23-9).

Salt needs to be replaced on a regular basis. As salt pH rises above neutral, some salt should be removed and replaced with new salt to lower the pH. When sediment builds up in the bottom of the tank, all of the salt should be replaced.

To chemically temper crown and tinted glass lenses together, the temperature of the salt is 450° C 0 5° C (842° F 0 9° F). To temper photochromic glass lenses, the salt is heated to 400° C 0 5° C (752° F 09° F).

If the temperature of the bath is not exact, there will be problems with photochromic lenses being off-color, splotching, or not lightening or darkening properly.

The Chemical Tempering Process. Lenses are cleaned and placed in a lens holder. That holder is held above the bath to allow the lenses to preheat, preventing breakage caused by extreme temperature changes. The lenses are then immersed in the molten salt bath for 16 hours.* (By using a special process it is possible to Salts are available in both commercial and reagent grades. Reagent grade is more expensive, but being purer, does not require conditioning and prevents salt-related problems.

*It is possible to leave the lenses over the weekend for 64 hours. Impact resistance drops slightly, but the amount of drop is normally insignificant.

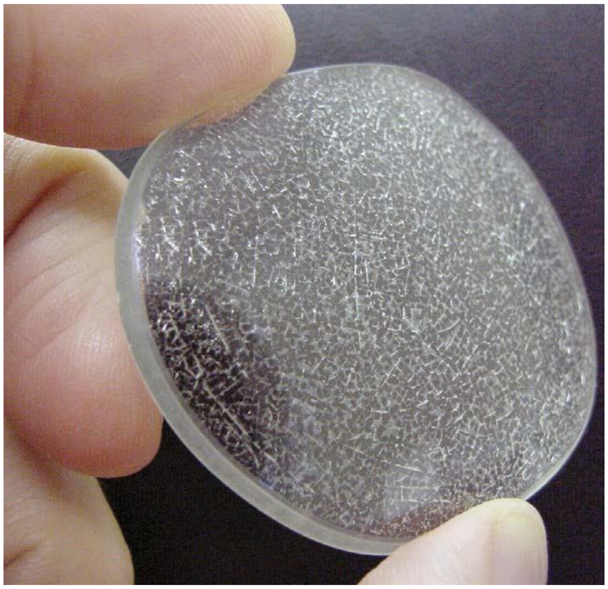


Figure 23-9. A crown glass lens mistakenly placed in a photochromic salt bath will craze.

chemically harden standard photochromic lenses in 2 hours.*) At the end of the cycle, the lenses are again held above the bath. The postbath cool times are the same as the preheat times. Lenses are then removed from the unit, allowed to cool at room temperature, then rinsed in hot water to remove the salt.

Chemically hardened crown glass lenses are more impact resistant than thermally hardened crown glass lenses and maintain their strength better, even when scratched. They will not warp during the chemical tempering process, as do some lenses during the heat-tempering process. Because their internal tensile stress is less than that of a heat-tempered lens, chemtempered lenses may be re-edged or resurfaced without breaking. If a pair of chemically tempered glass lenses has been removed from a broken frame and reshaped for a new frame, the lenses should be rehardened. (Heat-tempered lenses should never be re-edged on an edger or hand edger unless they have been dehardened† first.)

Compared with heat tempering, chemical tempering of crown glass lenses is clearly the method of choice.

Effect of Re-edging of Glass Lenses on Impact Resistance

Edging a plastic lens does not significantly affect impact resistance. However, edging or re-edging a glass lens that has already been hardened will affect impact resistance. May a hardened glass lens be re-edged and then worn? Here is the FDA’s response to the question.

Q. May a glass lens, after it has been chemically or thermally treated for impact resistance, be processed further in any way?

A. Lenses that are treated for impact resistance by induced surface compression may be re-edged or modified for power. However, the beneficial effects of surface compression may be substantially reduced. Such lenses must be retreated and tested before they are dispensed to the patient.[6]

Effect of Drilling and Grooving on Glass Lens Impact Resistance

Drilled glass lenses that are heat treated are not safe to wear. They may pass the drop ball test in their unmounted state, but the compounded stress brought about by the mounting causes the mounted lenses to fail too easily.

Drilled lenses that are chemically tempered will pass the drop ball test and are not as affected by drill mounting as are heat-treated lenses. Nevertheless, glass lenses are seldom used in a drill mounting, even when chemically tempered.

In fact glass lenses are seldom used with grooved lenses either. In 1993 Optical Laboratories Association Technical Director George Chase addressed the glass lens grooving and drilling issue in an OLA Tech Topics paper. He indicated that even though drilled and grooved

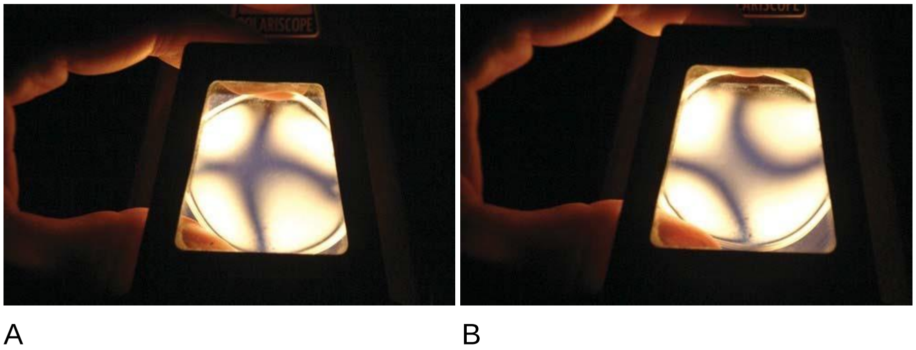


Figure 23-10. A and **B,** A heat-treated lens may be identified by the characteristic Maltese- cross pattern seen when the lens is viewed through the crossed polarizing filter of a colma- scope. The symmetry of the Maltese-cross pattern is not the important factor. As a lens is rotated, the pattern seen will vary, as seen in the above two photos of the same lens seen in two different angles of rotation between the polarizing films.

TABLE **23-5**
ASTM Standards Applicable to Ophthalmic Dispensing

Standard Identification	Year of	Sports Covered by the Standard

Number	Revision	
ASTM F513	2000	Standard specification for eye and face protective equipment for hockey players
ASTM F659	1998	Standard specification for skier goggles and face shields
ASTM F803	2003	Standard specification for eye protectors for selected sports These sports are listed as racquet sports (such as racquetball, badminton, and tennis), women's lacrosse, field hockey, basketball, baseball, and soccer
ASTM F910	2004	Standard specification for face guards for youth baseball
ASTM F1587	1999, reapproved 2005	Standard specification for head and face protective equipment for ice hockey goaltenders
ASTM F1776	2001	Standard specification for eye protective devices for paintball sports

glass lenses would normally pass the drop ball test, the unprotected, exposed lens edges were likely to chip or microcrack with normal use, reducing impact strength. If drilled or grooved glass lenses are to be made, the OLA encourages optical laboratories to first obtain a waiver from the person ordering the lenses.[18] If the laboratory wants a waiver from the dispenser, it is a clear indication that the dispenser should not be using glass lenses for a drill mount or groove mounted frame.

EYE PROTECTION FOR SPORTS

The appropriate selection of eyewear for sports is increasingly important. Correct eyewear selection may improve performance in the sport and at the same time protect the wearer. At the present time, there are only certain standards specifically designed for sports eye protection.

An increase in litigation following eye injuries has served to raise the consciousness of eye care practitioners who are now more aware of the need for providing appropriate information on eye protection customized to patient needs.

American Society for Testing and Materials

As the name implies, the American Society for Testing and Materials (ASTM) develops standards for testing and for materials. There are several ASTM standards that apply to ophthalmic dispensing. These are shown in Table 23-5.

These standards describe tests that must be used to evaluate the ability of the eyewear to withstand and protect from the impact of common equipment used in the chosen sport. Examples would be balls and rackets. The standard most often encountered in an eye care practice is the F803 standard. This is called *F803 standard specification for eye protectors for selected sports*. It is especially applicable since

it applies to many of the most popular
sports, such as baseball, basketball, soccer, and tennis.

ASTM Product Marking

ASTM sports eyewear product marking includes (1) marking on the eyewear, (2) a label or tag, and (3) specific warnings about product use.

Marking on the Eyewear. ASTM standards include required product marking. For example,[19] all ASTM F803-approved eyewear must be marked with:

1. The manufacturer's identity marking.
2. The eye protector model identity.

Label or Tag. In addition, it should include a label or tag with the following information:

1. Week and year of manufacture
2. The protector size and also guidance concerning the age and gender of the wearer that the protector has been designed for
3. A clear statement on the package as to the sport or sports for which the protector was designed **Specific Warnings to Accompany ASTM-Approved**

Eyewear. There should be specific warnings listed. (These warnings are important for dispensers to know because they are generally applicable for safety and sport eyewear). Warnings include, but are not limited to, the following:

1. Lenses should be replaced when scratches become troublesome or if cracks appear at the edges.
2. If the eye protector is severely impacted, short of failure, then the degree of protection provided will be reduced, and the eye protector must be replaced. Failure to do so may result in permanent injuries to the eye.
3. If a lens pops out because of impact during play, the wearer should stop playing and have the protector replaced.
4. If the eye protector is stored at cold temperatures, it should be allowed to return to room temperature before use.
5. Instruction as to the cleaning and antifog agents that may be used should also be included.

There is not just one type of protector that is intended for F803 protection. F803 protection can be in 4 different types. These are listed in Box 23-2.

Other Cautions With Sports Eyewear. Frames that are designed to be worn with lenses should not be worn without lenses even if designed for safety or sport. Small, fast moving balls may elongate and penetrate the empty lens opening, even if the opening is smaller than the ball.

When even a large ball, such as a soccer ball, strikes the eye, the blunt trauma can produce a shock wave impact that causes the eyeball to distort then rebound with a large amount of force resulting in severe damage. So even though a large ball would not seem like it would

BOX 23-2

Four Types of F803 Sport Protectors

Type I	The front piece is molded as one unit—lens or lenses and front together
Type II	A unit with lens(es) separate from the frame front and then assembled; the lenses are either plano or prescription lenses
Type III	A protector without a lens
Type IV	A full or partial face shield

be able to damage an eye surrounded by the bony structure of the skull, it still can. Sports eyewear protection is still important.

If spectacle lenses are worn under protective eyewear, then polycarbonate lenses should be worn in the spectacles.

Custom Eyewear Needs for Individual Sports Each sport has certain unique visual demands. Some demands may be met by simply providing appropriate sunglasses. Others may require a specialized prescription that includes a uniquely positioned multifocal segment. A number of sports and their hazards and problems are listed in Table 23-6, along with recommended solutions. Yet as with occupational needs, there is not always a single "cookbook answer" for every individual's sports vision needs. Each situation should be discussed and any corrective or protective eyewear designed to meet the needs of that particular individual. However, there are certain common themes that recur in sports eyewear.

Themes in Sports Eyewear

Sports eyewear can be confusing because of the large number of sports and sports situations possible. Here are some general statements about sports eyewear that help in getting an overall picture:

- Virtually all sports demand highly impact-resistant lenses made from such materials as polycarbonate.
- Helmets are required when there is danger of head injury.
- Outdoor sports call for UV protection, and when intense sunlight is a factor, sun lenses are appropriate.
- Most sports using round balls call for ASTM F803-approved protectors. These include baseball, basketball, soccer, and any racquet sports, such as tennis or badminton.
- Underwater sports for those dependent upon their prescription need special in-mask or in-goggle prescription adaptations.
- Billiards and pistol shooting may require prescription changes.
- Golf, flying, and shooting may require relocation of multifocal segments and/or optical centers.
- Bicycling and billiards may require changes in the positioning of the frame

front.

PROVIDING BEST CHOICES AND PREVENTING LIABILITY

The Dispenser's Obligation in Helping Choosethe Most Appropriate Product

The process of dispensing eyewear is one that involves helping the wearer choose the best product for a particular need. This may include absorptive lenses, high-index and aspheric lenses, specialized multifocal lenses, eyewear for certain sports or hobbies, or protective eyewear. Thus it becomes the responsibility of the dispenser to provide each individual with sufficient information

so that an informed decision may be made. The dispenser has a "duty to inform" about the availability of eyewear alternatives that provide optimal eye safety in the particular wearing conditions applicable for that individual.

When lawsuits involving eyewear occur, the case is usually made on the basis of either product liability or negligence.

Product Liability

Product liability means that the product was not up to accepted standards. What those standards are depends on the type of eyewear.

- For dress eyewear, determine if the drop ball test was administered when appropriate.
- For safety eyewear, the critical factor is determining if Z87 standards were met—particularly thickness standards.
- For sports eyewear, the critical factor is faulty design or failure to meet impact resistance expectations. If ASTM standards are appropriate, was this type of eyewear chosen so that those standards were met?

Negligence

To prove negligence, it must be shown that, "the defendant practitioner did not conform to the standard of care.

Responsibility to Inspect the Finished Product

When newly fabricated spectacles are returned from the laboratory, it is the dispenser's responsibility to inspect the finished product. If the lens is classified as a safety or sports product, it must comply with all the requirements outlined by ANSI or ASTM standards.

It is to be expected that if an eye injury occurs, all these factors will be checked for the injured by their legal council. If any ANSI or ASTM standards are unmet, it is obvious that either (a) an inspection was never done, or (b) that inspection was done incompetently or inadequately.

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Sample Questions:

1. ***When May Nonimpact-Resistant Lenses Be Dispensed?***

Some dispensers may assume that a written agreement having the patient assume responsibility makes it possible to dispense nonimpact resistant lenses. This does not ensure freedom from liability. Here is the way the FDA responds to three frequently asked questions on dispensing nonimpact-resistant lenses.

2. Under what circumstances may retailers dispense lenses that are not impact resistant?

A. Lenses that are not impact resistant may be dispensed when a physician or optometrist determines that impact-resistant lenses will not fulfill the visual requirements of a particular patient. The physician or optometrist directs this in writing and gives written notification to the patient.

3. Can a retailer supply a nonimpact-resistant lens if a patient requests it or if the patient/customer agrees to assume all responsibility?

A. No. Nonimpact-resistant lenses may be provided only when the physician or optometrist determines that impact-resistant lenses will not fulfill the visual requirements of the patient...... In such cases the physician or optometrist must give notice in writing to the patient, explaining that the patient is receiving a lens that is not impact resistant.

4. May a physician or optometrist prescribe nonimpact-resistant lenses for a

patient for purely cosmetic reasons?

A. No. If medical problems are related to cosmetic considerations, however, the physician or optometrist may invoke special exemption provision of the regulation based on professional judgment. For example, if the patient's prescription cannot be filled by impact-resistant lenses because the physician or optometrist knows from previous experience that the weight of the heavy lenses may cause headaches, undue pressure on the bridge of the nose or ears, pressure sores, etc., the physician or optometrist may find that the visual requirements of the patient cannot be met by use of impact-resistant lenses.

For lenses to qualify for impact resistance, they must meet certain qualifications.

Unit 14:

How Lenses Are Edged

Learning Objective:

An optical laboratory may consist of two separate areas. One area creates the needed lens power. This is usually done by a process called *lens surfacing,* and the facility that does it is referred to as a *surfacing laboratory*.

The second area takes the correctly powered lens and finishes it. This is done by optically positioning the lens and grinding the edges so that the lens fits the shape of the chosen frame. The area where this occurs is known as the *finishing laboratory*. A finishing laboratory is also referred to as an *edging laboratory* because it is here that lenses are "edged" to the proper shape to fit the spectacle frame.

At the end of this chapter, students will be able to learn:

1. Defining and marking centration of lenses.
2. Edging of lenses.

SPOTTING OF SINGLE VISION LENSES WITHOUT PRISM

First, a lens is made ready for edging so that the refractive power and optical centration will be correct. For edging we should always be starting with a lens of a known power.

Power Verification and Spotting of Spheres When the power of the lens to be verified is of known power, set the lensmeter for the expected sphere value. If the lens is a sphere, the target should be immediately clear, indicating a lens of the correct power.

Optically center the lens in the lensmeter by moving the lens until the center of the illuminated target crosses the center of the crosshairs in the lensmeter eyepiece or screen (Figure 24-1.) The marking device is then swung into position, and the front surface of the lens spotted.

Power Verification and Spotting ofSpherocylinders

When verifying spherocylinder lenses, the lensmeter power wheel is turned to the expected sphere power. The cylinder axis wheel is also turned to the axis of the prescription. The lens holding device is not allowed to touch the lens, and the lens is rotated until the sphere lines of the lensmeter target are sharp and unbroken. When these lines are clear, the cylinder axis is correct. With the lens correctly rotated for axis position, turn the lensmeter power wheel in the appropriate direction for checking the cylinder power.

Next carefully move the lens left, right, upward, or downward until the target is accurately centered. (Remember to pull the lens holding device away from the lens surface so that the lens will not get scratched.) When the target is accurately centered, the lens may be spotted (Figure 24-2).

The power verification in a spotting procedure for spherocylinder lenses is summarized in Box 24-1.

Marking the Lens for Right or Left

As soon as the lens is spotted, it should be removed from the lensmeter and marked for the right or left eye. Lenses are marked on the front surface with a wax pencil. The letter *R* or *L* in uppercase letters is written in the upper half of the lens above the three spots (see Figure 24-2).

SPOTTING OF SINGLE VISION LENSES WITH PRISM

The Optical Center of a Lens

When there is no prescribed prism in the prescription, the needed point of reference is the optical center (OC). The OC becomes the reference point. It is of major importance in aligning the lens. Therefore it is known as the *major reference point* or *MRP*. So *when there is no prism in the prescription, the OC* ***is*** *the MRP*.

When the Optical Center Is Not in theLine of Sight

Sometimes a prescription includes prescribed prism. The lens must be positioned so that the amount of prism called for will be in front of the wearer's pupil in the eye's line of sight. When prism is called for in the pre- scription, the point on the lens with the correct amount of prism becomes the point of reference. *When the pre- scription contains prescribed prism, the OC and MRP are two separate points*.

BOX 24-1

How to Spot Single Vision Sphere or Spherocylinder Lenses Using a Standard Crossed-Line-Target Lensmeter

1. Dial in the lens sphere power and lens cylinder axis into the lensmeter.
2. Place the lens in the lensmeter.
3. Locate the MRP.
4. If the lens is spherical, spot the lens.
5. If the lens has a cylinder, rotate the lens until the sphere lines are clear.
6. If the lens has Rx prism, move the illuminated target until it is located at the position where the prism equals that called for in the prescription.
7. Spot the lens.

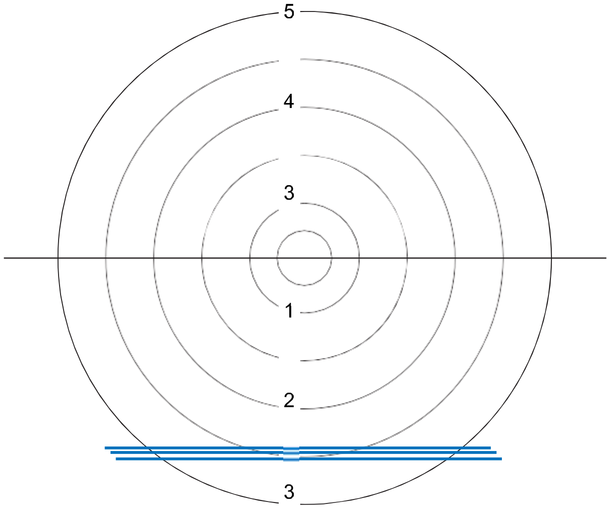


Figure 24-1. When both sphere and cylinder lines focus at the same time, the lens has a uniform power in all meridians and is spoken of as being spherical.

If the sphere and cylinder lines do not intersect at the center of the mires, the lens OC is not centered in front of the lens- meter aperture, and prism is being manifested.

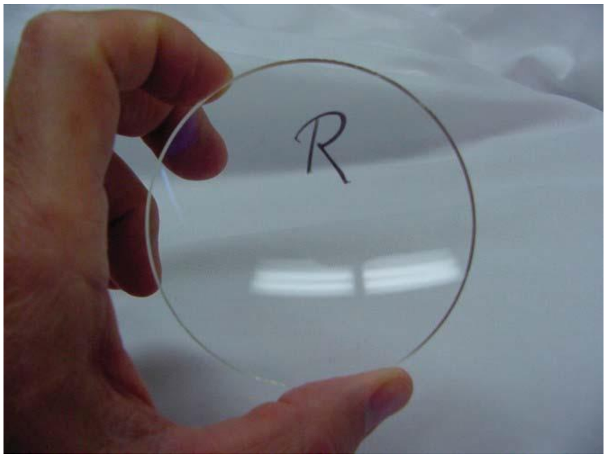


Figure 24-2. The lens designation (R or L) is always marked on the upper half of the lens so that the lens will not be blocked upside down. Though not as critical for nonprismatic finished single vision lenses, an inverted prism or an upside down multifocal would be worse than useless. (The lens is being viewed from the back side.)

There is a synonym for the MRP that is perhaps even more descriptive. That synonym is "*prism reference point*" or PRP. MRP and PRP are the same.

The procedure of spotting single vision lenses with prism is nearly identical to that of nonprism lenses. The only difference is in how the illuminated target is cen- tered.

Instead of placing the center of the illuminated target at the center of the crosshairs, the center of the illuminated sphere and cylinder target lines must be positioned to correspond to the location of the desired prismatic effect.

When Prescribed Prism Includes Both Horizontal and Vertical Components

In a case in which both horizontal and vertical prisms are called for simultaneously in the same lens, the target must be moved both laterally and vertically until it reaches the desired position. That position is one where the target center is directly above (or below) the required horizontal prism reading. It is also exactly left or right of the required vertical prism reading.

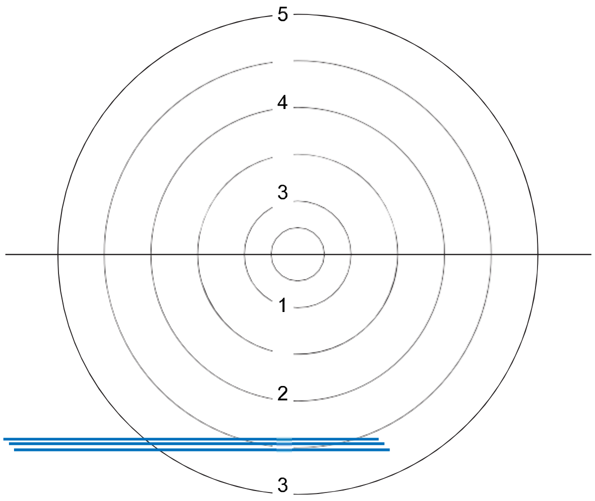
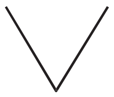


Figure 24-3. Prismatic effect can be created by decentering the lens in the lensmeter until the sphere and/or cylinder line intersection is posi- tioned for the indicated amount. (Achievement of desired prism by decentration is limited by lens size and refractive power.)

Location of Nose or Frame bridge



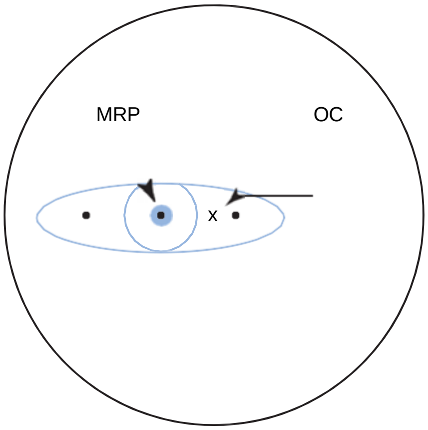


Figure 24-4. The MRP of a lens will ultimately be positioned before the wearer's pupil center. If prism is indicated in the prescription, the OC is displaced purposely. Therefore the point that will be important in centration and is consequently spotted is the MRPDnot the OC.

SPOTTING OF FLAT TOP MULTIFOCALS

For multifocals the bifocal should be placed in the lens- meter like it will be when mounted in the frame. This means that for flat-top bifocals, the segment top should be horizontal. The sphere power is dialed into the lens- meter. If the lens has a cylinder component, the axis of the cylinder should be dialed in as well.

Next the MRP of the lens is located. When the lens is spherical, the lens may be spotted.

For multifocals with spherocylinder powers, the axis of the cylinder has been custom ground for that particular lens. The lensmeter is set for the axis ordered, and the lens rotated to the correct axis. With MRP and cylinder axis correct, the lens is spotted, just like a single vision lens. After the lens has been spotted, the three dots on the 180-degree line should be parallel to the upper edge of a flat-top segment (Figure 24-6, *A*). If they are not parallel to the top of the bifocal segment, the cylinder axis is off, and the lens was surfaced improperly.

To precheck the lenses as a pair, hold the lenses front to front with the segments overlapping (Figure 24-6, *C*). If there are not two different MRP heights or two different seg insets, the center spots of both lenses should be at the same place. If they are not, there is likely to be a problem with unwanted horizontal or vertical prism after the lenses are edged.

For a summary of spotting flat-top multifocals, see Box 24-2.

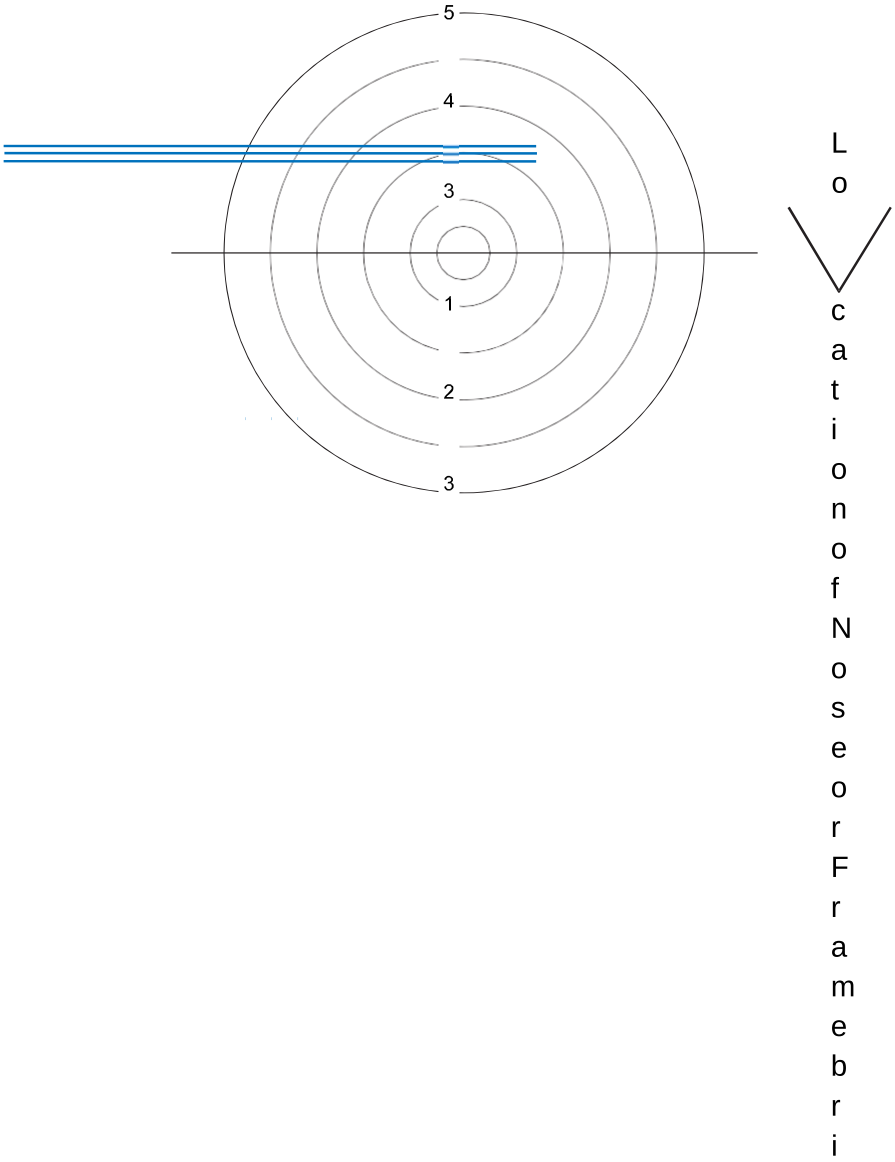
SPOTTING PROGRESSIVE

ADDITION LENSES

Progressive addition lenses have certain “hidden” markings used in establishing lens orientation. Lenses coming from the surfacing laboratory are also marked with non-water-soluble ink. If the visible inked marks are correctly applied, there is no need to spot the lenses. However, they should be verified before edging.

Verifying Premarked Progressives

To check distance lens power, position the lens in the lensmeter to view through the circled area above the PRP.



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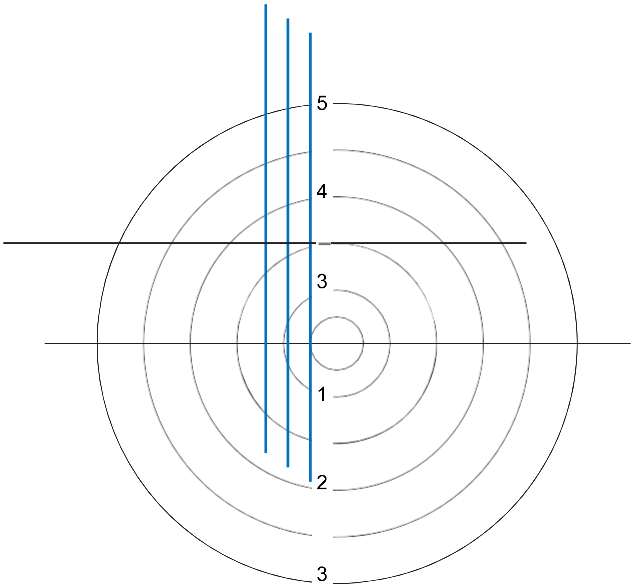

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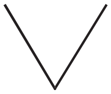

cation of Nose or Frame b

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Figure 24-5. In positioning a prismatic lens, the only important reference is the center of the illuminated target. This is the place where the center sphere and cylinder lines cross each other. Where other parts of those lines may cross the circular mires is of no importance.

In the example shown, the sphere and cylinder line crossing point must be directly above or below the place where the 4.0D circle crosses the horizontal line farthest from the “nose.” The sphere and cylinder line crossing point must simultaneously also be exactly at the same level as the top of the 2.0D circle. **A,** This is easy to see because the sphere and cylinder lines are aligned horizontally and vertically. However, if there is cylinder present at any axis other than 90 or 180, the lines will not look like this. Instead they may appear as shown in **(B).** The prismatic effect shown in **(B)** is exactly the same as in **(A).** Both are 4 base out and 2 base up.

It may be difficult to tell the exact position of the center of the illuminated target for a spherocylinder lens with an oblique axis. If you have difficulty, try this procedure. Temporarily turn the cylinder axis to 90 or 180 degrees. This will cause the illuminated target lines to be exactly horizontal and vertical. Now although the lines will be a bit blurred, they will duplicate the situation shown in **A** and make it easier to tell how much vertical and horizontal prism is present.

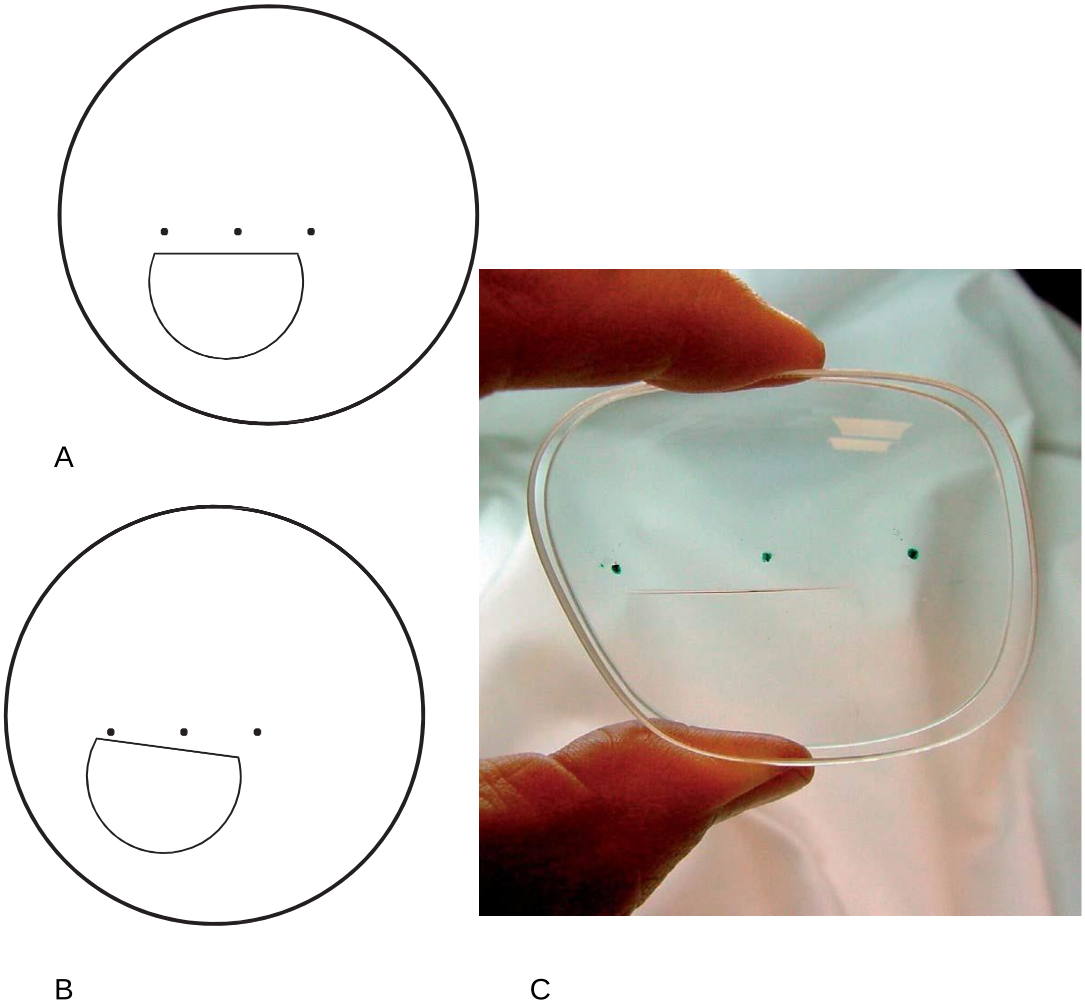


Figure 24-6. A, For spherocylinder lenses, the three dots should be parallel to the top of the segment. If they are not, the cylinder axis will be wrong. **B,** For spherical lenses, an angle between the three dots and the segment top is not a problem, even through it looks off. However, if the lens has a cylinder component, the axis of the cylinder will be wrong. **C,** Once flat-top bifocals have been spotted, they may be prechecked before edging. Hold the edged lenses front to front. They are held front to front because the segments and spots are closer to one another and will reduce the amount of parallax seen. Do not press the lenses into contact with one another to prevent scratching. Make sure the segments exactly overlap each other. With

both lenses having equal seg insets and drops, the spots should also overlap as shown. If they do not overlap, there may be a problem with PDs being off or unwanted vertical prism.

. (The PRP usually comes marked with a dot.) This circled area used to locate the point for verifying distance power is called the *distance reference point* or *DRP* (Figure 24-7). Incidentally, remember that there will almost always be some prism at the DRP since the DRP of the lens is not the OC of the lens.

To check distance power, set the power wheel to the sphere power and the cylinder axis wheel to the ordered cylinder axis. Rotate the lens until the target lines are clear and unbroken. The non–water-soluble horizontal reference marks on the lens should be horizontally oriented and not tilted. If they are tilted, the axis of the cylinder is incorrect.

To check for prism, the lens is centered in the lens- meter at the PRP. (Remember, the PRP is the same as the *MRP*.)

Progressive lenses often come with equal amounts of vertical prism in both right and left lenses. This allows the lenses to be made thinner. Equal amounts of “yoked” vertical prism for “prism thinning” purposes are both allowable and usually expected. Both right and left lenses may read 1.5D base down at the PRP and are considered free of unwanted vertical prism.

As stated earlier, if the lenses are correct and have non–water-soluble progressive lens markings, there is no need to spot the lens. The existing markings will be used in the blocking process. If the lenses do not come with markings, or if it appears that the markings were inaccurately applied, then the markings must be reapplied.

When Progressive Lenses Are Not Premarked

In the event that a progressive addition lens has no visible markings, reconstruct the manufacturer’s recommended system of identifying marks. This procedure was explained in Chapter 20.

PATTERNS

Pattern Measurements and Terminology

To allow the edger to shape the lens to fit the frame, a pattern is needed. That pattern can be a physical pattern

BOX 24-2

Spotting Flat-Top Multifocals

1. Dial the lens sphere power and lens cylinder axis into the lensmeter.
2. Place the lens in the lensmeter.
3. Locate the MRP.
4. If the lens is spherical, spot the lens.
5. If the lens has a cylinder, rotate the lens until the sphere lines are clear.
6. If the lens has Rx prism, move the illuminated target until it is located at the position where the prism equals that called for in the prescription.
7. Spot the lens.
8. For spherocylinder lenses and lenses with Rx prism, verify that the segment top and three lensmeter dots are parallel to one another.
9. When both lenses have been spotted, line up the lenses front to front to check for R-L spotting accuracy. The central spots should overlap.

made of plastic or an electronic pattern in the memory of a computer. Here are some specifics on pattern measurement and terminology.

The *mechanical center* of a pattern is the point on the pattern around which the pattern rotates. The mechanical center is easy to find since it is found in the middle of the large hole in the pattern (Figure 24-8).

Centration and Decentration

The process of moving a lens so that it will be in front of the eye is called *centration*. To center the lens in front of the eye, the lens must be moved *away* from a given reference point. When a lens is moved away from a given point, it is said to be *decentered* from that point. In this case the lens is moved away from or *decentered* from the location of the mechanical and boxing centers.

Pattern Making

Because of the vast number of available frame styles, it is impossible to have a complete library of patterns so that the correct pattern is available for every frame presented for lens fabrication. Ordering a pattern for every single frame that passes through the laboratory is totally impractical. The delays caused would not be acceptable to the wearer, not to mention the volume of paperwork that would be generated. For this reason, when running an edger that uses patterns, a system for making patterns is a necessity.

How the Pattern Is Placed on the Edger

By convention most people begin the edging process with the right eye. When the pattern is snapped into place on the edger, it will fit on the edger with either the front or the back of the pattern going on first. Going on one way will edge a right lens shape, whereas the other way will produce a left lens shape.

Progressive lens fitting and verification points

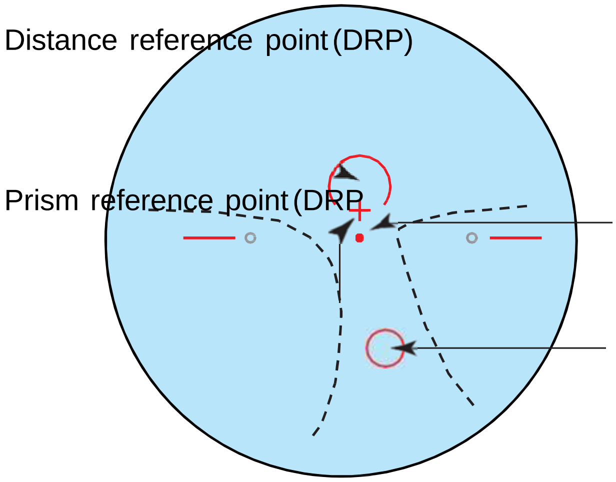


Figure 24-7. Points of reference on a progressive addition lens.

17 logo

Fitting cross

Near reference point (NRP)

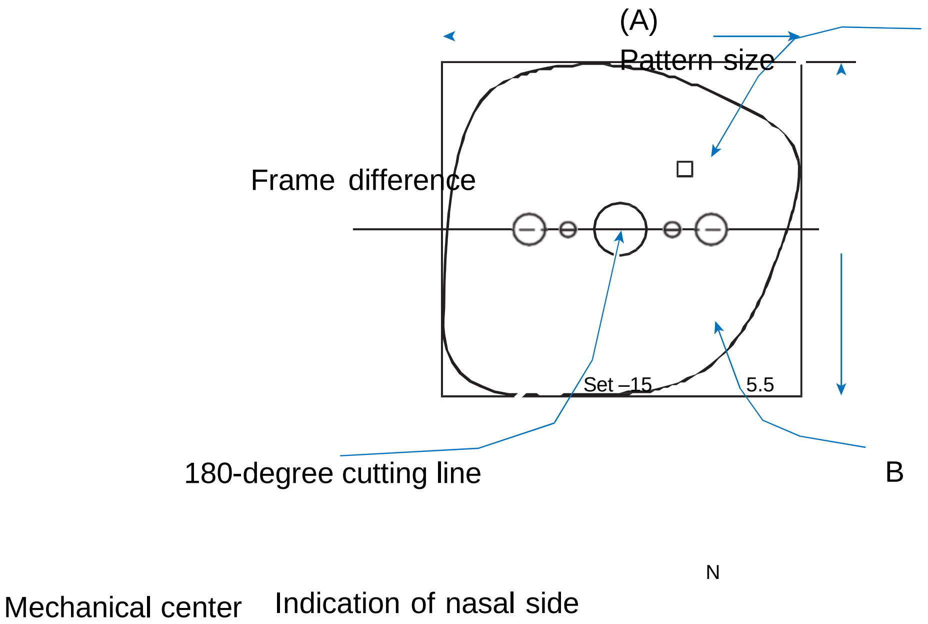


Figure 24-8. The same system of measurement that is used for frames and lenses is also used for patterns. Patterns do not come with A and B dimensions marked. But they do have a pattern set number to help in finding the correct edger setting. The “frame difference” helps in positioning MRP and multifocal heights when the laboratory does not have the frame.


Triumph
Triumph

Figure 24-9. Here a tracer is next to the edger. It is electronically linked to the edger and has a screen to allow the traced shape to be viewed before edging.

USING A FRAME TRACER FOR PATTERNLESS SYSTEMS OF EDGING

Patternless edgers that do not use a physical pattern still need a shape to go by. This shape is given to the edger in digital form. Still to get a digital version of the shape, that shape must sooner or later be physically traced and transferred to the edger digitally.

A pattern shape is generated by using a frame tracer. A *frame tracer* is an apparatus that traces the shape of the frame's lens area and converts it into digital form.

A Frame Tracer Can Be Used in a Variety of Locations

A Tracer Can Be Situated Right Next to the Edger When a tracer is situated right next to the edger, the person doing the edging has the frame in front of them (Figure 24-9). The advantage to this setup is ease in visualizing what bevel placement will look best.

A Tracer Can Be a Part of the Edger

A tracer that is part of the edger has the advantage of requiring less working space (Figure 24-10).

A Tracer May Be Placed in the Order Entry Area of a Laboratory

When the tracer is placed in the order entry area of the laboratory, information is only entered once. The laboratory that has a tracer at "order entry" will be wired with a central laboratory computer.

A Tracer May Be Placed in a Remote-Site Dispensary One of the biggest headaches for dispensers is the situation where a wearer wants to keep his or her old frame,

Figure 24-10. A frame tracer can be integrated into the edger and save space in the laboratory.

but cannot or will not give it up long enough to send it to the laboratory. If there is a frame tracer on site, the dispenser can remove one or both lenses, trace the shape, reinsert the lens or lenses, and give the spectacles back to the wearer (Figure 24-11).

The information is then sent to the laboratory electronically. It enters the computer system just as if it had been entered in the laboratory order entry area.

When the dispensary uses a frame tracer to send information, the laboratory can get a head start on any Rx before the new frame arrives. In the interest of time, the dispensary may choose to not send the new frame at all and insert the lenses themselves.

Tracers Can Transfer Data to a Surfacing Laboratory

For the surfacing laboratory to grind a lens to the optimum thickness, the laboratory needs accurate data. This is especially true for plus lenses. The size and shape the lens will have when edged is essential for calculating plus lens thickness. The more exact the data, the more precisely the thickness may be controlled. If the lens is traced, those tracing values may be sent to more places than just the edger. Values can be sent to a surfacing program that calculates lens curves and thickness, then controls the lens generator.

CENTRATION OF LENSES

Centration of Single Vision Lenses

During the edging process, the lens rotates around a central point while being ground to a specific shape to fit the frame. This central point of rotation corresponds to a hole in the pattern. This hole should always be in the middle of the pattern used on the edger to generate the shape. This middle point, the *geometric* or *boxing center* of the lens, is defined as being the center of the smallest rectangle that encloses the lens shape using horizontal and vertical lines.

For the MRP of the lens to be centered before the wearer's pupil, the lens must be moved, or *decentered*, away from the boxing center of the lens.

Distance Between Centers

For frames that conform to the boxing system of measurement, the distance between centers (DBC) is equal to the eye size (abbreviated A) plus the *distance between lenses* (DBL).

DBC = A D DBL

Decentration per Lens

Most commonly the wearer's PD will be less than the DBC. This will require that the lenses be decentered inward (nasally) toward the center of the frame. The amount of decentration per lens can be determined by

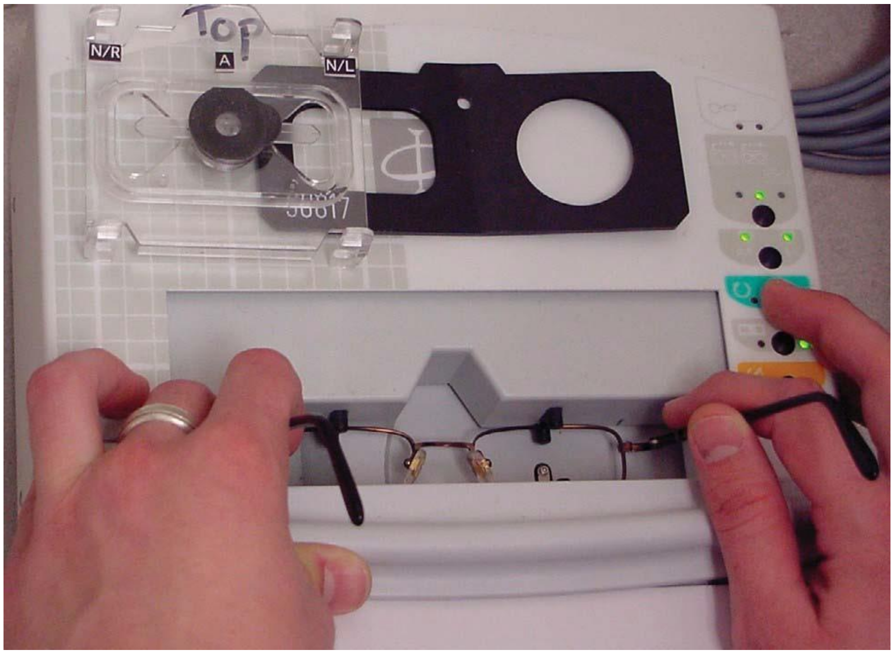


Figure 24-11. A frame tracer may be used at a remote, off-site location. This ensures that the frame dimensions as read at the dispensary are exactly what will be input into the edger.

subtracting the wearer's PD from the DBC (frame PD) and dividing by two.

DBC D wearer PD D decentration per lens.
2

Determining Decentration From Monocular PDs When a prescription specifies the wearer's PD in refer- ence to each eye individually, PDs are taken one eye at a time. This measurement is referred to as the *monocular PD*. For a monocular PD, the reference is basically from the center of the bridge of the nose to the center of the pupil. For example, if we have a more conventionally measured *binocular PD* of 64, we may have a right mon- ocular PD of 31 and a left monocular PD of 33. This difference between left and right PDs is not unusual considering the asymmetry of facial features of many normal individuals.

For a monocular PD, decentration is determined by *first* dividing the distance between centers (DBC) of the frame by 2, *then* subtracting the monocular PD; thus

decentration D DBC D monocular PD2

or

decentration D A D DBL D monocular PD2

Steps in Centration of Single Vision Lenses Here are the steps in using a centration instrument for single vision lenses:

Step 1: Spot the lens (as described earlier).

Step 2: If the instrument has blocking capabilities, stick a double-sided adhesive blocking pad on a lens block and mount the block on the instrument. Then peel the paper off the pad to expose the adhesive.

Step 3: Calculate the amount of horizontal decentration per lens required using the formula

decentration per lens D *A* D *DBL* D *PD*
2

Step 4: Determine if the lens must be decentered to the right or to the left. In most centering devices,

the lens will be face up. If the lens is a right lens and is facing up, decentration “in” is to the right. A left lens facing up would be decentered to the left.

Step 5: Adjust the position of the movable vertical reference line* in the instrument to the right or left by the amount of decentration calculated.

Step 6: Next place the right lens face up (front surface up) on the screen. Align the three spots on the lens with the horizontal line on the instrument screen.

Step 7: Place the center lens dot on the movable vertical reference line. (Remember, the position of this line corresponds to horizontal decentration.)

Step 8: When the MRP height is specified, decenter the lens up (or in rare instances down). The amount of decentration is according to the correct number of millimeters of MRP raise (or drop).

Step 9: Grasp the handle and swing it into place or press the button or foot switch. This will block the lens (Figure 24-13).

*For single vision lenses, the movable vertical line is basically used as a place marker. When laying out single vision lenses, some people prefer not to use the movable vertical line at all. Instead they move the dot on the lens directly to the desired amount of decentration.

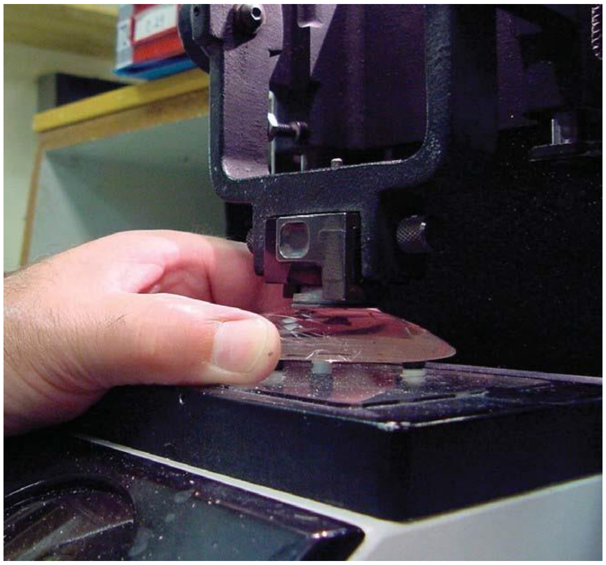


Figure 24-13. The lens is being blocked for edging.

To preset the movable vertical line in the instrument for the left lens, first recall in which direction the MRP should be moved. Because the wearer’s PD is smaller than the frame’s geometric center distance or “frame PD”*Dthe lenses will decenter nasally or inward. The lens is placed convex side up. Therefore the left lens is moved to the left so the movable vertical line is positioned 4 mm to the left of the central reference line.

Now place the lens face up in the instrument. Align it such that the central dot is at the intersection of the horizontal line and the movable vertical line, as shown in Figure 24-14. The other two dots must fall directly on the horizontal reference line.

Block the lens. The location of the center of the lens block will become the boxing center of the edged lens (Figure 24-15).

Centration of Progressive Lenses

The fitting cross is to be positioned exactly in front of the wearer’s pupil and comes visibly marked on the lens. It is the only reference point for both horizontal and vertical lens positioning for the dispenser. It is also the primary reference point for both horizontal and vertical lens positioning for the edging laboratory.

In simplest terms, centration of a progressive addition lens is done as if the lens were a single vision lens. For single vision lenses, the MRP is placed at the correct monocular or binocular PD, depending upon how it is ordered. For a progressive lens, the fitting cross is placed at the correct monocular PD.

For a single vision lens, the MRP is placed on the horizontal midline of the lens, or at the specified MRP height, if one is ordered. For a progressive lens, the fitting cross is placed at the specified fitting cross height.

*“Frame PD” is equal to A D DBL.

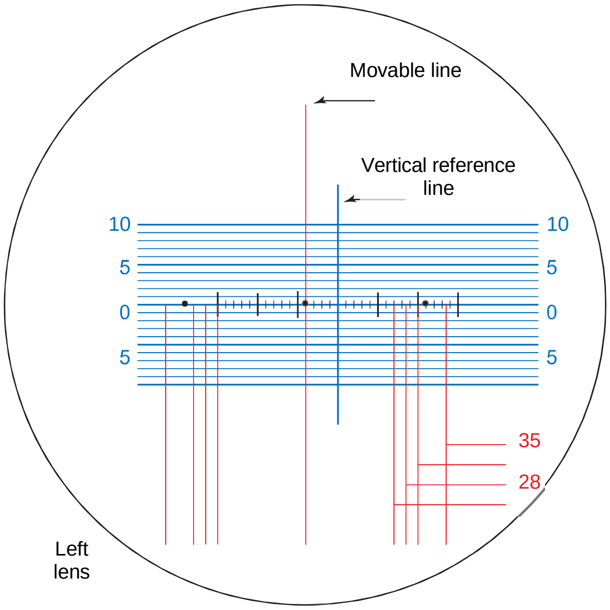


Figure 24-14. The movable line is preset to the correct decentration. The movable line helps to prevent the dot on the lens from getting “lost” on the grid. With the movable line pointing out the desired MRP location, the lens is positioned as shown.

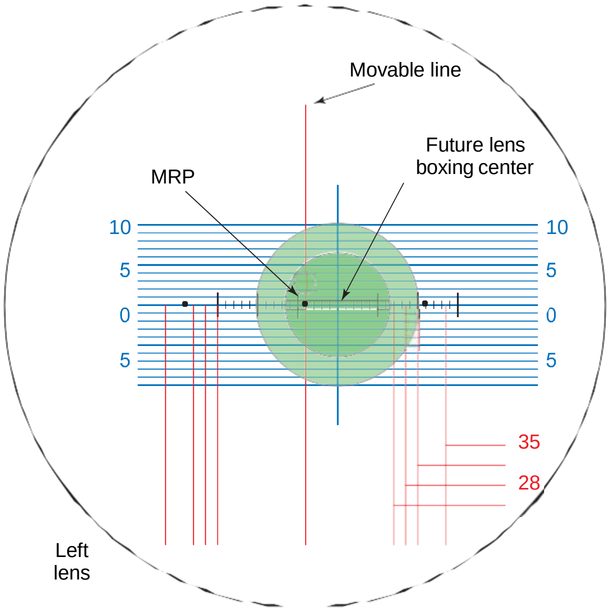


Figure 24-15. On the centration device, the block is always placed at the origin. The block center corresponds to the *future* geometric or boxing center of the *edged* lens.

Centration of Segmented Multifocal Lenses

The near-viewing segment area in conventional multifocal lenses has a clearly demarcated line that borders it. This can be used as a stable, convenient reference when positioning the lens for blocking.

The vertical location of the segment is measured for each wearer. The dispenser gives this vertical location in terms of segment height. This segment height must be converted to segment raise or drop.

The dispenser gives the horizontal location of the segment in terms of the wearer's distance and near PDs. This must be converted to segment inset relative to the boxing center of the edged lens.

The centration of standard flat-top bifocals is done as follows:

1. Verify the lens for power and MRP location. Spot the location of the MRP with the lensmeter.
2. Place the lens block in the instrument.
3. Determine the total seg inset required.

total inset D DA D DBL D near PD

2

4. Determine if the lens must be decentered to the right or to the left. If the lens is convex side up, for a right lens decenter to the right; for a left lens, to the left.
5. Position the movable vertical line in the instrument to the right or left by the amount of decentration calculated.
6. Calculate the amount of seg drop or raise required.

seg drop D seg height D B

2

7. Place the lens face up in the instrument and align the segment between the segment border lines.
8. Move the lens up or down so that the segment top is at the seg drop or raise called for.
9. Grasp the handle of the instrument and swing it into place or press the button or foot switch. This will block the lens.

EDGING THE LENS

Edgers that require a physical pattern to guide the edger are often referred to as *patterned edgers*.

However, the template to produce a lens shape does not have to be something tangible, such as a plastic pattern. It can be a shape that is stored digitally. That electronic version can also guide the lens edger. Because this type of an edger works without a physical pattern, it is referred to as a *patternless edger*.

Edging With Patterns

Setting the Edger Size

If all lens patterns were exactly the same size as the required finished lens, then no size setting would be required. However, this would mean that instead of having one pattern for each frame shape, a separate pattern would be required for every available size.

This raises the question of pattern size. The “standard size” was set at 36.5 mm.

To Prevent Pattern Distortion, the Pattern is Made Larger

When a lens is edged to a shape that is 2 mm larger than the size of the pattern, the edger makes the lens a milli- meter larger in every direction—nasally, temporally, upward, and downward. But in adding an equal amount of lens size to the original shape in every direction, the integrity of the original shape starts to be lost. To keep the shape from being distorted, the only feasible solution was to produce a pattern for larger style frames that was closer in size to the actual lens size being edged.

If the pattern is made larger than the standard 36.5- mm size, the lens will be too large. Without compensation, the lens will be edged larger than the frame eye size.

Set Numbers

To make it easier to know how to compensate for a pattern that is larger than the 36.5-mm standard pattern size, frame manufacturers put a compensation number on the pattern. This compensating number is called the *set number*. Because patterns are almost always larger than the standard, this difference must be subtracted from the eye size. For this reason, set numbers are seen as negative numbers.

Patterns that accompany a manufacturer’s frame in most cases have a set number stamped directly on the pattern. Knowing the eye size and pattern set number means the edger setting can be done without having to measure the pattern.

Sample Questions:

1. **A right lens calls for 2.0D base-out prism. How would it be positioned for spotting?**

To correctly position this lens:

- The center of the sphere and cylinder target intersection must be on the circular mire marked 2.0.
- Because the prism is horizontal, the illuminated target must be on the 180-degree line.
- Base out for the right eye is to the left. Therefore the center of the illuminated target must be on the 2D prism circle where it crosses the 180-degree line to the left.

When the lens is correctly positioned, the lensmeter target appears.

Once this position is achieved and the cylinder axis is correct, the lens may be spotted. Figure 24-4 shows the lens spotted with the three lensmeter dots. The center lensmeter ink spot is no longer at the center of the uncut lens, but the center dot still indicates the location of the MRP.

2. **A lens is to be edged for a frame having an A dimension of 53 mm. The pattern is stamped “set-15.”**

1. What is the proper edger setting?
2. If measured, what would the expected A dimension of the pattern be?

“Set-15” means that we need to set the edger 15 mm less than the desired lens size. Therefore to find the edger setting, we use

edger setting = eye size D (set number)

In this case that will be

edger setting D 53 D (D15)
D 38 mm

So the edger is set for 38 mm.

Now what would the size of the pattern be? Set number is the difference between the standard sized pattern and the actual sized pattern. In other words,

Set number D standard pattern size D actual pattern size
D 36.5 D actual pattern size

In this case we know what the set number is, but not the pattern size. So changing the formula around algebraically results in

Actual pattern size = 36.5 – (set number)

In this example, the numbers become

actual pattern size D 36.5 D (D15)
D 36.5 D 15
D 51.5 mm

This pattern can be expected to have an A dimension of 51.5 mm.

3. **What if the Pattern is the Same Size as the Frame'sEye Size?** When an edger is calibrated for a standard size pattern whose A dimension is 36.5 mm, setting the edger at 36.5 mm will always produce a lens that is

Some Patternless Edgers Do Decentration Calculations

Patternless edgers reduce the need for calculating edger setting numbers. This is because the digital "pattern" and the needed lens sizes are the same.* Some patternless edgers go further. Calculating lens decentration is not difficult. But like any simple arithmetic computation, it is easy to make a simple mistake.

It is not difficult for a patternless edger to do the decentration. When tracing both right and left lenses, the tracer also knows the DBL. The only thing that is not known is the wearer's PD. By asking for the PD, decentration can be easily given.

Some Edgers Do Both Calculations and Decentration. Even if the edger figures decentration, the person blocking the lens still has to first decenter, then block the lens.

Some patternless edgers are made to work with the blocker. If there is a direct interface between blocker and edger, the lens does not have to be decentered nasally by the operator. The operator just positions the spotted lens so that the OC (or MRP) is in the middle of the blocker grid as if there were no decentration at all. Then one of two things happens.

1. The blocker moves the lens block over to where it would normally be positioned.
2. The lens is blocked right in the middle, and the edger takes that factor into consideration when it is edging the lens.

exactly the same size as the pattern. So if a pattern is made directly from a frame and duplicates the frame’s eye size, then a 36.5-mm setting will give the correct lens size.

*Sometimes it is necessary to trace a frame or pattern that is the same shape, but not the same size as the frame to be used. In this case size compensation in edger settings will be necessary.

4. A pattern is supplied for a certain frame. This pattern mea-sures 46.5 in its A dimension. Suppose the lens is to be edged for a 50-mm eye size. If the edger is calibrated for a pattern size standard of 36.5 mm, what size lens will be edged if the edger sizing dial is set for 50 mm?

For this edger, a 36.5-mm pattern will produce the lens size at which the dial is set. If a 50-mm lens is desired, the dial is set at 50 mm. However, since the pattern is 10 mm too large, the lens produced will also be 10 mm too large. Setting the edger at 50 mm in conjunction with this pattern will produce a lens having a 60-mm eye size.

5. A frame has an eye size (A) of 54 mm and a DBL of 20 mm. The wearer’s PD is 66 mm. The lenses are already spotted. How must the instrument be set and the lens placed to properly block the lens? Assume that the lens is a *left* lens.

Lens decentration is calculated as

$$\text{decentration per lens D } \frac{A \text{ D } DBL \text{ D } PD}{2}$$

$$\text{D } \frac{54 \text{ D } 20 \text{ D } 66}{2}$$

$$\text{D } \frac{8}{2}$$

$$\text{D } 4 \text{ mm.}$$

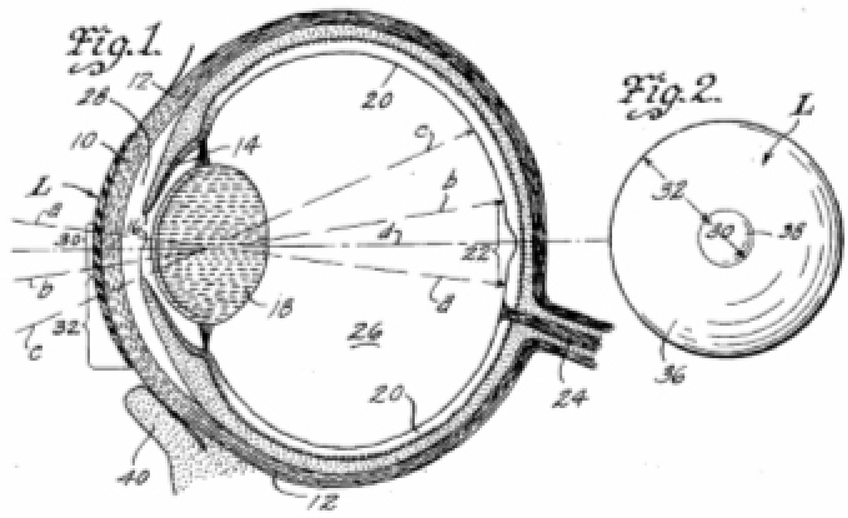
Unit 15:
Contact lenses

Learning Objective:

At the end of this chapter, students will be able to learn:

1. Introduction of different types of contact lenses.
2. Uses, indications, complications of contact lenses.

Contact Lenses



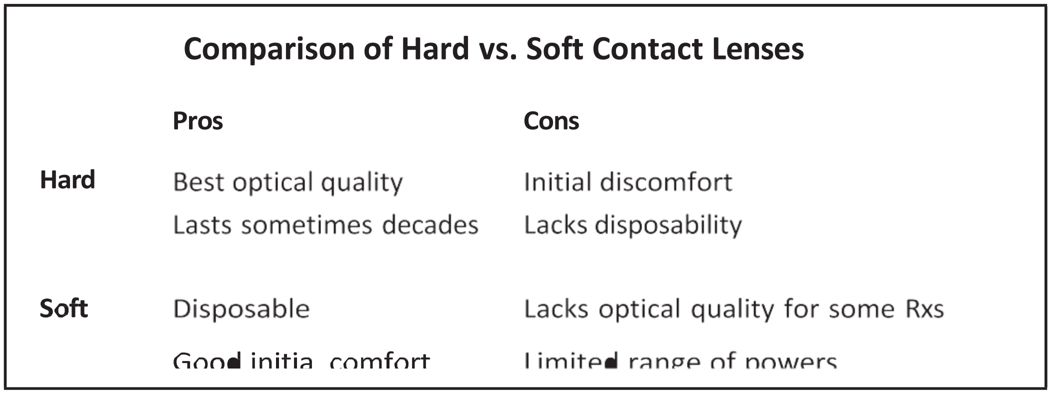
Contact lenses are one of the most fun areas in the eye care field … for the patient. For you, the optician, it can be a nightmare of paperwork and training on the application and removal of lenses. This chapter will help you understand how to train someone on the use of contact lenses, the care and handling of the lenses, and how to find specifics about contact lenses when needing to place an order.

First, though, let's give you some basics about contact lenses. There are generally two types of contact lenses, hard and soft. Hard lenses, also known as *rigid gas permeable*, have been around the longest, dating back to about the 1940s. Hard lenses have become the exception rather than the rule in recent times for a variety of reasons, but they will always have their place in certain cases, as we will discuss.

The benefit of hard lenses is two-fold. One, they can last several years or longer with proper care. You may see many patients who have been wearing the same hard lens for a decade! Two, they can correct many eye conditions that soft ones simply cannot, such as high amounts of astigmatism or keratoconus (a misshapen cornea). In such cases, the rigidity of hard lenses is necessary mask the irregular shape of the front corneal surface, thereby providing a higher level of optical quality.

The pitfall to hard lenses is the initial adaptation to comfort. A hard lens will not be as comfortable as a soft lens initially, but a majority of patients will get accustomed to it. In this age of instant gratification, not all patients are willing to wait a week to a month for the lens to begin to feel comfortable, however.

The benefit of soft lenses is also two-fold. The first is that soft lenses, unlike hard ones, are disposable in most cases. Several brands are even designed to be thrown away daily. This feature is useful for patients who have a tendency to lose their lenses or tend to have tears that deposit protein on the lenses, causing them to become cloudy over time. The pitfall to soft lenses is their limited use in irregular corneas such as in high amounts of astigmatism. Soft lenses will not give the optical quality needed in such cases that hard lenses provide through their rigidity.



Comparison of Hard vs. Soft Contact Lenses

	Pros	**Cons**
Hard	Best optical quality Lasts sometimes decades	Initial discomfort Lacks disposability
Soft	Disposable Good initial comfort	Lacks optical quality for some Rxs Limited range of powers

Soft lenses come in a variety of options:

1. Yearly
2. The 2-week to 1-month disposable (the most commonly used)
3. The daily disposable (quickly becoming the lens of choice for many doctors)

And a couple of lens materials:

1. The conventional material (silicon), which cannot be slept in
2. Silicon hydrogel, which may be slept in for one week to a month at a time with a doctor's approval.

Here are a few of the most common contact lens-related terms you may hear and will want to know:

1. Soft contact lens: A flexible contact lens. Usually disposable.
2. Hard (rigid gas permeable, or RGP): A rigid contact lens. Not disposable.
3. Spherical: A contact lens that does not correct astigmatism.
4. Toric: A contact lens that corrects astigmatism.
5. Multifocal / Bifocal: A contact lens that corrects distance and near vision simultaneously.
6. Disposable: A type of contact lens that is thrown away anywhere from on a daily basis to monthly.
7. Conventional: A soft contact lens that is not thrown away for an entire year.
8. Colored / Opaque: A contact lens designed to change a person's eye color.

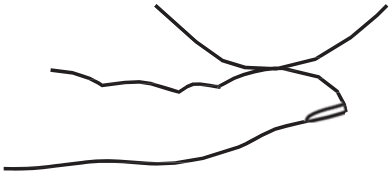
Contact lens cleaning solutions have come a long way in the last ten years. There was a time not long ago when cleaning contact lenses was a three- or four- step process. One solution was used to clean the lens, one disinfected the lens, one removed protein buildup, and one rinsed the lens before reapplication to the eye. Most of the modern solutions are *multipurpose solutions* that are able to do all of these steps in one bottle. We will discuss the proper cleaning of contact lenses shortly.

Training a patient on the application and removal of lenses will likely become a common practice in your work place. We will now discuss how to do this and look like a pro! There are some major differences between applying and removing hard and soft lenses. We will discuss the hard lenses first.

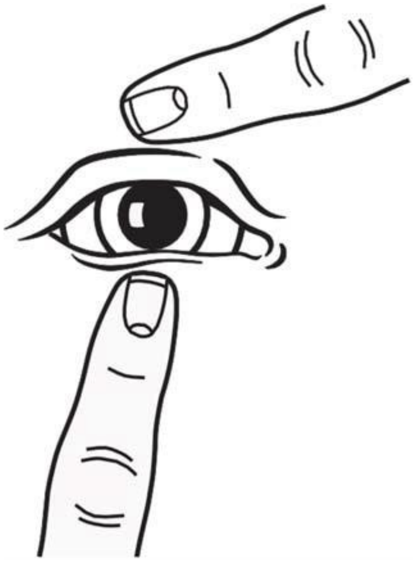
Application and removal of hard contact lenses

To apply a hard lens to the patient's eye:

1. Wash your hands well and be sure to rinse all soap residues away. Have a lint-free cloth available for the patient to dry her eyes when they begin to water, which they will when the patient is learning to insert a rigid contact lens for the first time.
2. Place the lens on the tip of your index finger, concave side up. Use your right index finger if you are right-handed, your left if you are left-handed.



3. Place the index finger of your other hand on the upper eyelid close to the eyelash margin and raise the eyelid. With the middle finger of the hand with the contact lens, pull the lower eyelid downward. *Having good control over the eyelids is essential*.



4. Instruct the patient to look straight ahead, and with the index

finger holding the contact lens, make gentle contact with the lens onto the cornea. The lens should easily remain in place on the cornea as you pull your finger away.

Index finger holding upper lid

Middle finger holding lower lid

Index finger holding contact lens

6. elease control of the lids *slowly!* A sudden release of the lids, which causes them to clamp down over the contact lens too quickly before the lens has a chance to settle, can turn the lens into a flying projectile! Watching pro athletes on their hands and knees looking for a contact lens is funny; being the one having to do it, however, is not!
7. You have done it! Now get going on the other eye

Focus point: Manufacturers of hard lenses place a small black dot on the lens of the right eye. This is to help you and the patient know which lens is for which eye.

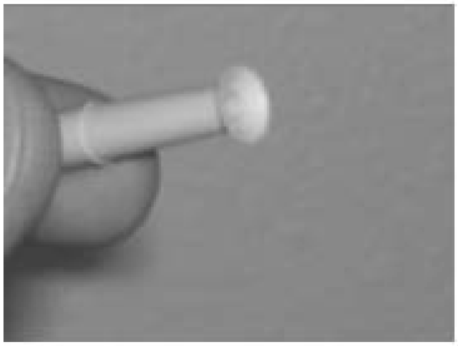
To have the patient apply a hard lens to his or her own eye:

Simply repeat the same steps, but obviously using the patient's fingers and a mirror for the patient to look into. Patients use the same fingers when applying the lens themselves as you use when you are doing it for them. When selecting the index finger hand to hold the contact lens for insertion, select the index finger on the hand opposite from the eye the lens is being inserted into. This makes the lid support a little more efficient.

Always instruct the patient to have a clean working environment and to insert lenses over a solid countertop, not a sink, so that the lens does not get lost down the drain! Additionally, it is helpful to have a colored washcloth or towel on the counter under the patient's head to make finding the lens easier should it fall. There are few things more difficult than finding a clear lens on a white countertop!

To remove a hard lens from a patient's eye:

A *greenie* is a device designed for the removal of hard contact lenses.



"Greenie"

It is a soft, rubber, handheld plunger (typically green, hence the name) that when placed on the contact lens will suction to it and remove it from the eye. Extra caution must be made with this device, however, since **severe harm can be caused to an eye if the bare eyeball is plunged with the greenie**. For this reason, rarely do we allow patients to use a greenie on themselves to remove a contact lens. However, they can be useful for us to remove a contact lens when other methods fail.

To use a greenie to remove a contact lens:

1. Visually locate the contact lens on the eye. **DO NOT TAKE THE PATIENT'S WORD THAT A CONTACT LENS IS ON THE EYE.**
2. Slightly moisten the suction-cup end of the greenie with saline and place it directly on the center of the contact lens at a perpendicular angle.

3. Pull the greenie away. The contact lens should be firmly suctioned on the end of the greenie and removed easily from the eye. You may hear a small "*pop*" break in suction as it is removed from eye.
4. **Gently** remove the lens from the greenie

Focus point: Before removing a contact lens with a greenie, make certain you visually locate the contact lens on the eye. Do not use a greenie on an eye that you simply assume has a contact lens on it. Serious damage can occur to the eye if you use a greenie on an eye without a contact lens or simply fail to plunge the lens and instead plunge the eyeball.

To remove a hard contact lens without *a greenie:*

There are a couple of methods. Practice with each method and find the one that is easiest for you.

The Pinch-off Method:

1. Wash your hands and rinse off all soap residue.
2. Sit the patient over a table to catch the lens if it falls.
3. Have the patient look straight ahead.
4. Place one index finger on the upper eyelid margin and one on the lower eyelid margin, directly adjacent to the upper and lower contact lens edges.
5. With gentle inward pressure, bring your two fingers toward one another slightly.

6. The lens should pop out as the eyelids catch under the upper and lower edges of the contact lens.

The Tug-and-Blink Method

1. Wash your hands and rinse off all soap residue.
2. Have the patient look straight ahead with eyes wide open. The patient must be able to open his eyes wider than the diameter of the contact lens for this method to work. For older individuals with floppy eyelids, this likely will not be the best method.
3. Tighten the eyelids by gently pulling outward on the outer corner of the eyelids. Have the patient blink with her hand under her cheek to catch the lens as it falls out.

To teach a patient to remove a hard lens from his or her own eye:

Never allow a patient to go home with a greenie. A well-intentioned patient who tries to remove a contact lens with a greenie when the lens is not actually in the eye can do serious and permanent damage.

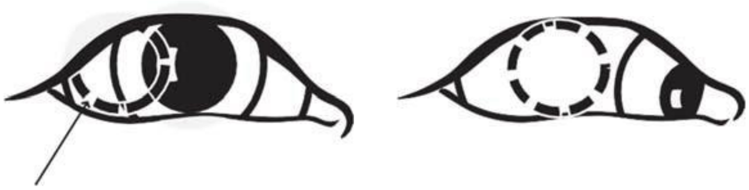
Both the Pinch-off Method and the Tug-and-Blink Method will work by the patient on themselves. The Tug-and-Blink Method is probably the most widely used, but find the one that works best for you and your patients and use it as your first line of training. Keep in mind that not all methods work for everyone, and some patients create their own very creative methods. As long as it is not a method that will cause harm to the eye, or to anyone else standing nearby, let the creative juices flow! However, I do recommend becoming proficient at these two methods before you start trying to get too creative with other methods.

To recenter a hard contact lens:

Oftentimes, a patient will come into the office with a hard lens that has become decentered off the cornea and onto the white sclera, and ask you for help to get it recentered. It is a good idea to include recentering training with all of your new contact lens patients. This will prevent the proverbial five o’clock Friday afternoon patient knocking on your door for help.

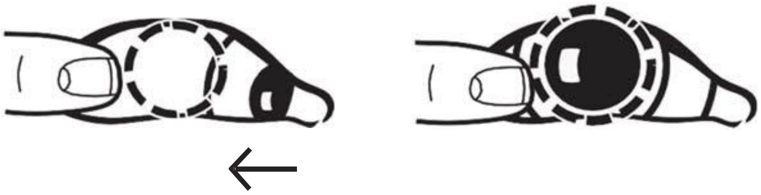
To recenter the lens:

1. Have the patient look in a direction away from the side of the eye the lens is on.
2. With your index finger, gently support the outer edge of the lens.
3. Have the patient slowly return to looking straight ahead.
4. As the patient looks straight ahead, your finger will act as a roadblock keeping the lens stationary. The patient's eyeball will slide under the lens, and the lens will become recentered.



Contact lens

Initial presentation Step 1



Step 2 Step 3-4

Steps in recentering hard lens

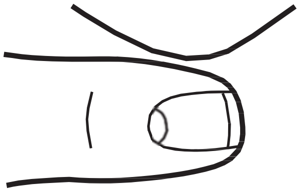
Application and removal of soft contact lenses

Soft contact lenses are more easily damaged than the rigid variety of lens. First-time wearers must be properly trained in their application and removal to avoid costly tears that can occur in the soft lenses.

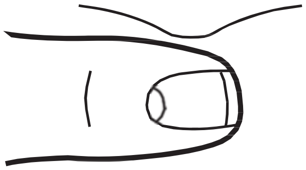
Apply soft lenses in much the same fashion as hard lenses. However, soft lenses tend to be much larger, so it is even more important to have good control over the eyelids to ensure they are out of the way for lens insertion. *Eyelids and eyelashes getting in the way are the biggest obstacle to* *successful lens insertion.*

Application of a soft contact lens:

1. Wash your hands and have a clean work environment.
2. Place the contact lens concave side up on the index finger opposite the eye it will be inserted into.
3. Ensure the lens is right side up.
    a. Unlike hard contact lenses, soft lenses by their very nature are capable of becoming inverted. An inverted lens will not cause any harm to the eye, but it will make the lens much more irritating and may slightly decrease the patient's vision.
    b. To tell if a lens is right side up:
        1. Place the lens on the tip of a finger and look at it in profile.
        2. If the lens looks bowl shaped, smooth and even along the edges, the lens is likely right side up. Otherwise, flip the lens over and inspect again.



Correct



Incorrect

Proper orientation of soft lens prior to insertion

4. Apply the lens as described for hard contact lenses. Soft

lenses, unlike hard lenses, will have a tendency to center themselves once applied. Therefore, if the patient is hesitant with your finger (or even his or her own finger) coming directly at the eye, you may place the lens on the white part of the eye and then move the eye toward the lens to achieve centration. Additionally, if the soft lens and finger are too wet, the lens may stick to the finger and not transfer to the eye. If you find this happening, simply dry your finger with a lint-free cloth and try again.

5. Instruct the patient not to blink immediately. A hard blink too soon after insertion will likely fold the lens and cause it to fall out of the eye. The lens must settle for a few seconds before the lids close. After a few seconds, you may instruct the patient to *gently* close his or her eyelids and *gently* massage the closed eyelids to remove any air bubbles that may be under the lens.

Removal of soft contact lenses

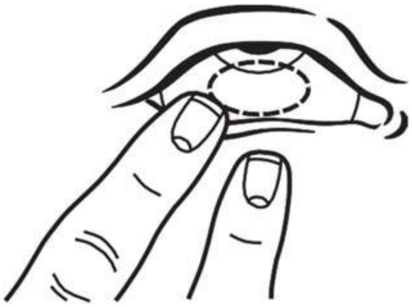
Some opticians and patients have an easier time removing hard lenses, others soft. The basic mechanics of removing a soft lens are simple, but do take some practice to master. Like riding a bike, once you learn how, it becomes an easy task.

To teach a patient to remove a soft contact lens from an eye:

1. Wash your hands and have a clean work environment. Make sure to have your cleaning supplies and a mirror nearby.
2. Look upward or to the side, exposing a large area of the sclera (the white part of your eye).

3. With your middle fingers, support the upper and lower eyelids, making sure to get eyelashes out of the way.

4. With your index finger, slide the contact lens onto the exposed white part of the eye.



5. Without releasing your index finger from the lens (otherwise the lens will just recenter itself again), gently pinch the contact lens with your index finger and thumb and remove from the eye.

6. Proceed immediately with cleaning and storing.

Focus point: Never remove the contact lens from the eye by pinching it directly off the cornea. The cornea, the clear part of the eye, is very susceptible to damage. The sclera, the white part of the eye, is much tougher and can tolerate your finger pinches much more readily.

To remove a lens from a patient's eye yourself, follow these similar steps:

1. Have the patient look upward or to the side.
2. Support the patient's upper and lower eyelids.
3. Slide the lens to the white part of the eye with your index finger.
4. Pinch off.
5. Clean and store.

Contact lens cleaning, disinfection, and storage

Fortunately, for all of our patients as well as for us, contact lens care and cleaning have come a long way in recent years in terms of convenience and effectiveness. This is largely because of the introduction of soft disposable contact lenses. By throwing away your contacts every two weeks to a month, they never have a chance to build up the protein that the older cleaning systems had. There are even contact lenses available now that you throw away after each use, eliminating the need for cleaning solutions altogether.

Another advance that has greatly improved the convenience of cleaning solutions is the introduction of *multipurpose solutions*. These combine cleaning and disinfection into one step. You can be thankful that you came along when you did into the field of eye care. Although we have more options than ever before in the type of contact lenses we fit for a patient, the care of these lenses no longer requires a chemistry degree!

There are four things we must do to a contact lens (and therefore the solution must do) at the end of the day to ensure it is properly cleaned and disinfected for the next day's wear:

1. Clean: Cleaning a contact lens removes the debris that builds up on a lens during normal daily wear. The mucus, dust, and any other particles on the lens must be cleaned off before the next step,

disinfection, can be accomplished. Therefore, a solution must be capable of breaking through these foreign substances on a lens without damaging the lens itself.

2. Disinfect: Disinfecting a lens means removing harmful bacteria.
3. Enzymatically clean: A patient's tears will eventually deposit protein on a contact lens, and enzymes can clean it. Protein film will make the lens less comfortable, less oxygen-permeable, and reduce the patient's vision, so having a lens free of protein buildup is important. As lenses become more disposable, this step is becoming less vital.
4. Rinse: Prior to reinserting the lens the following day, the lens must be rinsed free of the solution it was soaked in overnight to remove anything that may have settled on the lens. (The exception is with hard contacts. You would lose some of the conditioning effect the solution performed on the lens.)

As you can see, it is a mighty tall order to ask one solution to do all four of these things. However, fortunately, these solutions are available and today are the standard of care. In years past, all four of these steps were separate solutions, so you can imagine how complex cleaning was and how lucky we are today. There are still times when using multiple solutions is the preferred method, and we will discuss when these times are. But these multipurpose solutions will be your solution of choice 95 percent of the time.

Proper care, cleaning, and handling of hard contact lenses

Now that we have the contact lens out of the eye, what do we do with it?

Boston makes a wonderful multipurpose hard contact lens solution called, aptly, Boston Simplicity. This solution will clean, disinfect, store, and rinse hard contact lenses; it will also *condition* the lens to make it more comfortable upon application to the eye. All hard lens care systems, whether a multipurpose solution or a multistep process, have a component that conditions the lens. Hard contact lenses are, by definition, hard. The eye typically does not like hard things put into it. The conditioning properties of the solution, therefore, aim at providing a cushioning-type effect when the lens is placed in the eye.

So what is the process of cleaning a hard lens with Boston Simplicity (or any hard lens one-step solution)?

1. Be sure to have clean hands and a clean work environment. Have

your solution and storage case nearby. Always start with the same lens so the patient develops a routine and will not forget which lens she is working with.

2. Clean: Place a few drops of the solution on the contact lens and rub gently in the palm of your hand with your index finger. Repeat this process for both sides of the lens. The mechanical action of your finger combined with the solution will dislodge debris from the lens.

Placing cleaner on lens

Rubbing lens with cleaner

3. Rinse the lens with multipurpose solution. For hard lenses, it is OK for patients to rinse with tap water, and patients will admit they do this regularly to save money by not using as much solution. However, never recommend this to a new patient. Tap water impurities will not absorb into a hard lens like it will a soft lens, and, as you will learn, if you give patients an inch, they will take a mile. If you allow them to cut this corner, they may be tempted to cut others. So for safety’s sake, train them to rinse their lenses with the multipurpose solution. A better option than tap water, and more economical than using the multipurpose solution, would be to use saline solution, which is basically just sterile water. It is relatively cheap and can be found at any grocery store, so it is a good alternative for patients who balk at the expense of the multipurpose solution.
4. Disinfect: Fill half the storage case with the multipurpose solution and place the lens in the case. Then fill the remainder of the case with the multipurpose solution. Store the lenses for at least four hours, but preferably overnight. As the lenses soak in the solution, the antimicrobial properties kill any germs on the lens and condition the lens so insertion is more comfortable the next morning.

Preparing case for lens

Inserting lens into case for storage

5. Repeat with the other eye.
6. In the morning, remove the lenses and place them in the eyes. No rinsing is necessary or even recommended at this stage. It would only remove the conditioning and make the lens less comfortable.
7. Occasionally, a doctor will notice unacceptable amounts of protein deposits on the lens. If this is the case, he may prescribe an *enzymatic cleaner* for the patient. These solutions typically involve just placing one drop in the storage case along with the multipurpose solution for overnight soaking.
8. After the lens is inserted, the case should be rinsed with hot water and allowed to air-dry.

Boston Original™ (or Advanced) is a multisolution system that is also very popular for cleaning hard contact lenses. Your office may use this instead of the Boston Simplicity™. If this is the case, these are the steps for the Boston Original™ or Advanced system:

1. Be sure to have clean hands and a clean work environment. Have your solution and storage case nearby. Always start with the same lens so the patient develops a routine and will not forget which lens she is working with.
2. Clean: Place a few drops of the RED CAP cleaner on the contact lens and rub it gently into the palm of your hand with your index finger. Repeat this process for both sides of the lens. The mechanical action of your finger, combined with the solution, will dislodge debris from the lens. The red cap on this bottle is a sign that you *never* want this solution on the lens when it is placed in the eye.
3. Rinse the lens with saline solution.

4. Disinfect: Fill half the storage case with disinfection/conditioning solution and place the lens in the case. Fill the remainder of the case with the same solution. Store the lenses for at least four hours, but preferably overnight. As the lenses soak in the solution, the antimicrobial properties of the solution will kill any germs that may be on the lens as well as condition the lens to make insertion more comfortable the next morning.
5. Repeat with other eye.
6. In the morning, remove the lenses and place them in the eyes. No rinsing is necessary or even recommended at this stage. It would only remove the conditioning and make the lens less comfortable.
7. Enzymatic cleaners may be added to the system for additional protein removal.
8. After the lens is inserted, the case should be rinsed with hot water and allowed to air-dry.

You will notice that with the multi-solution system, there are two extra bottles, the cleaner and the saline. The cleaner in the Boston Original™ system is a little more effective than in the Boston Simplicity™.

There are many hard contact lens cleaning systems available to the patient at any grocery store. Boston, however, is the most doctor-recommended and used brand. All brands, however, use the same basic cleaning regimen.

Focus point: In the event of any lens discoloration or eye irritation with contact lenses, tell patients to contact their eye care professional immediately.

Proper care, cleaning and handling of soft contact lenses

Just like with Boston Simplicity™ for hard lenses, the most common soft- lens cleaners are also one-bottle multipurpose systems. Optifree™, Renu™, and Complete™ are the most commonly used multipurpose soft-lens systems on the market, and your office is likely to use one of these. Soft lenses are easily torn, so women with long fingernails must be careful during the cleaning process.

To clean a soft contact lens:

1. Be sure to have clean hands and a clean work environment. Have your solution and storage case nearby. Always start with the same lens so the patient develops a routine and won't forget which lens she is working with.
2. Clean: Place a few drops of the multipurpose solution on the contact lens and rub gently in the palm of your hand with your index finger. Repeat this process for both sides of the lens. The mechanical action of your finger combined with the solution will dislodge debris from the lens.
3. Rinse the lens with multipurpose solution, *never with tap water.* It has many impurities that can become absorbed into a soft lens. A patient may use saline solution as a cheaper alternative.
4. Disinfect: Fill the storage case halfway with the multipurpose solution and place the lens in the case. Fill the remainder of case with multipurpose solution. Store the lenses for at least four hours, but preferably overnight. As the lenses soak, the antimicrobial properties of the solution kill any germs that may be on the lens.
5. Repeat with the other eye.
6. In the morning, remove the lenses and place them in eye. No rinsing is necessary at this stage.
7. Rinse the case with hot water and allow it to air-dry.
8. As with hard contact lenses, there are enzymatic cleaners for soft lenses the eye doctor may recommend. The most common of these is Supraclens. As with the hard-lens enzymatic cleaner, use only one drop
   in the case as the lenses are soaking overnight. Most disposable lenses do not need this step, since the lenses are disposed of before protein has a

chance to build up. However, some patients are in the same soft lens for the entire year and will definitely need an enzyme protein remover for their lenses.

Are these steps starting to sound familiar? They ought to. Whether cleaning hard or soft lenses, the same actions must occur: cleaning and disinfection. With the disposability of soft lenses, enzymatic cleaners for protein removal are rarely necessary.

In certain cases, a doctor may recommend a *hydrogen peroxide* lens care system. These systems are better at dealing with certain bacteria and viruses than the multipurpose solutions. In individuals with conditions that compromise their body's own immune system, such as HIV or diabetes, these hydrogen peroxide systems may be the safest choice. AOSept™ is the most commonly used. The regimens for using these systems vary by brand and are considerably more complex than the multipurpose solutions. You should read the instructions provided with such systems or have your team leader, manager, or doctor show you how to use it.

Focus point: When not using a multipurpose solution, it is important to remember that cleaners do not disinfect, disinfectants do not clean, and that saline solution (a solution for rinsing) does not clean or disinfect.

Storage of lenses between uses

Most contact lens wearers may go a week or more between wears. Many use their contacts only during certain times of the year, such as for social occasions or sports. So what must be done with the contact lenses during these long periods of storage?

Storage for up to one week: Lenses may be stored for one week. The lenses should be recleaned with fresh solution no more than forty-eight hours prior to lens reinsertion.

Storage for up to one month: Lenses must be recleaned with fresh solution at the end of every week of storage, when the antibacterial action of the solution begins to diminish. As with one-week storage, the lenses also must be recleaned no more than forty-eight hours prior to reinsertion. Read the product insert if you are using a solution not cited in this book.

Storage for more than one month: At the end of each month, the lens case (found at any grocery store) should be replaced and a new solution applied. As before, the lenses need to be cleaned again no more than forty-eight hours before wear.

Cosmetics and contact lenses

Cosmetics and contact lenses do not get along well together, but there are ways to make for a compatible union. Educate your patients on these points:

1. Always think of the contact lens first. The patient must place her contact lenses on the eyes *before* any makeup, and she must remove the makeup *before* removing the lenses. This will minimize any chance of makeup coming in contact with the lenses.
2. Avoid “lash-building” mascara. It contains elements that may cause irritation or damage the contact lens.
3. Cover your eyes while using hairspray. Alcohol-free types of hairspray are best, but we still want to train the patient to avoid exposing the lenses to the spray fumes.

Contact lens-wearing schedule

For most typical new contact-lens wearers, the doctor will recommend gradually increasing the wear time each day until the patient is up to a full day. This helps the eye build tolerance to the lens and to the decreased supply of oxygen. A lens- wearing schedule may look like this:

Day 1-2: 8 hours
Day 3-4: 10 hours
Day 5-6: 12 hours
Day 7-8: 14 hours
Day 8-10: 16 hours

So far, the FDA has approved only a very small handful of lenses for sleeping in. A couple of the most common ones are the Night and Day™ brand by Ciba and Purevision™ by Bausch and Lomb. The Night and Day™ brand may be worn for one month, with doctor approval, between removals. The Purevision™ brand may be worn for one week between removals. New ones are coming out quickly, so ask your doctor which ones he prescribes for his patients to sleep in so you can educate your patients on this issue.

The primary reason most contact lenses are not safe to sleep in is their lack of oxygen permeability. The cornea, the front surface of the eye, needs oxygen in order to perform many of its functions, not the least of which is combating infections. With a contact lens on the front of the eye, the amount of oxygen the cornea receives is greatly diminished. Continue this lack of oxygen supply into the nighttime hours, and the eye becomes much more susceptible to serious infections. The FDA has shown that nighttime brands allow a safe amount of oxygen to penetrate to the cornea, even when the eyes are closed.

You will have many patients wearing lenses other then these two brands for extended days. It is in your best interest, and the patients', to educate them on the infection danger of doing this.

Focus point: In life-threatening conditions, 50 percent of patients do not follow doctor's orders well enough to be effective. For contact lens care, compliance is only 23 percent! Be sure to give written instructions for all lens-care regimens. Your office will likely have these on hand to distribute to your patients.

Finding contact lens specifications

There are literally hundreds of contact lens brands available. In your office, you will find that you routinely use only a handful repeatedly. This helps you remember prices and lens parameters more easily when you order lenses. However, there are bound to be times when a doctor asks you to order a lens you have never heard of.

Manufacturer: This is the name of the company that makes the contact lens. The phone number for the manufacturer is listed for placing orders or for questions.

1. Series: This is the brand name of the contact lens. Just like Ford (the manufacturer) makes many models of cars, contact lens manufactures make many different models of contact lenses.
2. Material/Water Content: This is the material the lens is made of. Each material will have different properties, some with a high content of water and others with a lower content. Some will have a higher propensity for attracting protein deposits, and so forth. It will be up to the doctor to determine which material is best for each patient.

3. Prod.: This is the production method for making the lens. It may make a difference in how well the lens centers on the eye.
4. Base Curve: This is the inside curvature of the contact lens. This determines how “loose” or how “tight” the lens will fit on the eye. If a doctor finds that the contact lens moves too much, or is “too loose,” he may decide to steepen the base curve, effectively tightening the lens on the eye. The lower the base curve number, the steeper the curve.

   Therefore, a high number base curve would likely move more on an eye than a base curve of a lower value.
5. Diameter: This is the overall diameter of the lens. The bigger the lens, the more stability it may have on the eye—but also the tougher it may be for the patient to insert, especially for those with smaller eyes.
6. Power Availability: This is the range of powers in which this particular contact lens is manufactured.
7. Optic Zone: The power of a contact lens does not span the entire diameter of a lens. Some of the periphery of a lens is just to add mass and stability. This value tells you what size zone in the center of the lens actually carries the prescription. This value may be of use for patients with exceptionally large pupils. In a case such as this, the doctor may wish to use a lens that has a larger optic zone.
8. Center thickness: This is the thickness of the center of the contact lens. The thicker it is, the less oxygen can pass through and may affect comfort..
9. Disinfection Method: This is the manufacturer’s suggested disinfection techniques. C stands for chemical disinfection. This is the most common type of disinfection and would include the solutions we discussed earlier in this chapter. H stands for heat disinfection. We do not see this type used very often anymore. O stands for oxidation.
10. dK value: This is a measure of the oxygen permeability of the lens material for a given power. The higher the dK, the greater amount of oxygen capable of penetrating through the lens to the cornea.
11. Unit Cost: This is the wholesale value of the lenses—what your office actually pays for them. Your office will then use a multiple of this, such as 2×, to compute the retail cost for the patient. You will need to learn the multiple your office uses. This column also describes how the lens is supplied, such as a single lens in a vial, a six-pack, or some other combination.

Let us look at a few examples of how *Tyler’s Quarterly* may be used.

Sample questions:

1. **Describe steps to clean a soft contact lens?**

1. Be sure to have clean hands and a clean work environment. Have your solution and storage case nearby. Always start with the same lens so the patient develops a routine and won't forget which lens she is working with.
2. Clean: Place a few drops of the multipurpose solution on the contact lens and rub gently in the palm of your hand with your index finger. Repeat this process for both sides of the lens. The mechanical action of your finger combined with the solution will dislodge debris from the lens.
3. Rinse the lens with multipurpose solution, *never with tap water.* It has many impurities that can become absorbed into a soft lens. A patient may use saline solution as a cheaper alternative.
4. Disinfect: Fill the storage case halfway with the multipurpose solution and place the lens in the case. Fill the remainder of case with multipurpose solution. Store the lenses for at least four hours, but preferably overnight. As the lenses soak, the antimicrobial properties of the solution kill any germs that may be on the lens.
5. Repeat with the other eye.
6. In the morning, remove the lenses and place them in eye. No rinsing is necessary at this stage.
7. Rinse the case with hot water and allow it to air-dry.
8. As with hard contact lenses, there are enzymatic cleaners for soft lenses the eye doctor may recommend. The most common of these is Supraclens. As with the hard-lens enzymatic cleaner, use only one drop in the case as the lenses are soaking overnight. Most disposable lenses do not need this step, since the lenses are disposed of before protein has a chance to build up. However, some patients are in the same soft lens for the entire year and will definitely need an enzyme protein remover for their lenses.

2. **Write a note on cosmetic contact lenses?**

Cosmetics and contact lenses

Cosmetics and contact lenses do not get along well together, but there are ways to make for a compatible union. Educate your patients on these points:

1. Always think of the contact lens first. The patient must place her contact lenses on the eyes *before* any makeup, and she must remove the makeup *before* removing the lenses. This will minimize any chance of makeup coming in contact with the lenses.
2. Avoid “lash-building” mascara. It contains elements that may cause irritation or damage the contact lens.
3. Cover your eyes while using hairspray. Alcohol-free types of hairspray are best, but we still want to train the patient to avoid exposing the lenses to the spray fumes.

Unit 16:

Low Vision

Learning Objective:

At the end of this chapter, students will be able to learn:

1. Definition of low vision. Impact of low vision on persons' quality of life.
2. Introduction of different optical, non optical, electronic aids.
3. Dispensing of optical aids.

1. Definition and Scope:

Low vision refers to a permanent, correctable visual impairment that significantly impacts daily living activities despite optimal conventional spectacles or contact lens correction. This broad term encompasses a wide range of visual problems, including blurry vision, reduced field of view, contrast sensitivity issues, and glare sensitivity. While the definition emphasizes functional limitations, the severity and specific challenges vary greatly from person to person, requiring individualized management strategies.

The World Health Organization defines "low vision" as visual acuity between 20/70 and 20/400, with the best possible correction, or a visual field of 20 degrees or less. "Blindness" is defined as a visual acuity worse than 20/400, with the best possible correction, or a visual field of 10 degrees or less.

2. Prevalence and Causes:

Globally, an estimated 2.2 billion people have vision impairment, of which 36 million are classified as blind and 216 million have moderate-to-severe vision impairment, constituting significant proportions of the world's population. The World Health Organization (WHO) predicts that these numbers will rise due to an aging population and increasing prevalence of chronic diseases like diabetes and age-related macular degeneration.

The causes of low vision are diverse and include age-related macular degeneration, glaucoma, diabetic retinopathy, congenital or developmental anomalies, corneal opacities, and traumatic injuries. Understanding the underlying cause is crucial for prognosis, management, and potential future treatment options.

3. History Taking:

A comprehensive history taking is fundamental to understanding the impact of low vision on an individual's life. Key aspects to explore include:

Onset and duration of vision loss: This helps understand the progression of the condition and potential future implications.

Nature of visual complaints: Describing blurry vision, glare sensitivity, field of view limitations, and specific difficulties encountered in daily activities provides valuable insights into functional needs.

Past medical and eye health history: Identifying underlying medical conditions and previous eye treatments are crucial for considering potential interactions and contraindications for various management options.

Occupational and recreational activities: Assessing the demands of work, hobbies, and daily living tasks helps tailor solutions to maximize independence and participation.

Psychological and social impact: Exploring feelings of frustration, helplessness, and social isolation helps address emotional needs and facilitate adaptation.

Support systems: Identifying family, friends, or community resources available for providing aid and emotional support contributes to holistic care.

4. Assessment:

A low vision assessment builds upon the information gathered through history taking and aims to objectively quantify the visual limitations and functional needs. Key components include:

Visual acuity: Measuring distance and near vision acuity with standardized charts reveals the magnitude of visual loss.

Refraction: Assessing the need for additional refractive correction to optimize visual clarity.

Visual field: Mapping the extent of peripheral vision identifies potential blind spots and limitations in navigation.

Colour vision: Evaluating colour perception for tasks like reading colour-coded information.

Contrast sensitivity: Testing the ability to distinguish differences in light and dark, crucial for reading and everyday tasks.

Glare sensitivity: Assessing discomfort and visual performance under bright or distracting lighting conditions.

Functional assessment: Exploring daily living activities through standardized questionnaires or direct observation reveals specific areas of difficulty and informs the selection of appropriate low vision aids and training.

Advanced Assessment Techniques:

Beyond basic visual and functional assessments, several advanced techniques provide insights into specific visual limitations and guide targeted low vision management. These include:

Electroretinography (ERG): Measures electrical activity in the retina, aiding in diagnosing retinal dysfunction and monitoring disease progression.

Visual evoked potentials (VEPs): Measures brain activity elicited by visual stimuli, revealing hidden visual field deficits and potential cortical processing limitations.

Mobility assessments: Evaluates orientation and navigation skills in real-world environments, informing training needs and recommendations for travel aids.

Low vision rehabilitation assessment: Comprehensively explores all aspects of the individual's life affected by low vision, encompassing emotional adjustment, social support systems, and vocational potential.

5. Management:

The management of low vision is not a one-size-fits-all approach. It requires a tailored strategy based on the individual's unique needs, preferences, and lifestyle. The primary goals include:

Maximizing remaining vision: Optimizing visual clarity with appropriate refractive correction, low vision devices, and environmental modifications.

Enhancing functional abilities: Training individuals on using low vision aids and adaptive strategies to perform daily living tasks, such as reading, cooking, and navigating.

Promoting independence and confidence: Addressing emotional needs, providing counselling and support groups, and advocating for accessibility resources empowers individuals to live actively and participate in society.

6. Low Vision Devices:

A wide range of low vision devices can supplement remaining vision and optimize functional abilities. These can be categorized as:

Optical devices: Magnifiers, telescopes, and loupes increase visual magnification for near and distance tasks.

Non-optical devices: Stands, adjustable furniture, and specialized lighting improve the visual environment and task performance.

Electronic devices: Handheld magnifiers, smartphones with accessibility features, and reading tablets offer additional magnification and voice assistance.

Choosing the appropriate low vision devices requires careful consideration of individual needs, visual characteristics, and lifestyle factors. Training and follow-up support are crucial for successful adaptation and maximizing the benefits of these aids.

Furthermore:

1. Optical Devices:

Magnifiers:

Handheld magnifiers: Available in various powers and working distances, handheld magnifiers offer immediate magnification for near tasks. Fresnel lenses offer lightweight portability, while aspheric lenses provide wider fields of view and reduced distortion.

Stand magnifiers: Ideal for desk work, stand magnifiers offer stable magnification with hands-free operation. Dome magnifiers provide full-page magnification, while bar magnifiers allow line-by-line reading.

Telescopes: Monocular and binocular telescopes magnify distant objects, aiding in navigation and activities like reading signs or watching sporting events. Galilean telescopes are compact and affordable but have narrower fields of view, while Keplerian telescopes offer wider fields but are larger and more expensive.

Loupes: High-powered magnifiers worn like spectacles, loupes offer magnification for intricate tasks like watch repair or jewellery making. Jewellers' loupes have single lenses, while prismatic loupes offer magnification without obstructing the opposite eye.

2. Non-Optical Devices:

Stands: Adjustable reading stands raise reading materials to comfortable eye levels, reducing neck strain and improving posture. Fixed-angle stands are simple and affordable, while tilting stands offer additional adjustability for optimal viewing angles.

Lighting: Adjustable lamps with glare filters improve contrast and reduce eye fatigue for near tasks. Floor lamps illuminate reading areas, while clip-on lights provide focused illumination for specific tasks.

Non-slip mats and contrasting colours: Enhance safety and orientation by marking edges, stairs, and obstacles with textured surfaces and high-contrast colour schemes.

3. Electronic Devices:

Handheld electronic magnifiers: Combine digital zoom with image enhancement features like adjustable contrast and colour modes, offering versatility for various tasks. Some models integrate text-to-speech functionality for reading assistance.

Smartphones and tablets: Accessibility features like text magnification, voice control, and high-contrast settings transform these devices into powerful low vision aids. Apps dedicated to reading, navigation, and communication further enhance functionality.

Optics of Low Vision Devices:

Understanding the principles governing low vision devices allows for informed selection and optimization of their use. Key optical considerations include:

Focal length: Determines the magnification power and working distance. Short focal lengths provide higher magnification but require closer working distances, while longer focal lengths offer lower magnification but allow for greater viewing distances.

Field of view: Refers to the area visible through the device at a given distance. A wider field of view allows for larger areas of observation, while a narrower field provides higher magnification but restricts focus.

Aperture size: Determines the amount of light entering the device and impacts visual brightness. Larger apertures provide greater light transmission but may increase glare, while smaller apertures reduce glare but can dim the image.

Lens coatings: Anti-reflective coatings minimize glare and improve image clarity, while UV coatings protect eyes from harmful ultraviolet radiation.

Selecting the Right Device:

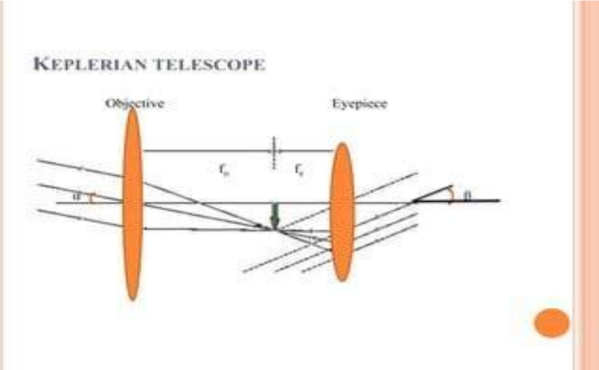
Choosing the appropriate low vision device requires a personalized approach that considers individual needs, visual characteristics, and lifestyle factors. Factors to consider include:

Type and severity of vision loss: Different devices address specific visual limitations, such as low magnification for near tasks or high magnification for distance viewing.

Functional needs and daily activities: The choice of device should align with the individual's daily tasks and routines, considering portability, ease of use, and compatibility with other visual aids.

Dexterity and manual skills: Ease of operation and handling are crucial for individuals with limited dexterity or hand function.

Personal preferences and comfort: Appearance, weight, and overall comfort play a significant role in ensuring device acceptance and adherence.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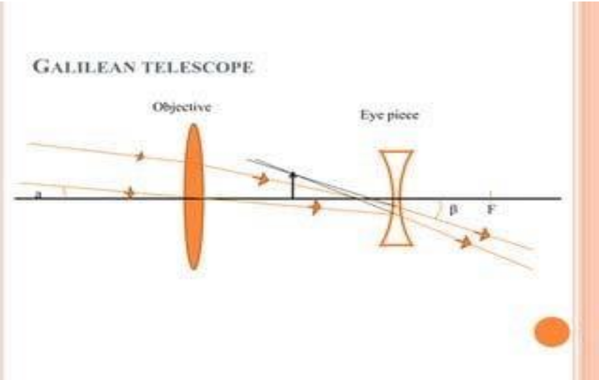
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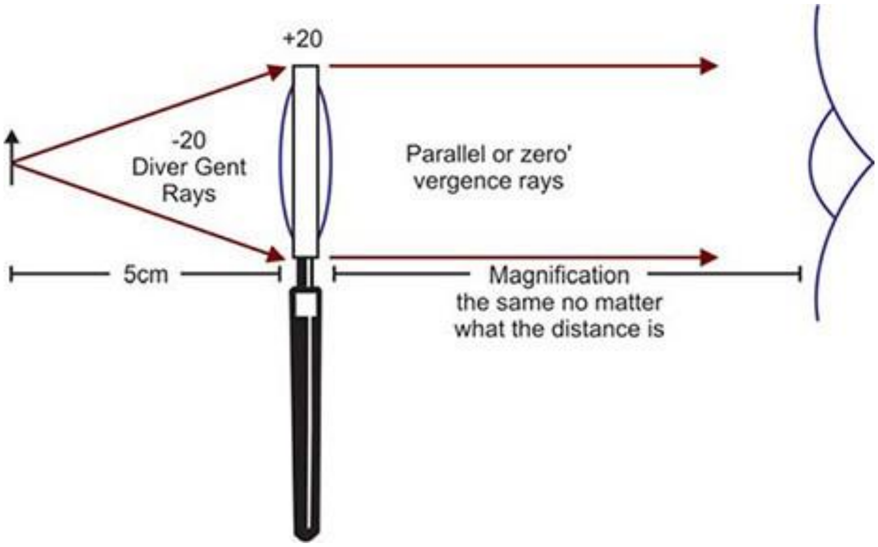

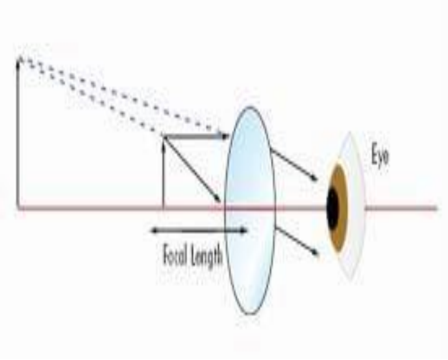

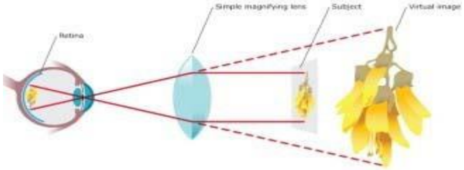

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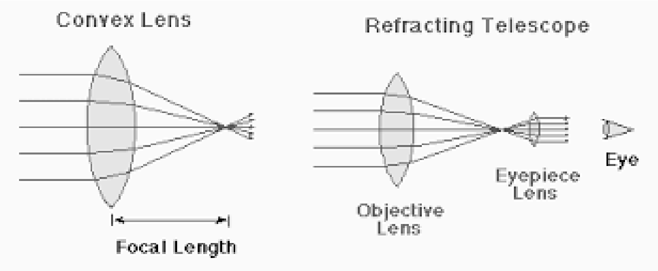


Low vision aids are mainly used this people who are unable to see and low vision devices are mainly used to magnify. All low vision devices are computed this formula, M=D/4, here M= magnification, D = dioptric power. This formula assumed that the unaided eye the patient can sustain just enough accommodation to hold the matter at 25 cm. For spectacles and magnifiers this formula can be written M=D+A/2.5, where A is the amplitude of accommodation.

Magnification of low vision devices: - low vision devices make use of 4 type of magnifications. They are relative size, relative distance, angular and electro optical.

Relative size: - Relative size means enlargement of the size of the object, it does not use an optical system. It is normally used to bigger the object

Relative distance magnification: -

Relative distance magnification achieved by moving the object of regard towards a person to subtend a larger image on the retina.

Angular magnification:

Angular magnification achieved by the apparent change of size of the object compared with the true size of the object.

Electro – optical magnification:

Electro optical magnification is produced by electronic systems which enlarge the objects by using computer.

Hand magnifiers optics: Mainly optics of hand magnifiers are difference between front vertex power (fv), back vertex power (bv) and equivalent power of the hand magnifier (fm)

With a Plano convex hand magnifier fc is closest to the front vertex power fv but back vertex power is greater

In a bi-convex lens of equal surface powers, front vertex power and back vertex power are equal but power of the hand magnifier is slightly less because the principal planes are inside the lens.

$Fe = Fm+Fa-z.FmFa$

Where Fe is the equivalent power of the system, Fm is the equivalent power of the hand magnifiers, Fa is the power of accommodation and Z is the eye to hand magnifiers distance,

When $Fe = Fm$

If the eye magnifier separation is exactly the same as the focal length, z is equal to fm ,

$Fe= Fm+Fa – z.FmFa$,

Thus, $Fe = Fm+Fa – fm.Fm Fa$

$fm. Fm =1$

$Fe= Fm+ Fa-Fa$

So, $Fc = Fm$

When $Fe> Fm$

zfm, if the eye to hand magnifier distance is greater than the magnifier’s focal length ,

$Fe=Fm+Fa-z.FmFa$,

$z.FmFa=>Fa$

Fe

Sample Questions:

1. **Write a brief note on History Taking?**

A comprehensive history taking is fundamental to understanding the impact of low vision on an individual's life. Key aspects to explore include:

Onset and duration of vision loss: This helps understand the progression of the condition and potential future implications.

Nature of visual complaints: Describing blurry vision, glare sensitivity, field of view limitations, and specific difficulties encountered in daily activities provides valuable insights into functional needs.

Past medical and eye health history: Identifying underlying medical conditions and previous eye treatments are crucial for considering potential interactions and contraindications for various management options.

Occupational and recreational activities: Assessing the demands of work, hobbies, and daily living tasks helps tailor solutions to maximize independence and participation.

Psychological and social impact: Exploring feelings of frustration, helplessness, and social isolation helps address emotional needs and facilitate adaptation.

Support systems: Identifying family, friends, or community resources available for providing aid and emotional support contributes to holistic care.

4. Assessment:

A low vision assessment builds upon the information gathered through history taking and aims to objectively quantify the visual limitations and functional needs. Key components include:

Visual acuity: Measuring distance and near vision acuity with standardized charts reveals the magnitude of visual loss.

Refraction: Assessing the need for additional refractive correction to optimize visual clarity.

Visual field: Mapping the extent of peripheral vision identifies potential blind spots and limitations in navigation.

Colour vision: Evaluating colour perception for tasks like reading colour-coded information.

Contrast sensitivity: Testing the ability to distinguish differences in light and dark, crucial for reading and everyday tasks.

Glare sensitivity: Assessing discomfort and visual performance under bright or distracting lighting conditions.

Functional assessment: Exploring daily living activities through standardized questionnaires or direct observation reveals specific areas of difficulty and informs the selection of appropriate low vision aids and training.

Advanced Assessment Techniques:

Beyond basic visual and functional assessments, several advanced techniques provide insights into specific visual limitations and guide targeted low vision management. These include:

Electroretinography (ERG): Measures electrical activity in the retina, aiding in diagnosing retinal dysfunction and monitoring disease progression.

Visual evoked potentials (VEPs): Measures brain activity elicited by visual stimuli, revealing hidden visual field deficits and potential cortical processing limitations.

Mobility assessments: Evaluates orientation and navigation skills in real-world environments, informing training needs and recommendations for travel aids.

Low vision rehabilitation assessment: Comprehensively explores all aspects of the individual's life affected by low vision, encompassing emotional adjustment, social support systems, and vocational potential.

2. Write steps of management of low vision?

The management of low vision is not a one-size-fits-all approach. It requires a tailored strategy based on the individual's unique needs, preferences, and lifestyle. The primary goals include:

Maximizing remaining vision: Optimizing visual clarity with appropriate refractive correction, low vision devices, and environmental modifications.

Enhancing functional abilities: Training individuals on using low vision aids and adaptive strategies to perform daily living tasks, such as reading, cooking, and navigating.

Promoting independence and confidence: Addressing emotional needs, providing counselling and support groups, and advocating for accessibility resources empowers individuals to live actively and participate in society.

Low Vision Devices:

A wide range of low vision devices can supplement remaining vision and optimize functional abilities. These can be categorized as:

Optical devices: Magnifiers, telescopes, and loupes increase visual magnification for near and distance tasks.

Non-optical devices: Stands, adjustable furniture, and specialized lighting improve the visual environment and task performance.

Electronic devices: Handheld magnifiers, smartphones with accessibility features, and reading tablets offer additional magnification and voice assistance.

Choosing the appropriate low vision devices requires careful consideration of individual needs, visual characteristics, and lifestyle factors. Training and follow-up support are crucial for successful adaptation and maximizing the benefits of these aids.

Unit 17:

Opticianry Related Instruments and Devices

Learning Objectives:

At the end of this unit participants will have strong knowledge of:

All opticianry instruments and tools' its usage, significance, care, maintenance, advantages and disadvantages.

Details of Opticianry Training Lab Tools & Equipment:

1. Auto Edger with all accessories:
An automated machine that grinds and polishes the edges of lenses to fit into frames precisely.
Accessories include diamond grinding wheels, polishing wheels, templates for different frame shapes, and safety features like eye shields and dust extraction.
Benefits: Efficient, accurate edging, consistent results, reduces manual labor.

2. Manual Edger:
A hand-operated tool used for edging lenses before the advent of auto edgers.
Requires skill and practice to achieve proper edge shape and finish.
Benefits: Provides a deeper understanding of edging principles, useful for repairs and adjustments.

3. Auto and Manual Buffer:
Machines that polish the edges of lenses after edging to remove scratches and achieve a smooth finish.
Auto buffers automate the process, while manual buffers offer more control for specific needs.
Benefits: Improves lens clarity and aesthetics, enhances comfort and wearability.

4. Tint Maker:
A device that mixes and applies colored dyes to lenses to create tinted glasses.
Modern tint makers often use pre-mixed dye capsules for ease and accuracy.
Benefits: Offers customized tint options, caters to individual needs like light sensitivity or fashion preferences.

5. UV and Photosynthetic Lens Checker:
Instruments that evaluate the presence and effectiveness of UV protection and photochromic properties in lenses.
UV checkers measure UV transmittance while photosynthetic checkers assess the

darkening response of photochromic lenses to light.
Benefits: Ensures compliance with UV protection standards, verifies functionality of photochromic lenses.

6. Auto Groover:
An automated machine that creates grooves in lens edges for secure attachment to frames.
Offers different groove types and depths for compatibility with various frame styles.
Benefits: Ensures precise and consistent grooves, improves frame holding strength.

7. Hot Air Frame Warmer:
Tool that heats up plastic frames to make them more pliable for adjustments and lens fitting.
Allows for bending and shaping the frame without damage.
Benefits: Facilitates frame adjustments for optimal fit, simplifies lens insertion.

8. Basic Frame Warmer:
A less high-tech option for warming up plastic frames, often using a heating lamp or hairdryer.
Requires more caution to avoid overheating and damaging the frame.
Benefits: Affordable alternative, suitable for basic adjustments.

9. CR Cutting Machine:
A machine that cuts polycarbonate or Trivex lenses to specified shapes and sizes based on frame measurements.
Can be manual or digital, with digital models offering increased precision and efficiency.
Benefits: Ensures accurate lens shapes, reduces waste, speeds up lab workflow.

10. Driller and Hinger:
Driller creates screw holes in lenses for frame attachments, while the hinger inserts and secures hinges for folding frames. Both require precision and proper alignment for optimal functionality and aesthetics.
Benefits: Enables secure lens mounting, ensures smooth functionality of folding frames.

11. Aqua Sonic Ultrasonic Cleaner:
A device that uses ultrasonic waves to remove dirt, fingerprints, and oily residues from lenses and frames.
Offers efficient and thorough cleaning without damaging the delicate materials.

Benefits: Improves lens clarity and hygiene, extends the life of eyewear.

12. Focimeter:
An instrument that measures the optical power of lenses to determine their refractive correction for nearsightedness, farsightedness, or astigmatism.
Crucial for verifying lens accuracy and ensuring proper vision correction.
Benefits: Ensures accurate prescription fulfillment, improves patient satisfaction.

13. Digital PD Meter:
Measures the pupillary distance (PD) – the distance between the pupils – which is essential for precise lens centration in frames.
Digital PD meters offer faster and more accurate measurements compared to traditional rulers.
Benefits: Improves centering accuracy, optimizes visual clarity and comfort.

14. Pupilometer:
A manual instrument used to measure pupillary distance when a digital PD meter is unavailable.
Requires careful alignment and practice for accurate results.
Benefits: Backup option for PD measurement, useful in remote locations or limited settings.

15. Dispensing PD Ruler:
A simple ruler with markings to measure pupillary distance directly on a patient's face.
Less accurate than digital PD meters but readily available and portable.
Benefits: Quick and convenient option for basic PD measurement, useful for preliminary fitting or troubleshooting.

16. Lens Marking Machine:
Etches identification marks on lenses for tracking and record-keeping purposes.
Can be hand-operated or laser-based, with laser marking offering a permanent and precise etch.
Benefits: Ensures proper tracking of lenses within the lab, simplifies prescription fulfillment, promotes accountability.

Dispensing Hand Tools:

Adjusting Pliers:

Numont Plier Tri-Angling Plier: Allows precise bending of temple angles in three directions.
Combo Round Chain Nose/Delrin Plier: Combines chain nose pliers for gripping and Delrin jaws for protecting rims during adjustments.
Combo Flat Chain Nose/Delrin Plier: Similar to the above but with flat jaws for holding wider surfaces.
Wide Jaw Angling Plier: Offers extra opening width for adjusting large or thick frames.
Finger Piece Plier: Provides leverage and control for delicate adjustments with fingertip grip.

Bracing Pliers:
Double Delrin Jaw Plier: Features padded Delrin jaws for secure and scratch-free gripping of delicate areas.
Zyl Gripping Plier: Specially designed for holding Zyl frames with a cushioned grip.

Chain/Snipe Nose Pliers:
Long Nose Chain Plier: Reaches into tight spaces for gripping small parts like screws or nose pads.
Chain Nose Plier: Standard chain nose pliers for grabbing and manipulating components.
Hollow Snipe Nose Plier: Offers angled jaws for reaching recessed areas and cutting wires.
Round Round Nose Plier: Provides smooth rounded jaws for gentle bending and manipulation.

The Screw In-Forcer: Helps push in stubborn screws with added leverage.
Curved Long Nose Chain Plier: Offers angled access for reaching difficult areas.
Cutters:

Side Cutting Plier: Cuts wires and thin metal parts cleanly.
Concorde Carbide Cutter: Cuts through hardened metals like spring hinges with ease.
Oblique Head End Cutting Plier: Angled cutting head for reaching awkward spots.
Oblique Head End Cutting Plier for Hard Metals: Similar to above but with increased cutting power for challenging materials.
Narrow End Flush Cutting Plier: Leaves smooth finish when cutting close to surfaces.
End Cutting Plier: General-purpose end cutting pliers for various materials.

Deblocking Tools:

Briot Axcell Deblocking Plier: Specialized tool for safely removing blockages from spring hinge mechanisms.

Deblocking Plier: Offers alternative for deblocking hinges and other mechanisms.
Eye wire, Temple, Bridge and Flaring Pliers:

Eye wire Forming Plier: Shapes and bends eye wires precisely.
Narrow Eye wire and Bridge Forming Plier: Suitable for delicate adjustments on narrow eye wires and bridges.

Temple Bending Plier: Bends temple arms smoothly and evenly.
Bridge Reducing Plier: Reduces bridge width on specific frame styles.
Screw Flaring Plier: Flares screw heads for secure sunglass lens retention.

Nose Pad Adjusting Pliers:
Nose Pad Adjusting Plier: Adjusts and tightens nose pads for optimal fit.
Round Flat Nose Plier: Provides general gripping and adjusting functionality for various parts.

Pad Arm Curving Plier: Bends nose pad arms for customized fit.

Nose Pad Popping Plier: Safely removes old or stuck nose pads.
Budge tool Nose Pad Inserting Plier: Assists in inserting new nose pads with ease.
Combo Pad Arm/Nose Pad Adjusting Plier: Combines functions for adjusting both pad arms and nose pads.

Line Parallel Jaw Pliers:
Temple Angling Plier: Adjusts temple angles precisely with parallel jaws.

Double Delrin Jaw Plier: Offers cushioned grip for adjusting various parts.

End Piece Adjusting Plier: Adjusts end pieces and hinges securely.

Long Chain Nose Plier: Reaches into tight spaces for gripping and manipulation.

Pantoscopic Tilt Plier: Adjusts pantoscopic tilt of lenses for optimal vision.

Shootout Frame Repair Multi-Tool:
The Shootout Frame Repair Multi-Tool Kit: Combines multiple functions for various frame repairs and adjustments in one convenient tool.

Spring Hinge Plier Kit: Specialized kit for opening, closing, and adjusting spring hinge mechanisms.

Bench Aids:
Rubber Guard Bench Block: Protects surfaces and provides stability for adjustments.
Bench Anvil Kit: Offers different anvil surfaces for various repair tasks.

Lens Clocks:
Ball Tipped Lens Clock: Measures lens curvature.

Lens Measuring:
Lens Thickness Gauge: Measures lens thickness for compatibility with frames.
Wide Mouth Lens Caliper: Measures lens diameters

Rimless:

Screwless Rimless Compressing Bracing Plier: Holds and compresses screwless rimless frames during repairs.
Screwless Rimless Compressing Plier/Lab Use: Similar to above but with added features for lab environments.
Rimless Bracing Plier: Provides general bracing for rimless frames.
Narrow End Flush Cutting Plier: Cuts wires flush with rimless frame surfaces.
Rimless Post Pulling Plier: Safely removes rimless lens posts.
Rimless Post Pushing Plier: Pushes in new rimless lens posts.
Rimless Tube Refresher: Cleans and polishes rimless frame tubes.
Lens Harpoon: Helps remove and insert lenses in rimless frames.
Rimless Tube Stripper: Strips old threads from rimless frame tubes.
Screw Finishing Tool: Smooths and polishes screw heads after adjustments.
The Swarf Removal Tool: Cleans debris from hinge mechanisms.

Deluxe Drivers:
Universal Screw and Nut Grabber: Grips and removes various screw and nut types.
The Stealth Driver: Discreetly adjusts eyewear screws with concealed design.
Stiletto Power Driver: Offers high torque for stubborn screws.
Le Forque Driver Set: Specialized drivers for specific screw types.
Spring Clamp Screwdriver: Holds small screws in place for easy insertion.

Standard Drivers:
Driveshaft Drivers: Interchangeable driveshafts with multiple screwdriver heads.
Pocket Clip Driveshaft Drivers: Compact and portable driveshaft drivers.
TruBlue Aluminum Driveshaft Driver: Durable and lightweight driveshaft driver.
Lock Nut Ejector Wrench: Removes stuck lock nuts.
Get-A Grip Driver Cushions: Provides improved grip and comfort for drivers.
Driver Blades: Replacement blades for various driver types.

Lens Pliers:
Sizing and Screw Inserting Plier: Helps size and insert screws in lens mounting holes.

Eyewire Closing Plier: Closes and secures eyewires precisely.
Lens Turning Plier: Rotates lenses for easier positioning during adjustments.
Glass Chipping Plier: Safely removes small chips from glass lenses.
Tweezer, Files, Deburring, Drills and Hammer:

Self-Closing Fine Tip Tweezer: Grasps small parts with precision.
Pillar File: Smooths rough edges on metal parts.
Round Rat Tail File: Accesses and smooths narrow spaces.
Screw Head Slotting File: Creates or repairs screw driver slots.
Screw Finishing File: Smoothes and polishes screw heads.
Zylonite File: Polishes and shapes Zyl frames.
Lens Harpoon: Assists with lens removal and insertion.
The Swarf Removal Tool: Cleans debris from hinge mechanisms.
Plastic Lens Screw Drill Set: Drills holes for plastic lens screws.
Riveting Hammer: Sets rivets securely in frames.
Frame Warmers:
Glass Beads: Heated beads warm frames for adjustments without damaging the material.
Hot Box Glass Bead Frame Warmer: Contains heated glass beads for efficient frame warming.
Pattern Blanks:
Pattern Blanks: Templates used for tracing and shaping custom frames.
PD Rules:
6" Stainless Steel PD Rule: Measures pupillary distance in millimeters.
6" White Plastic PD Rule: Similar to above but in white plastic.
7" Laboratory Millimeter Rule: Metric rule for various measurements.
7" Dispensing PD Rule: Combines PD measurement and pupil gauge markings.
The PD Extender: Extends the reach of PD rules for larger patients.
PD³ Multi-Rule: Incorporates multiple functions like PD measurement, ruler, and pupil gauge in one tool.

Numont Plier Tri-Angling Plier:

Combo Round Chain Nose/Delrin Plier:

Combo Round Chain Nose/Delrin Plier:

Finger Piece Plier:

- Double Delrin Jaw Plier:

Chain/Snipe Nose Pliers:

- Long Nose Chain Plier:

Long Nose Chain Plier

- Chain Nose Plier:

Chain Nose Plier

- Hollow Snipe Nose Plier:

Hollow Snipe Nose Plier

Cutters:

- Side Cutting Plier:

Side Cutting Plier

- Concorde Carbide Cutter:

Concorde Carbide Cutter

- End Cutting Plier:

End Cutting Plier

Eyewire, Temple, Bridge and Flaring Pliers:

- Eyewire Forming Plier:

- Temple Bending Plier:

Temple Bending Plier

- Screw Flaring Plier:

Screw Flaring Plier

Nose Pad Adjusting Pliers:

Nose Pad Adjusting Plier

- Round Flat Nose Plier:

Round Flat Nose Plier

Line Parallel Jaw Pliers:

- Temple Angling Plier:

Temple Angling Plier

Rimless:

- Rimless Post Pulling Plier:

Rimless Post Pulling Plier

- Lens Harpoon:

Lens Harpoon

Deluxe Drivers:

- Stiletto Power Driver:

Stiletto Power Driver

- Le Forque Driver Set:

Le Forque Driver Set

Driver Blades:

- Driver Blades:

Driver Blades set

Lens Pliers:

- Sizing and Screw Inserting Plier:

Tweezer, Files, Deburring, Drills and Hammer:

- Self-Closing Fine Tip Tweezer:

SelfClosing Fine Tip Tweezer

- Pillar File:

Pillar File

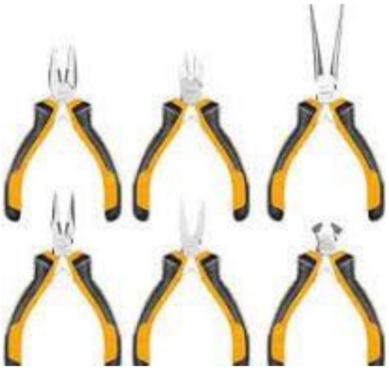
Frame Warmers:

- Glass Beads:

Glass Beads for frame warming

PD Rules:

- 7" Dispensing PD Rule:



Sample Questions:

1. **Define Following terms?**
   - a. **Focimeter**
   - b. **Digital PD meter**
   - c. **Dispensing PD ruler**
   - d. **Pupilometer**
   - e. **Lens Marking Machine**

Focimeter:

An instrument that measures the optical power of lenses to determine their refractive correction for nearsightedness, farsightedness, or astigmatism.
Crucial for verifying lens accuracy and ensuring proper vision correction.
Benefits: Ensures accurate prescription fulfillment, improves patient satisfaction.
Digital PD Meter:

Measures the pupillary distance (PD) – the distance between the pupils – which is essential for precise lens centration in frames.
Digital PD meters offer faster and more accurate measurements compared to traditional rulers.
Benefits: Improves centering accuracy, optimizes visual clarity and comfort.
Pupilometer:

A manual instrument used to measure pupillary distance when a digital PD meter is unavailable.
Requires careful alignment and practice for accurate results.
Benefits: Backup option for PD measurement, useful in remote locations or limited settings.
Dispensing PD Ruler:

A simple ruler with markings to measure pupillary distance directly on a patient's face.
Less accurate than digital PD meters but readily available and portable.
Benefits: Quick and convenient option for basic PD measurement, useful for preliminary fitting or troubleshooting.
Lens Marking Machine:

Etches identification marks on lenses for tracking and record-keeping purposes.
Can be hand-operated or laser-based, with laser marking offering a permanent and precise etch.
Benefits: Ensures proper tracking of lenses within the lab, simplifies prescription fulfillment, promotes accountability.

UNIT 18
INCLUSIVE EYE HEALTH

THEMES

1. Disability Inclusion
2. Safeguarding
3. Gender Equity

Learning Objectives:

After successful completion of the course participants should be able to:

- Understand the broader context of inclusion and its relationship with universal health coverage.
- Apply advance guidelines of attitudes and behaviours towards inclusive clinical practices.
- Apply principles of Reasonable accommodation on clinical/hospital settings.
- Design screening & outreach programs accessible by all.
- Understand the use of assistive devices for independent living.
- Understand the significance of ensuring gender equity in eye care.

SN	Topic	Contents	Hour 30	Activities to support learning objectives
1	Inclusion	•What does inclusion mean? •What does social exclusion mean	2	•Ask students to think about one change they will make to their ways of working to improve inclusive practices. •Show a short video on examples of exclusion and inclusion.
2	Disability & epidemiology of disability	•What is meant by disability? •How functional impairment (being a clinical/physical state) is different from disability imposed by systems and/or society, activity limitation and participation restriction?	2	•Show a short video that highlight impact of disability on health of a person
3	Accessibility	•What is meant by accessibility? • What does barrier free access? •What is meant by 'reasonable accommodation'	2 + 2	•Show a short video on accessibility options for persons with visual impairment, and persons with other disabilities

4	Inclusive code of ethics for medical/clinical practices	•In the context of inclusion, what is meant by attitudes, behaviour, and practices, and beyond? •Disability etiquettes necessary to ensure health equity	2	Students will develop a job specific code of conduct as part of the activity.
5	Reasonable accommodation	•What is meant by Reasonable accommodation? •What implications does this have for health professionals? •How can we apply Reasonable accommodation to provision of eye care services? •How to ensure accessibility of a building with special emphasis on ramps, washroom, equipment, and signage.	3 + 2	•Show a video on accessible buildings. •Undertake a group exercise using 3 groups to discuss and come up with suggestions on what implications accessible hospitals/clinics would have for (8 hours): •**Group 1** – eye clinic and refraction areas • **Group 2** – Eye wards •**Group 3** – lecture rooms and library
6	Inclusive Screening/ outreach programmes	•How can we make an eye health screening programme inclusive? •Guidelines for screening camps/outreach programmes	3 + 2	•Arrange for the students to work with the community eye health team to organise an inclusive eye health screening programme.
7	Assistive / Adaptive Technology	• Orientation on assistive/adaptive technology for clients of low vision, hearing, and mobility impairment	2	•Show a video that relates assistive devices with opticianry practices
8	•Child Safeguarding	•What is meant by Child Safeguarding? •What is the difference between child safety, child safeguarding and child rights? •What are basic rights of children according to United Nation Convention on the rights of children (UNCRC)? •What are six child safety rules in healthcare?	2	•

		•What steps currently need to be taken in our clinical practice to ensure child safety		
9	•Gender equity	•Why gender equity is important? •How we can improve the eye health outcomes of women and girls	2 + 4	•Show a video that highlights importance of gender equity. •Group exercise: identifying barriers and creating solutions

1. Disability Inclusion

Defining Inclusion

A process through which a society changes to recognise human differences and the struggle against discrimination. The goal of inclusion is to equalize opportunities, fostering a sense of belonging and ensuring that individuals feel respected and valued for who they are. It is the encompassing practice of ensuring that people of differing abilities, gender, age, ethnic groups, etc. belong, are engaged, and are connected to the goals and objectives of the whole society.

Defining social exclusion

Social exclusion is when some people or groups face barriers that keep them from fully participating in society. This creates unfair differences in access to resources, opportunities, and rights, leading to health inequalities. In simpler terms, it's a situation where certain individuals or groups are left out and face disadvantages in society.

"Understanding Disability: More Than Just Health Challenges"

Disability is not just about physical or clinical conditions; it involves how people interact with the world around them and the barriers they may encounter.

Defining Disability

Disability is commonly defined as a condition or function judged to be significantly impaired, limiting a person's ability to perform day-to-day activities. It is essential to recognize that disability is not solely a result of an individual's health condition; it is shaped by the way society and systems respond to differences.

Functional Impairment vs. Disability

Functional impairment refers to limitations in an individual's physical or mental functions. It is a clinical or physiological state, a description of what the body or mind may struggle with. Disability, on the other hand, extends beyond the clinical realm to encompass the challenges individuals face due to societal and systemic factors.

Activity Limitation and Participation Restriction

Activity limitation involves difficulties an individual may have in executing tasks or actions, such as walking or writing. Participation restriction relates to societal barriers that limit an individual's involvement in various life situations, such as exclusion from education or employment opportunities.

The Role of Society and Systems

Disability is often exacerbated by societal attitudes and systemic structures. Imagine a world without wheelchair ramps or braille signage—these omissions create barriers, restricting the participation of individuals with disabilities. Societal perceptions, stereotypes, and inaccessible environments contribute significantly to the disabling experience.

Breaking Down Barriers

Creating an inclusive society involves dismantling physical, communication, and attitudinal barriers. It requires recognizing and accommodating diverse needs, promoting accessibility, and fostering an environment where everyone, regardless of their abilities, can actively participate.

In essence, disability is not just a clinical label; it is a dynamic interaction between individual abilities and the world around us. By acknowledging the societal and systemic aspects of disability, we can work towards creating a more inclusive and understanding environment, ensuring that everyone has the opportunity to engage fully in all aspects of life.

Why is inclusion important?

Disability is present in all communities and about 15% of the population can have some form of disability. Women, older people, and poor people are more likely to have a disability. Everyone will experience conditions that contribute to disability at some point in their lives.

People with disability need to access health services for the same reasons as people without a disability. People with disability may also need to access health services for additional reasons relating to disability. People with disability can face several barriers to access to health services including accessibility, long distances, attitudinal barriers of health staff, lack of health information and awareness, and financial barriers. There are many ways primary health services can address the access barriers experienced by people with disability, often for little expense.

Health Communication regarding preventive measures and treatment plans should be made accessible for people with disabilities, especially those with vision or hearing impairment, which might include use of large font size, good colour contrast, electronic prescriptions, and use of essential signs of Pakistan Sign Language. Health care providers should communicate directly and establish rapport with community members and patients with disabilities during screening as well as health care service provision to address some of the communication barriers.

Accessibility

Accessibility means making things easy for everyone to use, especially for people with disabilities. It involves designing things like products, places, or services in a way that everyone can easily access and use them. The goal is to remove any obstacles and make sure that everything is understandable and usable for people of all abilities. This might involve approaches as simple as offering flexible schedules and timings or ensuring that buildings, services, and equipment are accessible for persons with disabilities.

Barrier-free access

Minimum provisions to accommodate a person=using a typical manual wheelchair or other manual mobility assistance devices such as walking aids, including canes, crutches, braces and artificial limbs.

Reasonable Accommodation

Reasonable accommodation refers to adjustments or modifications made in the workplace or other environments that allow individuals with disabilities to perform their job duties or access services without facing undue hardship. Reasonable accommodations can take various forms, such as providing assistive technologies, modifying work schedules, altering the physical layout of spaces, offering flexibility in policies, or providing additional support.

20 Key Steps for promoting Disability Inclusion

An accessibility audit of the health facility can help identify barriers - some of the main ways to address these barriers are presented in the Disability Inclusion matrix below.

Themes	Challenges faced by people with disabilities	How to promote disability inclusion in primary health care services

Attitudinal barriers	One of the most common barriers to health services is the negative and limiting attitude and knowledge some health workers and other health facility staff have towards people with disability. Health workers' negative and limiting attitudes often compound other types of barriers, such as physical and communication barriers	The most effective way to address attitudinal barriers is to raise awareness and build capacity for disability inclusion among all health service staff. 1. Raise awareness among all health service staff (including health workers, orderlies, receptionists, and security guards) of the rights and needs of people with disability
Physical barriers	Health service infrastructure, the equipment used in health facilities, and transport to and from health services can all pose a barrier to health care if they are inaccessible for people with disability. Some of the main barriers include: ♦ Uneven or rough pathways to entrances or between buildings ♦ Steps/stairs at entrances and lack of ramp access ♦ Narrow door openings that do not fit a wheelchair. ♦ Reception desks that are too high for wheelchair users ♦ Furniture in hallways ♦ Lack of height-adjustable or low examination tables that are easier to transfer on and off from	For existing facilities, reasonable accommodations can be made to overcome physical barriers. Improving the accessibility of healthcare facilities does not have to be expensive. Some of the main actions that can be taken include: 2. Designate accessible car parking spaces close to the facility entrance. 3. Have a ramped entrance into the facility. 4. Provide clear signage so that people know where to go. 5. Clear hallways and clinic rooms of obstructions and excess furniture. 6. Ensure reception desk height is low enough to be seen over if seated in a wheelchair. 7. Have a foldable cot available in examination rooms, which can be set up quickly for patients who are unable to climb on to an examination table. 8. Ensure health education/prevention activities are held on the ground floor

	♦ Inaccessible diagnostic equipment ♦ Doors that are heavy or door handles that are too high. ♦ Inaccessible toilets – insufficient space for wheelchairs or a carer to assist, lack of grab rails, inward-opening doors. ♦ Inaccessible drinking-water and handwashing facilities.	of buildings or in community spaces that are accessible. 9. Provide accessible toilets with a wide doorway, outward opening door and appropriately positioned grab rails. 10. Ensure drinking-water and hand hygiene materials are placed at heights accessible to wheelchair users.
Communication barriers	People with disability have less access to health information and lower levels of knowledge about their health and the health services available to them, compared with other people. People who have disabilities that affect their hearing, speaking, reading, writing or understanding, and who communicate differently from people who do not have these disabilities, commonly report communication barriers to accessing health information	Some of the main actions that can be taken include: 11. Involve people with disability in identifying and addressing communication barriers to health information and services. 12. Communicate health information to partners, families, and carers of people with disability. 13. Provide “patient-centred care” during one-on-one interactions with people with disability - health professionals should communicate directly with persons with disabilities during treatment provision. 14. Include people with disability in health promotion campaigns
Health Management Information	Health information systems must include collection of information about disability. A lack of data about people with disability results in their health needs being overlooked	Some of the main actions that can be taken include: 15. Disaggregate patient data about people with disabilities treated to the extent possible 16. Train health staff to collect and record disability data

Emergencies and Disasters	People with disability have an increased need for health information and services during emergencies and disasters. Emergencies can include natural disasters (such as earthquakes, floods and cyclones) as well as food insecurity, armed conflict and other situations where people are forced to evacuate or flee their homes. Emergencies can increase the number of people with disability due to injuries sustained during an emergency, or exacerbated during an emergency because they are left untreated. People with disability are generally excluded from the planning and delivery of emergency response measures, including the planning and delivery of health services	Some of the main actions that can be taken include: 17. Engage with people with disability and Organisations of Disabled Persons (OPDs) for emergency planning and preparation decision-making. 18. Address physical barriers faced by people with disabilities – these barriers are worsened during emergencies. 19. Ensure adequate communication so that people with disabilities receive early warning information about the onset of an emergency, about evacuation procedures, or where and how to access essential services (including health services) during an emergency. 20. Ensure training of health service providers to provide health services to people with disability during emergencies is conducted during routine emergency preparedness and response training, or as a component of disability inclusion training. In the event of an emergency, orient and sensitise health service staff and health workers to prioritise disability issues and needs

(Adapted from: Disability-inclusive health services toolkit: a resource for health facilities in the Western Pacific Region. Manila, Philippines. World Health Organization Regional Office for the Western Pacific. 2020)

Disability etiquettes

The Basics

ASK BEFORE YOU HELP

Interact with the person as a person first! Just because someone has a disability, don’t assume he or she needs help. Offer assistance only if the person appears to need it and ask how you may help before you act.

BE SENSITIVE ABOUT PHYSICAL CONTACT

Some people with disabilities depend on their arms for balance. Grabbing them – even if your intention is to assist – could knock them off balance. Avoid patting a person on the head or touching his wheelchair, scooter or cane. People with disabilities consider their equipment part of their personal space.

THINK BEFORE YOU SPEAK

Always speak directly to the person with a disability, not to his companion, aide or sign language interpreter. Don’t apologize if you use an expression such as “I gotta run” or “See you later” that relates to the person’s disability. These expressions are part of everyday language, and it is likely the apology will be more offensive than the expression.

DON’T MAKE ASSUMPTIONS

People with disabilities are the best judge of what they can or cannot do. Don’t make decisions for them about participating in any activity.

People Who Use Wheelchairs or Have Mobility Impairments

- Offer to shake hands when greeting someone.
- Don’t lean on or touch someone’s wheelchair.
- Place yourself at eye level when in conversation.
- People who use canes, crutches or other assistive devices use arms for balance. Refrain from touching them or moving an object around them unexpectedly.

People Who Are Blind or Visually Impaired

- Identify yourself and allow the rest of the group to do the same.
- Offer your elbow if someone needs to be guided; don’t take his.
- Walk on the opposite side of a guide dog or cane.
- Give specific, non-visual directions.
- Orient people with visual impairments using numbers on the face of a clock.

People Who Are Deaf or Hard of Hearing

- Follow the person’s cues to find out if she prefers sign language, gesturing, writing or speaking.

- Before speaking to a person who is deaf or hard of hearing, tap on her shoulder or wave your hand to get her attention.
- Use a normal tone, speak clearly and distinctly.
- Rephrase, rather than repeat, sentences that the person doesn't understand.
- If a sign language interpreter is present, speak directly to the person who is deaf, not to the
- interpreter.
- Be prepared to write notes to communicate, if necessary.

People with Speech Disabilities

- Give the person your full attention and be patient.
- Don't interrupt or finish the person's sentences.
- If you are not sure whether you have understood, you can repeat for verification.
- If, after trying, you still cannot understand the person, ask him to write it down or to suggest another way of communicating.

People with Developmental and Cognitive Disabilities

- Speak to the person in clear sentences, using simple words and concrete concepts.
- Rephrase comments or questions for better clarity.
- Stay focused on the person as he responds to you and be patient.
- Avoid talking about a person with a developmental disability when he is present.

(Adapted from: "Disability Etiquette – Tips on Interacting with People with Disabilities", United Spinal Association. www.unitedspinal.org)

Making Screening camps inclusive

This is a problem-based activity and students will generate material for scenarios presented.

Assistive devices

Assistive technology (AT) is any item, piece of equipment, software program, or product system that is used to increase, maintain, or improve the functional capabilities of persons with disabilities. Assistive devices are external devices that are designed, made, or adapted to assist a person to perform a particular task. Many people with disabilities depend on assistive devices to enable them to carry out daily activities and participate actively and productively in community life. Without assistive technology, people are often excluded, isolated, and locked into poverty, thereby increasing the impact of disease and disability on a person, their family, and society.

People who most need assistive technology include:

- people with disabilities

- older people
- people with noncommunicable diseases such as diabetes and stroke
- people with mental health conditions including dementia and autism
- people with gradual functional decline.

Levels of assistive devices

Assistive devices range from simple, low-technology devices (e.g. walking sticks or adapted cups), to complex, high-technology devices (e.g. specialized computer software/hardware or motorized wheelchairs). It is helpful to consider this wide variety of assistive devices under different categories.

"Low Tech" Assistive Technology

Low-tech assistive technology (AT) typically refers to non-electronic devices or simple tools that can be used to help people with disabilities to perform tasks. Some examples of low-tech AT include:

Large print books: Printed with larger than normal text, these are easier to read for people with vision impairments.

Talking calculators: Calculators that speak the numbers aloud are useful for people who are blind or have difficulty reading.

Wheelchair ramps: These structures offer wheelchair users access to buildings and other areas that would otherwise be inaccessible.

Magnifying glasses: A classic tool to boost the size of small text or objects for easier visibility.

Raised markings: Raised buttons or markings on household items like ovens or microwaves assist users in differentiating controls, especially if they have visual impairments.

Non-slip bathmat, walking sticks, long handled shoehorn, tactile dots and shower chairs are also examples of low-tech assistive devices.

"High Tech" Assistive Technology

High-tech assistive technology (AT) typically refers to electronic devices or software applications designed to ease interaction with their environment for people with disabilities. Some examples of high-tech AT include:

Power wheelchairs: Motorized chairs that can be operated by people who have difficulty walking; they provide a great deal of independence and mobility for people with disabilities.

Screen readers: Software applications that read aloud the text on a computer screen; they provide people who are blind or have low vision a way to use computers without seeing the screen.

Website accessibility overlays or plugins: Software applications that can be installed on websites or computers to make them more accessible to people with disabilities; they can be an especially valuable tool for people with disabilities who want to access websites and computers that were not originally designed with accessibility in mind. Accessibility overlays or plugins can provide a variety of features, such as:

- Text-to-speech conversion
- Zooming
- Color contrast adjustments
- Keyboard navigation
- Screen reader compatibility

Augmentative and alternative communication (AAC) devices: Used by people who have difficulty speaking or writing; AAC devices can be used to generate speech, type text, or use symbols to communicate.

Eye-tracking systems: People who are unable to use their hands to control computers and other devices can use these; they work by tracking eye movements.

2. Safeguarding

Introduction

Safeguarding means promoting and protecting people's health, wellbeing, and human rights, and enabling them to live free from harm, exploitation, and abuse. A Safeguarding approach means minimising the risk of harm, exploitation or abuse of children and adults from staff, operations, and programme activities. It includes reporting any Safeguarding concerns about a child or adult within communities where eye care programmes are implemented to the appropriate authorities.

A child is any human being under the age of 18 years. An adult-at-risk is any person aged 18 years and older who may be at risk of abuse or exploitation due to their dependence or reliance on others for services, basic needs, or protection, and according to context, for example, in humanitarian situations or people with disabilities.

An adult may also be at risk/vulnerable when in a relationship (social or work) with another who seeks to misuse their position of authority or trust to control, coerce, manipulate, or dominate them. An adult may also be at risk if their decision-making capacity is impaired and/or they do not have the support to make a decision. Safe recruitment, signing child safeguarding code of conduct and following the ‘two adult rule’ should be made compulsory as part of preventive actions for child safeguarding. Where possible, a guide/one window system be made available for elderly patients.

10 Key Steps for promoting Safeguarding

1. Keeping children, adults and adults-at-risk safe from any harm	6. Ensure that visitors to your health facility obtain appropriate consent before images or stories of adults and children are captured or shared
2. Create a culture that supports Safeguarding, prevents harm and protects people from visitors and staff from all forms of violence (physical, psychological, emotional, socio-cultural, and gender-based), abuse, exploitation, neglect and discrimination	7. Ensure that reporting and incident management procedures to handle incidents of abuse are in place, communicated to staff and effectively used to enable an appropriate and swift investigation of any given case
3. Take preventive action before harm occurs	8. Treat all Safeguarding Concerns in a professional, sensitive, timely and confidential manner that incorporates procedural fairness and take immediate and appropriate action in response
4. Appoint a Safeguarding Focal Person (SFP) with clear responsibilities for coordinating the implementation of Safeguarding in your health facility	9. Ensure any acts of Victimisation are investigated and dealt with promptly
5. Provide necessary orientation, training, and support to staff in your health facility to ensure effective implementation of Safeguarding	10. Take appropriate action on confirmation of a malicious or vexatious allegation made

UN Convention on the Rights of the Child

The UN Convention on the Rights of the Child (UNCRC) is the most complete statement of children’s rights ever produced and is the most widely ratified international human rights treaty in history. The Convention has 54 articles that cover all aspects of a child’s life and set out the civil, political, economic, social and cultural rights that all children everywhere are entitled to. Some of the articles that are directly related to clinical practice are mentioned here:

Article 2 (non-discrimination)

The Convention applies to every child without discrimination, whatever their ethnicity, sex, religion, language, abilities or any other status, whatever they think or say, whatever their family background.

Article 3 (best interests of the child)

The best interests of the child must be a top priority in all decisions and actions that

affect children.

Article 12 (respect for the views of the child)

Every child has the right to express their views, feelings and wishes in all matters affecting them, and to have their views considered and taken seriously. This right applies at all times, for example during immigration proceedings, housing decisions or the child's day-to-day home life.

Article 24 (health and health services)

Every child has the right to the best possible health. Governments must provide good quality health care, clean water, nutritious food, and a clean environment and education on health and well-being so that children can stay healthy.

Article 25 (review of treatment in care)

If a child has been placed away from home for the purpose of care or protection (for example, with a foster family or in hospital), they have the right to a regular review of their treatment, the way they are cared for and their wider circumstances.

3. Gender Equity

Gender equity is about making sure that everyone, no matter their gender, is treated fairly and equally. It means that people should have the same opportunities and chances in life, whether they identify as male, female, or intersex. When we talk about gender equity, we want to break the idea that certain genders should have more advantages or better treatment than others.

Having gender equity is important because it creates a world where everyone can thrive. It means that people, regardless of their gender, can go to school, work, and pursue their dreams without facing unfair obstacles. When we embrace gender equity, we're saying that every person's ideas, talents, and contributions are valuable, no matter their gender. It's about building a community where everyone is respected and can make a positive impact.

5 Key Steps for promoting Gender-Responsiveness in health.

1. Orient the health facility staff on gender-responsiveness, what it means in practice and its importance in health services including eye health	4. Ensure that women and men are both consulted when designing or implementing a health programme relating to your health facility
2. Assess the gender-responsiveness level of the services provided at your health facility and develop a plan of action to improve the level incrementally to a gender-transformative one	5. Address gender inequality throughout all stages of health planning, programming and service delivery and regularly monitor application of gender–specific and gender–transformative principles in the day-to-day work at the health facility
3. Disaggregate data by sex and age especially regarding morbidity, mortality and other key health indicators used at the health facility	

Sample Questions:

Short Question:

1. Explain why inclusion is crucial in society.
2. Discuss how it promotes equal opportunities and a sense of belonging for individuals with diverse abilities, backgrounds, and identities.
3. Elaborate on the concept of disability beyond physical or clinical aspects.
4. How does disability relate to societal interactions and the barriers individuals encounter.
5. Compare and contrast functional impairment and disability.

Long questions

1. Explore the various barriers that hinder inclusion (attitudinal, physical, systemic).

2. Discuss effective strategies to overcome these barriers and promote a more inclusive society.

3. Discuss need of safeguarding in a healthcare system.

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