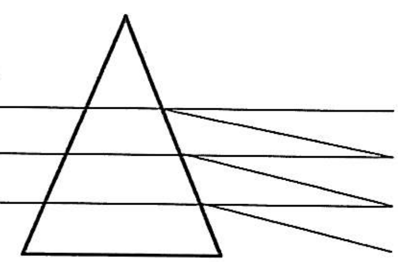
ABO PREPARATION

Week

2

Basic Optical Principles



ABO PREPARATION COURSE

2: Basic Optical Principles

Published By:

California Optical License School
4330 Barranca Parkway
Suite 101-129
Irvine, CA 92714
(714) 551-5455

1990

2: Basic Optical Principles

The basic unit of linear measurement in the metric system is the meter. It is often useful to compare units of measurement in the metric system with those of the English system of feet and inches which we use every day.

Metric System Of Measurement

One meter (m) is equal to:	39.37 inches
One inch is equal to:	25.4 millimeters (mm)

The two comparisons illustrated above should be memorized. They will help you in some of the practice exercises later in this section and you may be required to compare these two systems on the ABO exam.

One Dollar is Equal To:	One Meter is Equal To:
10 dimes	10 decimeters (dm)
100 cents	100 centimeters (cm)
1000 mils	1000 millimeters (mm)
(10 mils = 1 cent)	

The metric system of measuement is actually easier to use than the English system of inches and feet which we use every day. The metric system uses one basic unit of measurement, the meter. All other units are related to the meter by factors of ten. This can easily be compared to our monetary system of measurement which the above table illustrates.

If a basic unit of measurement in the metric system, such as the meter, is preceeded by the prefix "Kilo" that unit is multiplied by one thousand. For example one kilometer is equal to 1000 meters, one kilogram equals 1000 grams and so on.

In our daily work in optics we are primarily concerned with millimeters which is one one thousandth of a meter. Facial measurements such as PD's and bifocal segment heights are expressed in millimeters, as are lens and frame dimensions. However there is one other division of the meter which we need to consider in our field, and that is an incredibly small unit called the nanometer. There are one *billion* nanometers in a meter. On your PD ruler the smallest unit of measurement is a single millimeter. Within that single millimeter could fit one million nanometers. This unit of measurement becomes important when we cover the nature of light later in this session.

Mathematics Review

To be successful in optics, an understanding of certain basic mathematical principles is essential. If you are concerned about math, don't be. If you can add, subtract, multiply, and divide you will do fine in this section. Please be sure to follow the tape carefully for a complete explanation of the examples shown.

Algebra

In algebra, all numbers are preceeded by either a plus (+) sign or by a minus (−) sign. In optics, all prescriptions must also be preceeded by a sign. It is never enough to say that a person is wearing 2.00 diopter lenses. It must always indicated if they are +2.00 diopter lenses or −2.00 diopter lenses. The same is true in algebra, the sign must always be indicated before the number.

Addition Of Two Plus Numbers: The answers are always plus.

Examples:	+2.25	+1.75	+10.25
	+1.50	+2.50	+ 4.50
	+3.75	+4.25	+14.75

May Also Be Written:

+2.25 + 1.50 = +3.75
+1.75 + 2.50 = +4.25
+10.25 + 4.50 = +14.75

Addition Of Two Minus Numbers: The answers are always minus.

Examples:	−2.00	− 6.25	−17.50
	−1.50	− 4.75	− 5.25
	−3.50	− 11.00	−22.75

May Also Be Written:

−2.00 −1.50 = −3.50
−6.25 −4.75 = −11.00
−17.50 −5.25 = − 22.75

Mathematics Review

Addition Of A Plus And Minus Number: The sign of the answer will always be the same as the sign of the higher of the two numbers you are adding. A good rule to remember is as follows: *when adding two numbers of opposite signs, subtract the smaller number from the larger number, then give the answer the sign of the larger number.*

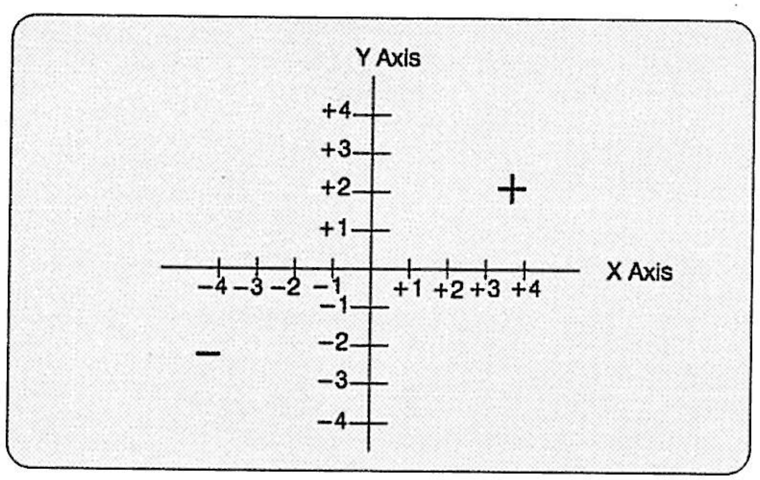
Examples:

+10.25	−3.50	+3.00
− 8.50	+4.75	−7.00
+ 1.75	+1.25	−4.00

May Also Be Written:

+10.25 − 8.50 = +1.75
− 3.50 + 4.75 = +1.25
+ 3.00 − 7.00 = −4.00

Algebraic Addition As A Function Of Direction:



Addition in algebra is a function of direction. Consider a thermometer. All numbers above the zero are plus and those below the zero are minus. If the temperature is three degrees above zero, then drops to two degrees below zero, the temperature has changed by five degrees. Or, stated another way, +3.00 −5.00 = −2.00.

Mathematics Review

Multiplication and Division:

Like Signs: When multiplying or dividing two numbers with the same sign the answer will always result in a number with a plus sign. That is, when two numbers with plus signs are multiplied or divided the answer will be plus. When two numbers with minus signs are multiplied or divided the answer will also be plus.

$-3 \times -3 = +9$	$+18/+3 = +6$
$+4 \times +6 = +24$	$-24/-8 = +3$
$(-3)(-3) = +9$	$+18 \div +3 = +6$
$(+4)(+6) = +24$	$-24 \div -8 = +3$

Note: Multiplication may be indicated by utilizing the times sign (x) or through the use of brackets ( ) as indicated above. Division may be indicated as a fraction or by utilizing the division (÷) sign.

Unlike Signs: When multiplying or dividing unlike signs, that is, when one number is preceeded by a plus sign and the other number by a minus sign, the resulting answer will always be minus.

Examples:

$-4 \times +3 = -12$	$+15/-3 = -5$
$+5 \times -7 = -35$	$-36/+6 = -6$
$-2 \times +4 = -8$	$-52/+2 = -26$
$+11 \times -3 = -33$	$+45/-3 = -15$

Practice Exercises

Add The Following Numbers Algebraically:

1) $+2.50 + 5.75 =$

2) $+1.75 + 3.00 =$

3) $-12.00 + 4.25 =$

4) $-9.50 + 3.00 =$

5) $+1.25 - 2.00 =$

6) $-2.50 - 21.75 =$

7) $-5.25 + 3.50 =$

8) $-1.50 + 1.50 =$

9) $-0.50 + 1.00 =$

10) $+3.375 + 5.125 =$

11) $\begin{array}{r} -4.50 \\ \underline{+3.00} \end{array}$

12) $\begin{array}{r} +2.75 \\ \underline{-3.00} \end{array}$

13) $\begin{array}{r} +9.00 \\ \underline{-3.75} \end{array}$

14) $\begin{array}{r} -3.00 \\ \underline{+4.00} \end{array}$

15) $\begin{array}{r} +3.75 \\ \underline{-4.50} \end{array}$

Simplify The Following By Multiplying or Dividing:

16) $-5 \times -6 =$

17) $\dfrac{+24}{-3} =$

18) $(+30)(-3) =$

19) $+45 / +5 =$

20) $-36 / -6 =$

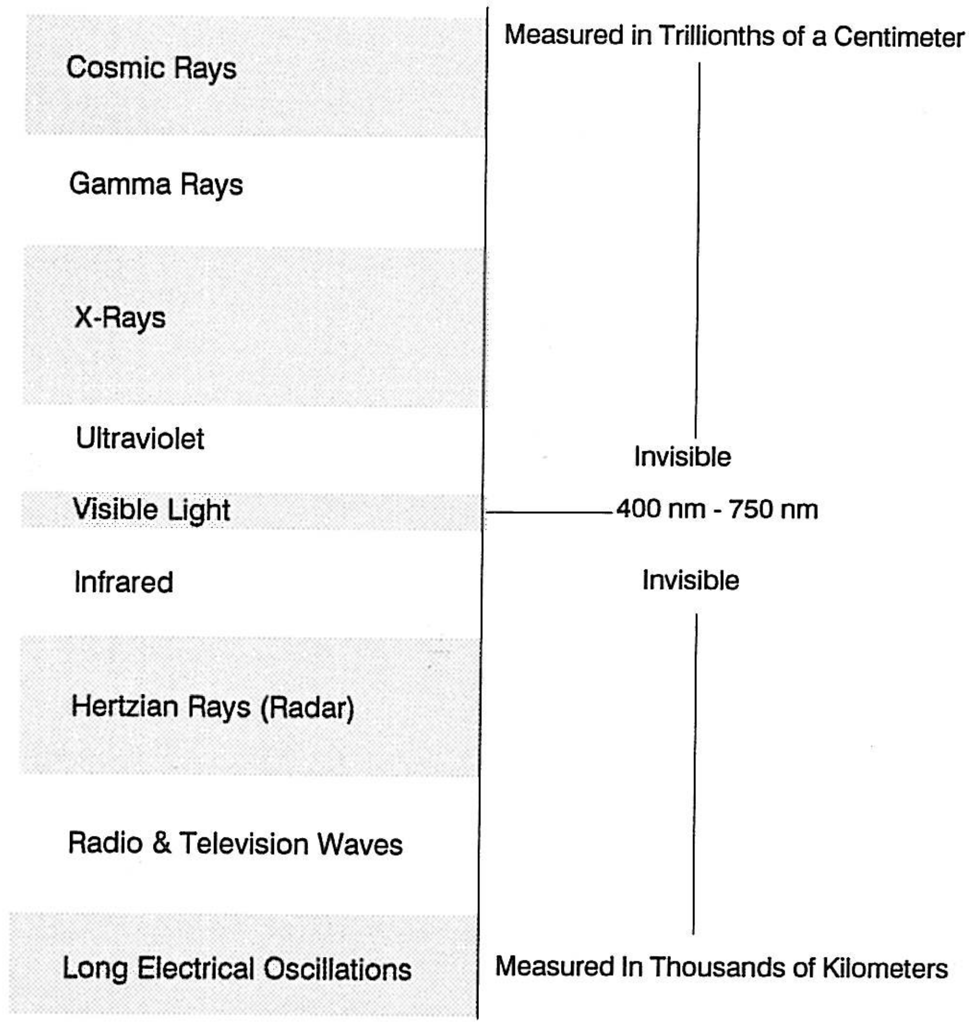
21) $\dfrac{-12}{+3} =$

22) $\dfrac{(+9)(-4)}{-3} =$

23) $\dfrac{-64}{(-2)(-4)} =$

24) $\dfrac{+12}{(-4)(-3)} =$

Electromagnetic Spectrum



E from Sun

Visible light is a form of radiant energy and is part of an overall spectrum of energy called the electromagnetic spectrum. As illustrated above, the scope of the electromagnetic spectrum is enormous. It ranges from extremely short waves such as cosmic rays measuring only about 4 *trillionths* of a centimeter in length, to radio and T.V. waves whose wave lengths measure in the thousands of kilometers. That portion of the electromagnetic spectrum to which the photosensitive receptors of the retina respond lies about in the middle of the spectrum and we call it *visible light*. As demonstrated above, visible light occupies only a very small portion of the overall spectrum of radiant energy. In optics we are concerned not only with the visible spectrum but also with those wave lengths immediately surrounding it which constitute ultra-violet and infrared radiation or "invisible light." The chart on the next page amplifies the visual spectrum.

Visual Spectrum

Short Ultraviolet	200-295 nanometers
Long Ultraviolet	296-400 nanometers
Visible Spectrum	390-750 nanometers
Short Infrared	750-400 nanometers
Long Infrared	1400-2000 nanometers

Waves of the visual spectrum are measured in billionths of a meter. As mentioned earlier, this unit of measurement is called a nanometer (nm). The range of the visible spectrum and its immediate surroundings is indicated above.

Violet	about 380 nanometers
Blue	about 460 nanometers
Green	about 510 nanometers
Yellow	about 560 nanometers
Orange	about 610 nanometers
Red	about 660 nanometers

The visual spectrum can be further broken down into the various colors which are the components of "white light."

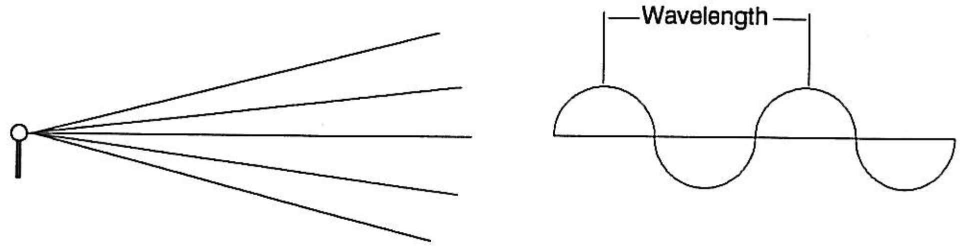
Theories Of Light

Light travels at the rate of about 186,000 miles per second in air. There are two theories which explain how light is propagated. Both theories are necessary to describe how light behaves under all circumstances.

Wave Theory: Put forth by Christian Huygens in the late 1600's describes light as moving in waves, very much like the motion of waves in water.

Corpuscular Theory: Described by Isaac Newton also in the late 1600's describes light as being minute particles which originate from the light's source. These tiny particles are called photons.

Wave Length & Frequency



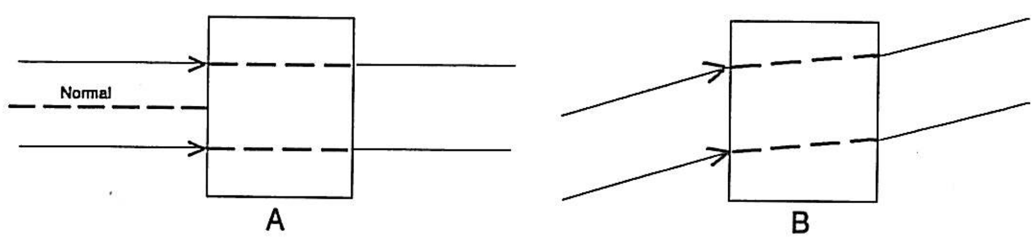
Rays of light diverge and radiate outwardly in all directions from their source. Light can be said to travel in waves.

$\nu \cdot \lambda = C$ (speed of light) ν λ

Wavelength: The distance from the crest of one wave to the crest of another.
Frequency: The number of times the crest or trough of a wave passes a point in space in a given unit of time.

Refraction Of Light

Snell's Law
some type of measurement



When light enters any given transparent material which is denser than air, the velocity of light in that material is reduced. If it enters the new medium at an angle parallel to the normal, as in Figure A above, the light is slowed down while it is in the new material then resumes its original speed after exiting. The direction of the light does not change. If it enters the material at some angle other than parallel, the direction of the light is altered as it exits the denser medium. The denser the material, the more the light is slowed down and the more it is deviated from its original course. The density of any given material can be expressed as *index of refraction* which is covered on the next section of the tape and illustrated on the following page.

Index of Refraction

Index of Refraction of Various Substances

Material	Index
Air	1.000
Cornea	1.370
Crystalline Lens	1.420
Vitreous Humor	1.333
Ophthalmic Crown Glass	1.523
CR-39 Plastic	1.490
Polycarbonate	1.586
Barium Glass	1.602
Flint Glass 1.8	1.805
Titanium Glass	1.701

The index of refraction of any given material is calculated by dividing the speed of light in air by the speed of light in that material. This can be expressed in the following formula:

$$n = \frac{\text{speed of light in air}}{\text{speed of light in material}}$$

where ***n*** is the mathematical symbol which indicates index of refraction.

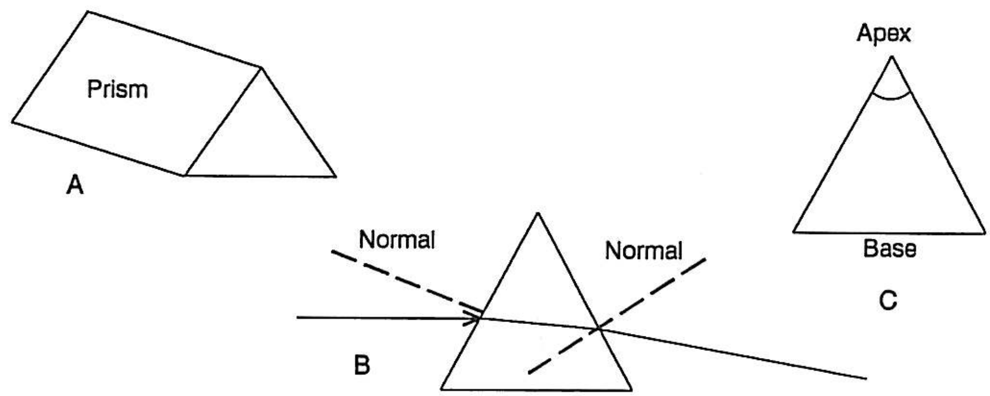
Therefore, if an given material such as CR-39 plastic has an index of refraction of 1.490, it can be calculated that the speed of light in this material=124,832 miles per second, or 1.490 times slower than it travels in air.

The standard index of refraction used in the optical industry is 1.530. Although there is no ophthalmic material commonly used with this index, most optical equipment and tools such as lens clocks and surfacing laps, are calibrated to this index. When materials with other indices are used , calculations are made to "compensate" for their varying densities.

SPEED OF LIGHT IN AIR

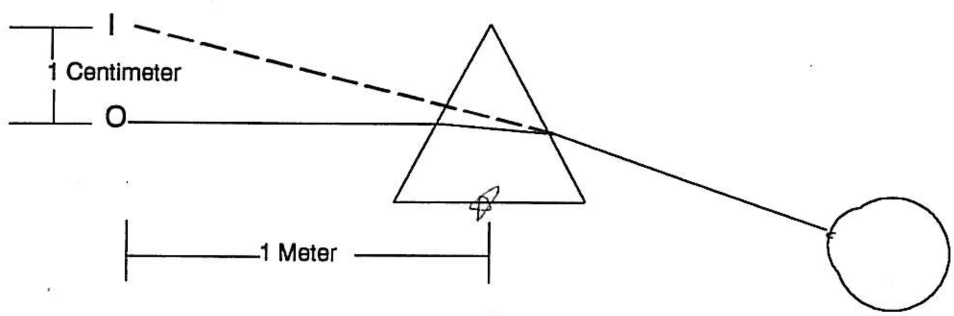
186,000 MILES PER SECOND

Prism



Geometrically, a prism may be said to look like a triangle. The parts of a prism include its apex and base as illustrated above in figure C. Since the sides of a prism are not parallel, rays of light entering it are usually at some angle other than parallel to the normal.

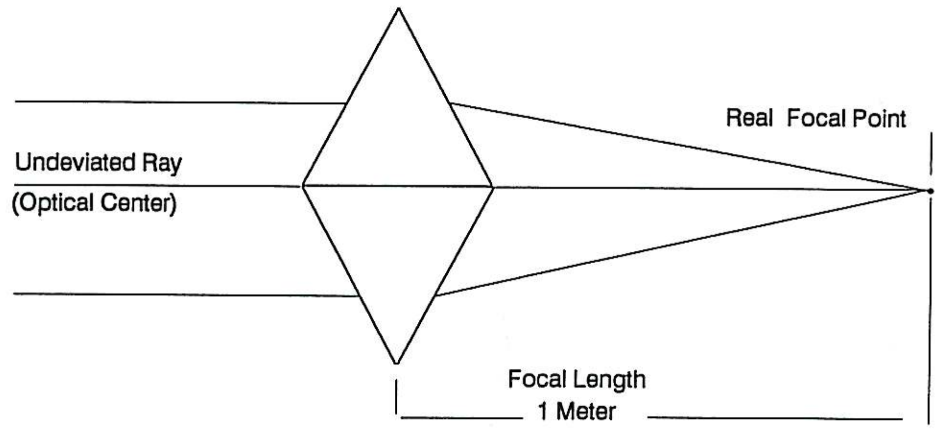
Light is always bent toward the base of a prism.



D

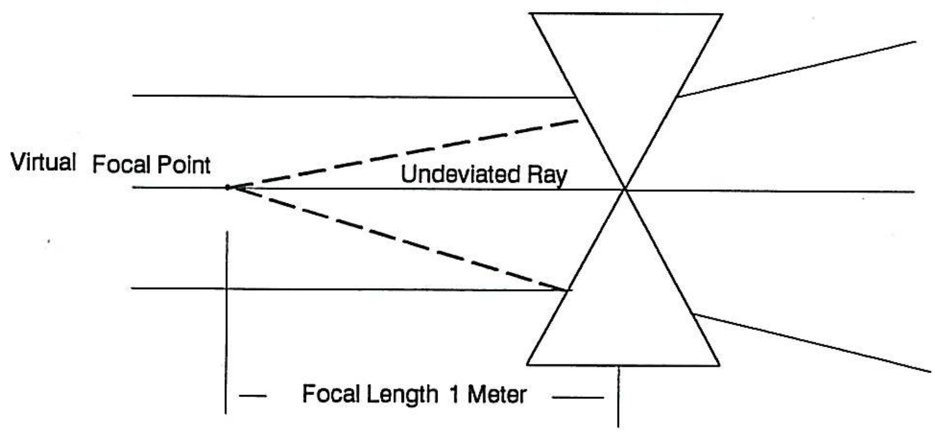
A prism has the ability to displace images. That is, when a ray of light which has been refracted toward the base of the prism enters the eye, it is perceived as having been traveling in a straight line, even though in reality it has been bent. Therefore, the image of the original object appears to be in a position other than the position from which the light had originally eminated. This is known as *image displacement.* Figure D above illustrates this principle where the letter "O"indicates the original position of the object and the letter "I" is the location of the displaced image.
If the original object is one meter from the prism, and the image is displaced a distance of one centimeter, that prism is said to have the power of one prism diopter. This basic definition of a prism diopter may be expressed mathematically as: $cm/m = \Delta$.

Lenses As Prisms



When two prisms are placed base to base they can be said to form a plus lens. Plus lenses cause parallel rays of light to converge or come together. The images formed by a plus lens are called a *real images* because the rays of light actually do come together to form a *real focal point*.. The distance from the lens to the focal point is called the *focal length*.. If the focal length of a given lens is equal to 1 meter, that lens is said to have a power of 1 diopter. The power of the lens above is equal to + 1.00 diopter since it is a converging or plus lens.

OPPOSITE DIRECTION



When two prisms are placed apex to apex they can be said to form a minus lens. Minus lenses cause parallel rays of light to *diverge* which means they never actually come together as they do in a plus lens. However, if we were to extend the rays backward as in the above diagram, they would eventually meet at a point which is called a *virtual focal point* since it doesn't actually exist. The image it forms is called a *virtual image*. The distance from the lens to the virtual focal point is called the focal length. If this distance is equal to one meter, the lens is said to have a power of −1.00 diopter.

Focal Length & Power

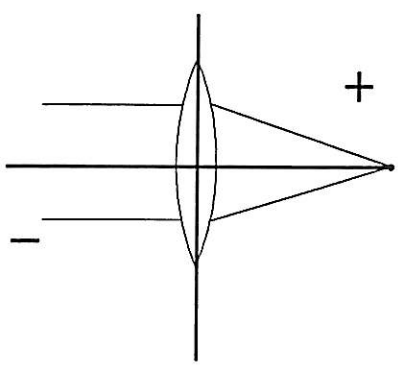
There is a definate relationship between the power of a lens in diopters and the resulting focal length in meters. The stronger the power, the shorter the focal length, the weaker the power, the longer the focal length. This relationship may be expressed in the following formula: **D = 1/f** or **f = 1/D**

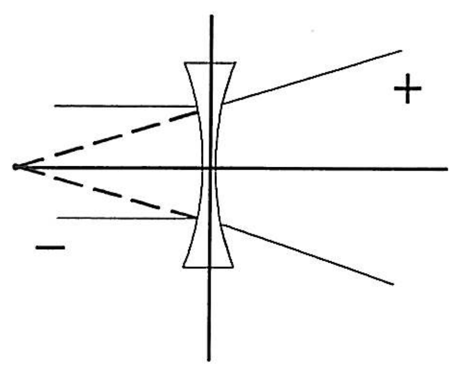
where D = power of the lens in diopters and f= focal length in meters.

Examples

Calculate Focal Lengths	Calculate Powers
D= +2.00 f=1/D f=1/+2.00 f=+0.5 m or +50 cm or +500 mm	f=+7.7 cm D=1/f D=1/+.077m D=+13.00 D
D=−7.50 f=1/D f=1/−7.50 f=−0.133m or−13.3 cm or −133 mm	f= +0.222 m D=1/f D=1/+0.222 m D= +4.50
D=−10.00 f=1/D f=1/−10.00 f=−0.10 m or 10 cm or 100 mm	f= −571 mm D=1/f D=1/−.571 D= −1.75

The focal lengths of minus lenses are negative while those of plus lenses are positive. This can be explained by superimposing a plus and minus lens on the cartesian coordinate system explained earlier, and by following the convention of diagramming rays of light as traveling from left to right. As illustrated below, the focal points of minus lenses fall in the minus quadrant of the x axis while those of plus lenses fall in the plus quadrant.





Practice Exercises

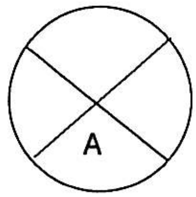
Calculate the focal length of the following lenses powers. Express the answer in meters, centimeters, and millimeters.

1) −2.50
2) −1.75
3) −0.50
4) −5.00
5) −12.50
6) +1.75
7) +3.25
8) +1.00
9) +6.50
10) +17.00

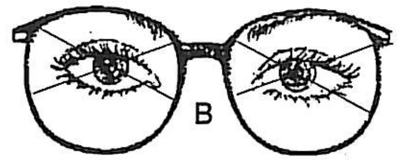
Calculate the power in diopters of the lenses with the following focal lengths. Be sure to convert the given focal lengths to meters before applying the formula. Round off each answer to the nearest quarter diopter.

11) −0.20 m
12) −.33 cm
13) −4 m
14) −5.5 cm
15) −0.15 m
16) +0.210 m
17) +044.0 cm
18) +80.0 cm
19) +0.125 m
20) +62.0 mm

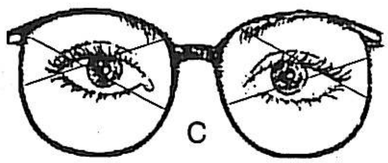
Minus Lens As Prism



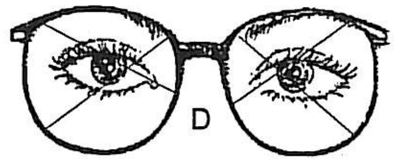
Minus Lens



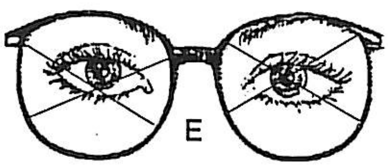
No Prism



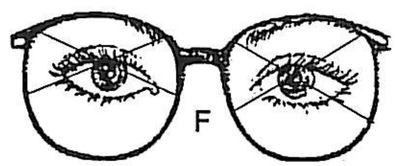
Base In Prism
(OCs Wider
Than PD)



Base Out Prism
(OCs Narrower
Than PD)



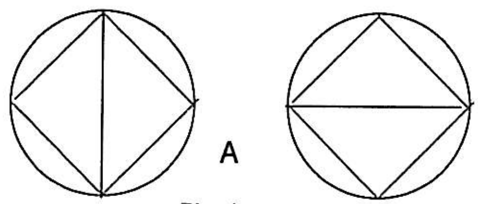
Base Up Prism
(Right Eye)



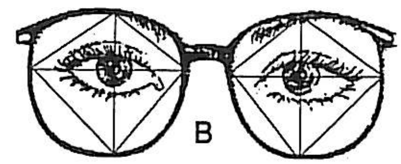
Base Down Prism
(Right Eye)

As mentioned earlier, a minus lens may be perceived as a series of prisms placed apex to apex. Given this information, it can be understood that prism is present everywhere in a lens except for the point at which the apices meet. This point is called the *optical center.* If no prism is prescribed, the optical centers should be positioned directly in front of the pupils as in figure B above. When the optical center is positioned at some other point, prism, either wanted or unwanted, is induced. The direction of the base will depend upon where the OC is positioned relative to the pupil as demonstrated by the other examples on this page.

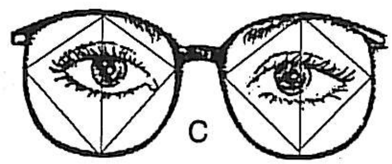
Plus Lens As Prism



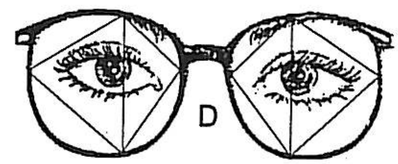
Plus Lens



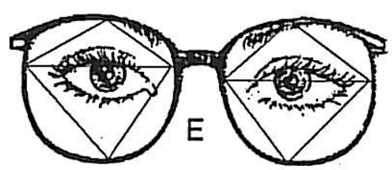
No Prism



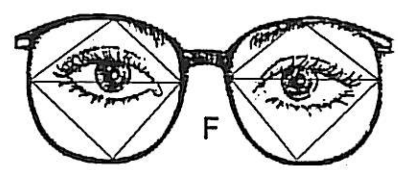
Base Out Prism
OCs Wider
Than PD



Base In Prism
OCs Narrower
Than PD



Base Up Prism
(Right Eye)



Base Down Prism
(Right Eye)

A plus lens may be perceived as a series of prisms placed base to base. Like a minus lens, prism is present everywhere except at the optical center which is the point at which the prism *bases* come together. When no prism is prescribed, the optical centers should be positioned directly in front of the pupils as in figure B above. When the optical centers are positioned at some other point, prism , either wanted or unwanted, is induced. By studying the examples on this and the previous page, it can be seen that prescribed prism may be intentionally induced simply by manipulating the position of the optical center of the lens relative to the position of the pupil.

Once it is found that either wanted or unwanted prism is present in any given lens and the direction of the base is determined, the *power* of the prism can then be calculated utilizing a simple formula called ***Prentice's Rule.*** It is important to become familiar with Prentice's Rule since it is used many times each day as a routine matter in the optical dispensary.

Prentice's Rule

Prentice's Rule states: ***The power of the prism is equal to the power of the lens in diopters times the amount of decentration in millimetes divided by 10.***

Stated algebraically:

$$\Delta = \frac{F \times dec\ (mm)}{10}$$

where

Δ = prism diopters
F = power of the lens in diopters
dec = decentration or distance in mm away from the optical center of the lens.

Example 1: How much prism is induced 4 mm away from the optical center of a +3.00 D spherical lens?

Applying Prentice's Rule, F = +3.00 and dec. = 4.0 mm
so: $\Delta = F \times dec/10$
$= 3.00 \times 4/10$
$= 1.2\,\Delta$

Example 2: A patient's PD was mistakenly noted to be 62 mm when the actual measurement is 66 mm. If the power of the lenses are −2.00 diopters in each eye, how much prism will be induced in the finished spectacles and in which direction is the base?

$$D = \frac{F \times dec}{10}$$

Right Eye: $-\frac{2.00 \times 2}{10} = 0.4\Delta$ Total: $= 0.8\Delta$ Base Out

Left Eye: $-\frac{2.00 \times 2}{10} = 0.4\Delta$

How do we know the direction of the prism is base out? The optical centers were positioned a total of 4 mm narrower than the actual PD. By referring to the figure D on page 16 which illustrates this situation with a minus lens, it can be observed that the direction of the base of the prism through which the patient is looking is oriented out, away from the nose.

Practice Exercises

1) When the optical centers of a pair of *plus* lenses are positioned narrower than the PD, it produces prism base___________.

2) When the optical centers of a pair of *minus* lenses are positioned narrower than the PD, it produces prism base___________.

3) When a patient looks through a plus lens *above* the optical center, it produces prism base___________.

4) When a patient looks through a minus lens *below* the optical center, it produces prism base___________.

5) How much prism is induced 5 mm away from the optical center of a +2.00 diopter lens?

(9) 4.75 ~~x~~ 2

6) How much prism is induced 10 mm away from the optical center of a −0.25 diopter lens?

7) How much prism is induced 2 mm away from the optical center of a +16.00 diopter lens?

8) In verifying a pair of spectacles which have recently been returned from the lab, you notice that the optical centers are positioned 61 mm apart. The work order indicates the patient's PD measures 64 mm and the prescrip tion calls for −3.00 spheres in each eye. How much *total* prism is induced and in which direction is the base?

IN .9 OUT △

9) A patient's prescription calls for OD: +4.75 OS: +2.50. The optical centers of the finished spectacles are found to be positioned 4 mm too wide. How much *total* prism is induced and in which direction is the base?

DO EACH EYE SEPARATE 1st

△ 2.9 D OUT

2.50
4.75
7.25
4
29.00

.675
.450
1.125

Answers To Practice Exercises

Page 5

1)	+8.25	9)	+0.50	17)	−8
2)	+4.75	10)	+8.50	18)	−90
3)	−7.75	11)	−1.50	19)	+9
4)	−6.50	12)	−0.25	20)	+6
5)	−0.75	13)	+5.25	21)	−4
6)	−24.25	14)	+1.00	22)	+12
7)	−1.75	15)	−0.75	23)	+8
8)	0	16)	+30	24)	+1

Page 13

1)	0.4 m; 40 cm; 400 mm	11)	−5.00
2)	0.57 m; 57 cm; 570 mm;	12)	−3.00
3)	2.0 m; 200 cm; 2,000 mm	13)	−0.25
4)	0.20 m; 20 cm; 200 mm	14)	−18.00
5)	0.08 m; 8.0 cm; 80 mm	15)	−6.75
6)	0.57 m; 57 cm; 570 mm	16)	+4.75
7)	0.31 m; 31 cm; 310 mm	17)	+2.25
8)	1.0 m 100 cm; 1000 mm	18)	+1.25
9)	0.15 m; 15 cm; 150 mm	19)	+8.00
10)	0.06 m; 6 cm; 60 mm	20)	+16.00

Page 17

1)	in	6)	0.25 Δ
2)	out	7)	3.2 Δ
3)	down	8)	0.9 Δ base out
4)	down	9)	1.45 Δ base out
5)	1.0 Δ		