DOCUMENT RESUME

ED 124 390 88 SE 019 613

TITLE So You "Gotta" Wear Glasses Minicourse, Career Oriented Pre-Technical Physics.
INSTITUTION Dallas Independent School District, Tex.
SPONS AGENCY Bureau of Elementary and Secondary Education (DHEW/OE), Washington, D.C.
PUB DATE 75
NOTE 126p.; For related documents, see SE 018 322-333 and SE 019 605-616

EDRS PRICE MF-$0.83 HC-$7.35 Plus Postage.
DESCRIPTORS Instructional Materials; Optics; Physics; *Program Guides; *Science Activities; Science Careers; Science Education; *Science Materials; Secondary Education; *Secondary School Science; Technical Education
IDENTIFIERS Elementary Secondary Education Act Title III; ESEA Title III; *Lenses

ABSTRACT

This instructional guide, intended for student use, develops the topic of optics through a series of sequential activities. A technical development of the subject is pursued with examples stressing practical aspects of the concepts. Included in the minicourse are: (1) the rationale, (2) terminal behavioral objectives, (3) enabling behavioral objectives, (4) activities, (5) resource packages, and (6) evaluation materials. The study of light, particularly that concerning the use of lens systems in the refraction of light, is discussed. This unit is one of twelve intended for use in the second year of a two year vocationally oriented physics program. (CP)

CAREER ORIENTED PRE-TECHNICAL PHYSICS

SO YOU GOTTA WEAR GLASSES

MINICOURSE

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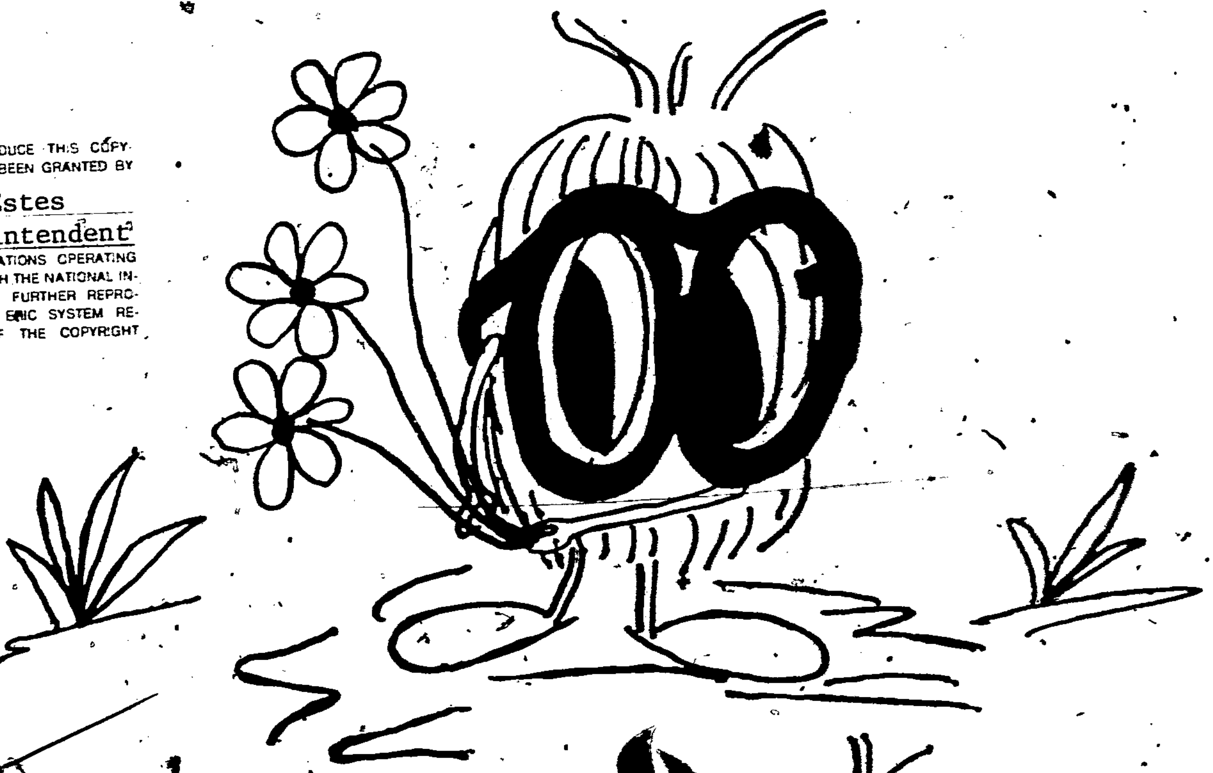

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CAREER ORIENTED PRE-TECHNICAL PHYSICS

So You "Gotta" Wear Glasses

Minicourse

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This Minicourse is a result of hard work, dedication, and a comprehensive program of testing and improvement by members of the staff, college professors, teachers, and others.

The Minicourse contains classroom activities designed for use in the regular teaching program in the Dallas Independent School District. Through minicourse activities, students work independently with close teacher supervision and aid. This work is a fine example of the excellent efforts for which the Dallas Independent School District is known. May I commend all of those who had a part in designing, testing, and improving this Minicourse.

I commend it to your use.

Sincerely yours,

Nolan Estes

General Superintendent

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CAREER ORIENTED PRE-TECHNICAL PHYSICS

SO YOU "GOTTA" WEAR GLASSES
(Optics)

MINICOURSE

RATIONALE (What this minicourse is about)

Only if our eyes are in working order can we behold the beauties of the land, the sea, and the sky. But too few people have perfect vision; and a majority of people wear, or need to wear, glasses.

Although scientists know a great deal about light, they do not try to tell us what light is; rather they quite precisely describe its behavior. Examples of this behavior would include the following: light affects photographic film, which makes picture-taking possible; light is absorbed by plants and is used in a process called photosynthesis, which results in plant growth; light shining on a radiometer causes its vanes to turn, which results in a "light engine"; light passing obliquely from air into glass causes it to bend, which makes reading glasses possible; light is reflected from certain materials, which makes mirror construction possible, etc.

These, and many other kinds of light behavior, indicate certain properties of light. One such property is that light is a form of energy. What is the nature of light energy, and how does light travel from place to place? This question caused such great men of science as Galileo, Newton, Faraday, Huygens, Maxwell, Planck, and Einstein (to name only a few) to stretch their minds to the utmost in search of answers. Several theories were advanced concerning the nature of light, but none of the older theories explained well the things which light was observed to do. Today's theory combines some of the various older theories. Today we say that whatever light is, it has a dual nature. In other words, light sometimes acts like a wave; and at other times, it acts like a particle. (But never does it behave as both a wave and a particle simultaneously.)

In this minicourse you will study some of the principles of the physics of light. Further, you will be involved in the laboratory investigation of lenses and lens systems, with application to such devices as eyeglasses, telescopes, microscopes, cameras, and polaroid lenses.

Optics relates directly to a wide variety of technical careers. Some of these careers may be entered by on-the-job training or by taking specialized courses for technicians; others require college training. Examples of such careers are: optometric assistant, dispensing optician, optical mechanic, optical laboratory technician, optometrist, ophthalmologist, orthoptist, photographer, physicist, astronomer, and analytical chemist.

You will want to keep a notebook during this minicourse. The notebook will contain accounts of your laboratory investigations, problem solutions, notes, and the like. Part of your grade for this minicourse will be determined by the content and quality of the material in your notebook.

In addition to the RATIONALE, this minicourse contains the following sections:

1) TERMINAL BEHAVIORAL OBJECTIVES (Specific things you are expected to learn from the minicourse)
2) ENABLING BEHAVIORAL OBJECTIVES (Learning "steps" which will enable you to eventually reach the terminal behavioral objectives)

3) ACTIVITIES (Specific things to do to help you learn)

4) RESOURCE PACKAGES (Instructions for carrying out the learning Activities, such as procedures, references, laboratory materials, etc.)

5) EVALUATION (Tests to help you learn and to determine whether or not you have satisfactorily reached the terminal behavioral objectives) These tests include:

   a) Self-test(s) with answers, to help you learn more.

   b) Final test, to measure your overall achievement.

TERMINAL BEHAVIORAL OBJECTIVES:

Upon completion of this minicourse, you will be able to:

1) explain the dual nature of light, and explain or illustrate some of the common properties of light (such as rectilinear propagation, reflection, refraction, interference, diffraction, and variation of intensity with distance).

2) give examples of the use of basic types of lenses and basic lens systems in such devices as eyeglasses, cameras, microscopes, telescopes, projectors, etc.

3) express the magnifying power of a lens (or lens combinations) in diopters, or calculate this power by the use of magnification formulas.

4) explain how eyeglasses are used to correct the myopic (near-sighted) eye, the hyperopic (far-sighted) eye, the presbyopic ("non-accommodating") eye, and the astigmatic ("irregular retina") eye.

5) explain how eyeglasses are used to protect the eyes from injurious environmental conditions.

6) use polarizing materials to demonstrate double refraction and other simple properties of polarized light.

7) illustrate the use of polarizing materials in anti-glare glasses and goggles.

ENABLING BEHAVIORAL OBJECTIVE #1:

Demonstrate four basic properties of light and explain what is meant by the dual nature of light.

ACTIVITY 1-1

Read and complete investigations listed in Resource Package 1-1. Complete Resource Package 1-2; then check by using Resource Package 1-3.

RESOURCE PACKAGE 1-1

"Nature of Light"

RESOURCE PACKAGE 1-2

"Self-Test Questions"

RESOURCE PACKAGE 1-3

"Answers to Self-Test Questions".

ENABLING BEHAVIORAL OBJECTIVE #2:

Illustrate how lenses are used in eyeglasses to correct or reduce eye defects, or to protect eyes from injury and discomfort. A quantitative understanding of this will be shown by solutions of simple lens problems.

ACTIVITY 2-1

Read Resource Package 2-1 and perform the activity in Resource Package 2-2. Complete Resource Package 2-3; then check by using Resource Package 2-4.

RESOURCE PACKAGE 2-1

"So You 'Gotta" Wear Glasses (Lenses and Lens Combinations)"

RESOURCE PACKAGE 2-2

"Image Formation by Eyeglass Lens"

RESOURCE PACKAGE 2-3

"Self-Test on Lenses and Lens Combination"

RESOURCE PACKAGE 2-4

"Answers to Self-Test"

ENABLING BEHAVIORAL OBJECTIVE #3:

Demonstrate how variations in lenses and lens systems make possible their practical application in cameras. Projector systems, and microscopes.

ACTIVITY 3-1

Read and complete investigations listed in Resource Package 3-1. Complete Resource Package 3-2; then check by using Resource Package 3-3.

RESOURCE PACKAGE 3-1

"Application of Lenses and Lens Systems"

ENABLING BEHAVIORAL OBJECTIVE #3 (Continued):

Practical understanding of this will be shown by building working models of at least one of these items.

ENABLING BEHAVIORAL OBJECTIVE #4:

Illustrate different means of polarizing light, some optical effects of such light, and several practical applications for polarized light.

ACTIVITY 4-1

Read and complete investigations listed in Resource Package 4-1. Complete Resource Package 4-2; then check by using Resource Package 4-3.

RESOURCE PACKAGE 3-2

"Self-Test Questions"

RESOURCE PACKAGE 3-3

"Answers to Self-Test Questions"

RESOURCE PACKAGE 4-1

"Polarized Light"

RESOURCE PACKAGE 4-2

"Self-Test Questions"

RESOURCE PACKAGE 4-3

"Answers to Self-Test Questions"

RESOURCE PACKAGE 1-1

THE NATURE OF LIGHT

Before you can enjoy your study of practical optics, you will need to review some of the basic principles of light. Probably the first question to come to mind would be, "What is light?" Many scientists have tried to answer this question by explaining the basic nature of light. Newton advanced a corpuscular theory, in which he said that a luminous body emits minute light packets called corpuscles in all directions at high speed. A contemporary of Newton, named Christian Huygens, advanced a wave theory, in which he suggested that light consists of waves rather than corpuscles. Huygen's wave theory seemed to be substantiated by Fresnel's and Young's experiments on the interference and polarization of light. Also, near the end of the nineteenth century, Maxwell showed that light had a special kind of wave nature; i.e., that light waves were electromagnetic in nature. But then Einstein and Planck discovered new evidence concerning the corpuscular nature of light and how the wave and corpuscle theories might be interwoven. For example, Einstein's photoelectric effect (the ability of certain substances to eject electrons when illuminated) provided experimental results supporting both the wave theory and the corpuscle theory. Thus, we end up today with a "dualist" theory of light, a theory which tells us that light energy can behave as if it were a wave under one set of conditions and as if it were a particle under a different set of conditions. It further tells us that light energy occurs in little bundles or packets or corpuscles called photons.

But why this duality? Why must light be considered sometimes as waves and sometimes as a particle? Is light matter or energy? Einstein-Planck gave us the answers, but few people can realize it until they look at (1) the well-known Einstein mass-energy equation, $E = mc^2$ (where E stands for energy, m for mass, and c for the speed of light) and (2) the Planck equation, $E = hf$ (where h equals Planck's constant and f equals the frequency at which the light is radiated). Einstein showed that the photon (light energy packet) could be assigned a "mass-like" property. If we mathematically equate the Planck and the Einstein equations, we get

$$E = mc^2 = E = hf$$

or, $mc^2 = hf$ (since the two were both equal to E)

then, $\frac{mc^2}{c^2} = \frac{hf}{c^2}$ (dividing both sides by c^2)

We get $m = \frac{hf}{c^2}$, or $m = \frac{hf}{c \times c}$, where c is the speed of light in a vacuum (free space).

The relationship between wavelength, wave speed, and the energy (frequency at which photons are emitted) is given by the wave relation, $v = f\lambda$. Therefore,

$v = c = f\lambda$ (for the speed of light, $c = v$)

or $c = f\lambda$

Substituting this equation into $m = \frac{hf}{c \times c}$ yields $m = \frac{hf}{f\lambda \times c}$

Solving for $\lambda = \frac{h}{mc}$.

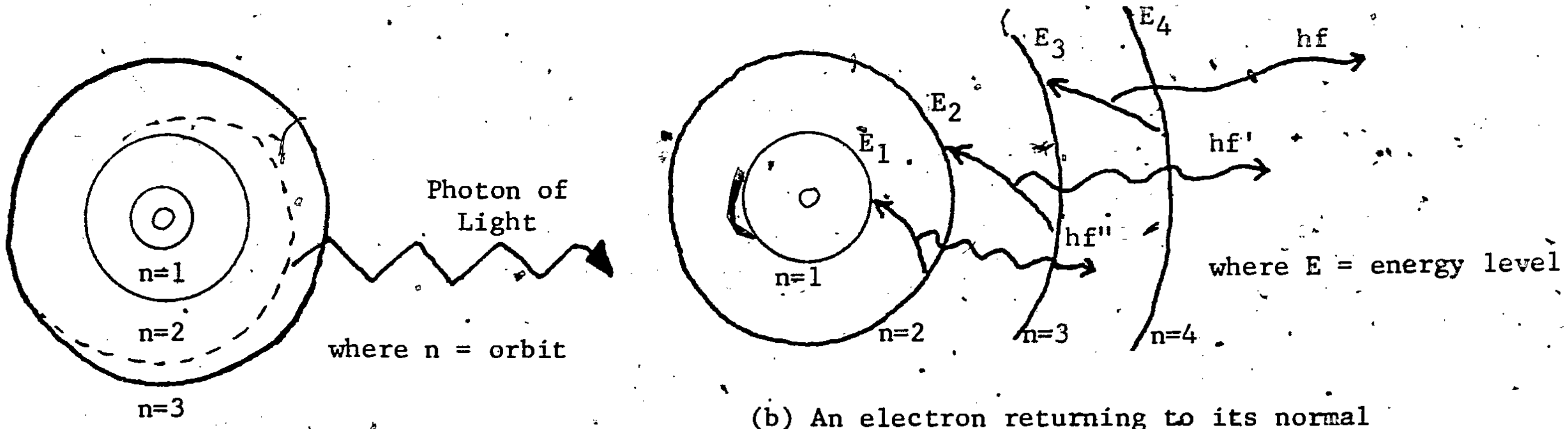
So you can see, even with a limited knowledge of mathematics, that the wavelength of a photon (a quantum of light energy) may be expressed in terms of its "mass-like" property, as in $\lambda = \frac{h}{mc}$. Can you now see why there is "duality" of light, that light is both "wave"-like and "particle"-like in nature? Can you also see how the wavelength for <u>any</u> particle having a speed <u>v</u> (not <u>c</u>) can be expressed in terms of its mass property, i.e.:

$$\lambda = \frac{h}{mv}.$$

If you like, you may read more about the development of this kind of mathematical physics (called wave mechanics); one of its applications is in the theory and practice connected with the electron microscope.

ORIGIN OF LIGHT:

Light has its origin in the changes of energy levels by electrons inside the atom. Electrons in motion constitute electric currents. And since relative motion of electrons inside the atom causes magnetic effects, we say that light is electromagnetic; i.e., light has both an electric and a magnetic character. When an electron in an atom is moved from its innermost (lowest) energy level, called its <u>normal state</u>, into one outer (higher) energy level, the atom is said to be in an <u>excited state</u>. Upon return of the electron from the energy position of the excited state to the energy position of the normal state, a photon(s) is/are emitted (see Fig. 1 on page 10). The energy, frequency, color, and wavelength of the emitted light depends upon the energy level(s) "jumped" by the electron. The electron "jump" is called a transition. Sometimes the energy levels are referred to as orbits and the atomic model is called an orbital or planetary atomic model. Other kinds of useful atomic models exist, so it is NOT necessary to speak of orbital changes of the electron as causing light emission; in fact, "energy level transitions" is much preferred over "orbital transitions."



(a) The atom emits light when the electron jumps from an outer orbit to an inner orbit.

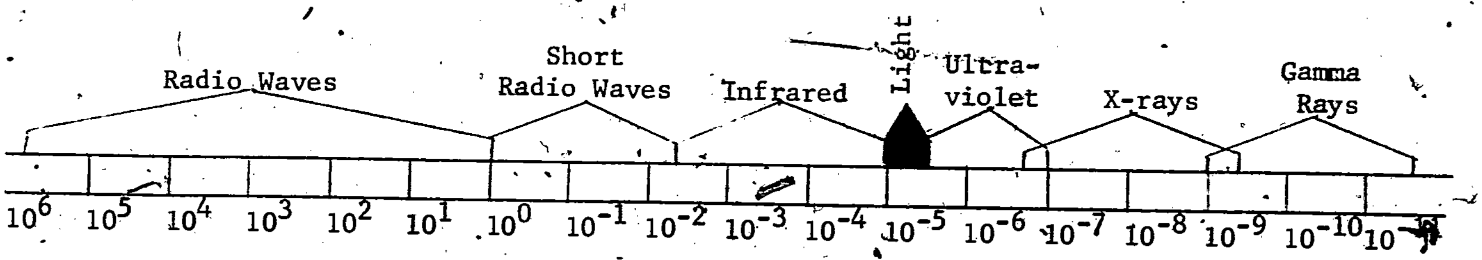
(b) An electron returning to its normal state may emit several light quanta (photons).

ORBITAL MODEL ELECTRON TRANSITIONS
(Light Production)
Fig. 1

A common method of producing light is to heat a filament hot enough for it to radiate photons, as is done in the case of an incandescent light bulb. As the filament is heated, the electron transitions are first of lower energies; the filament begins to radiate long wavelength, invisible, infrared "heat" photons. But as the filament gets hotter, its electron transitions are of higher energies and result in longer light wavelengths (red photons); and as it becomes still hotter, the photon wavelengths become even shorter (more energetic), and the visible light changes first to yellow and then to the white light to which we are so accustomed.

PROPERTIES OF LIGHT:

Visible light occupies a very small portion of the total electromagnetic spectrum of photon energies. This wide range of energies is associated with a correspondingly wide range of photon wavelengths and frequencies. Some of the longer waves are the radio waves (which may be miles long); infrared waves are longer than red, the longest visible wavelength. On the other spectral end are the ultraviolet rays (shorter than the shortest visible rays, the blues and the violets); and still shorter are the X-ray and gamma rays (see Fig. 2, below).



WAVELENGTHS OF THE ELECTROMAGNETIC SPECTRUM
Fig. 2

Figure 2 shows the electromagnetic spectrum arranged according to wavelengths. As mentioned previously, the speed, frequency, and wavelength of light are related by the formula:

speed = frequency x wavelength
or $v = f\lambda$

The distance traveled through space by all forms of electromagnetic waves in any given period is the same, since all travel at the same speed in a vacuum; namely, 3×10^8 m/sec or approximately 186,000 mi/sec.

Can you see that the wavelength will be inversely proportional to the frequency; that is, the greater the frequency of the waves, the shorter the wavelength? Examine the equation, $v = f\lambda$.

Visible light waves are the wavelengths of electromagnetic waves which our eyes can detect. Black is the sensation we get when no photons of visible wavelengths enter the eye, and white is the sensation we can get when photons of all visible wavelengths enter the eye at the same time. In other words, white light can contain all the visible colors (in addition, there are other mixtures of visible wavelength (frequencies) that will produce the sensation of white.

The various colors of the visible spectrum--red, orange, yellow, green, blue and violet--correspond to the sensations our brains produce when the eye experiences light of a specific frequency* (or combinations thereof). For example, when a photon of frequency 5.8×10^{14} waves/second reaches the eye, the sensation of green results. See the frequency chart on the next page:

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*Remember that to speak of a specific frequency is equivalent to speaking of a specific wavelength.

CHART OF FREQUENCIES

Pure Color	Frequency (in waves per second)	Wavelength (in centimeters)
Red	4.6×10^{14}	6.5×10^{-5}
Orange	5.0×10^{14}	6.0×10^{-5}
Yellow	5.2×10^{14}	5.8×10^{-5}
Green	5.8×10^{14}	5.2×10^{-5}
Blue	6.4×10^{14}	4.7×10^{-5}
Violet	7.3×10^{14}	4.1×10^{-5}

For a further discussion of color, refer to the minicourses, "Let There Be Light" and "Color."

An important property of light is known as rectilinear propagation (light travels in a straight line in a uniform medium). When light is emitted from a source, it travels out from the source in a straight line as long as the medium in which it is traveling remains uniform. Rectilinear (straight line) propagation (motion) is a basic assumption for analyzing many optics problems. A ray is a line showing the movement of a light wave; it is a line representing the path of light. The ray system of representing light is useful in diagrams to show how light acts in various optical devices. It will be used throughout this minicourse.

Here are two investigations you can complete in about thirty minutes; both will reinforce your understanding of light.

INVESTIGATION:

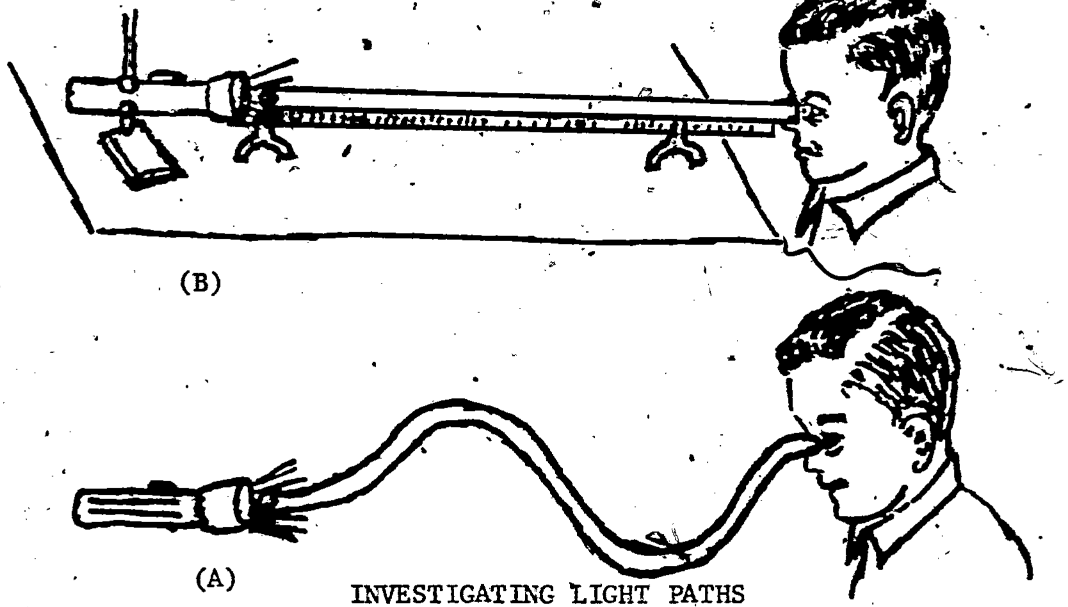
WILL LIGHT BEND IN A UNIFORM MEDIUM?
(Can light turn corners?)

Purpose: To strengthen the concept that light can essentially travel in a straight line, and that ray diagrams can therefore be used to show light paths.

Materials Needed: Optical bench consisting of a meter stick; 2 supports; light source; 5 screen holders; garden hose about 36 inches long; 6 filing cards about 5 x 8 inches; and an illuminated object screen (a brightly colored object on a 5" x 8" card will do).

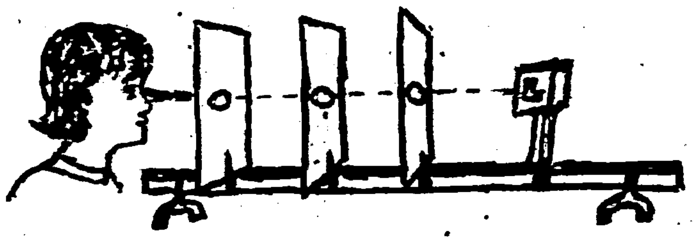
Procedure:

1) Set up a light source at one end of the garden hose. Curve the hose as shown in Figure 3A. Do you see the light? Now straighten out the hose and attach it to your optical bench as shown in 3B. Do you now see the light? Record your results in your notebook.



INVESTIGATING LIGHT PATHS

Fig. 3



INVESTIGATING LIGHT PATHS
Fig. 4

2) Make a nice hole in the middle of each of the 5" x 8" cards. Then support them on the meter stick optical bench, as shown in Figure 4, above. At one end of the meter stick place an illuminated object screen (or the brightly colored drawing on a card). Now sight through the holes in the cards toward the illuminated object. Do you see the object? Try moving the middle card first to the left and then to the right of center (keep the sideways movement to an inch or so from center). Can you see the object when the card is off-center? Surely you can think of other questions you should ask yourself; for example:

1. Does light travel in straight lines and crooked lines?

2. Does light travel around corners?

INVESTIGATION:

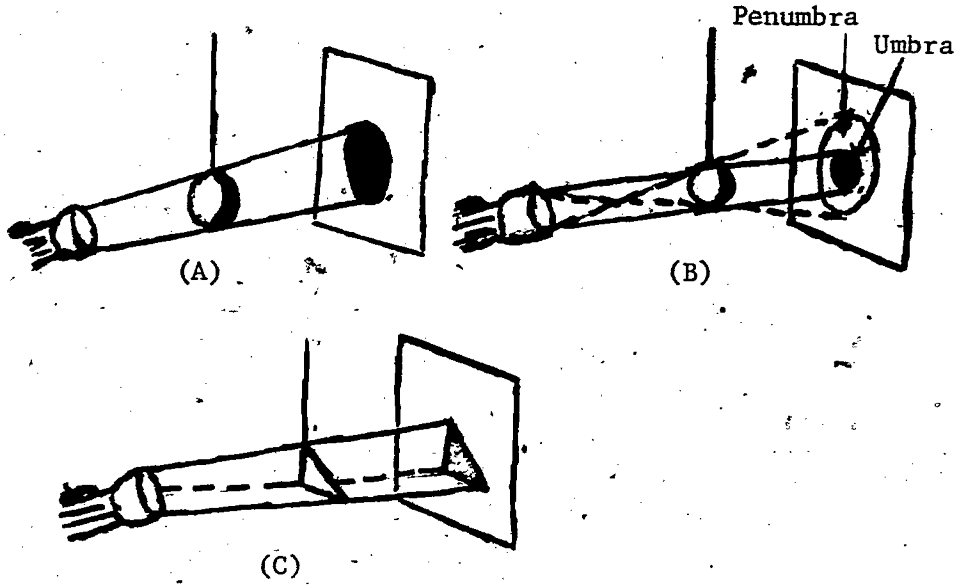
SHADOW FORMATION AS EVIDENCE THAT LIGHT TRAVELS IN A STRAIGHT LINE

Purpose: To show that shadows can be accounted for, in a general sense, by assuming that light travels in a straight line.

Materials Needed: Light source (flashlight, projector, gooseneck lamp or equivalent); a disk with a small hole in it; a screen; a tennis ball (or some other ball) with a string attached to it; and masking tape.

Procedure:

1) Cover the lens of a flashlight, or other source of light, with a disk that has a very small hole in it. Tape the disk onto the source with masking tape. Shine the small beam of light from the disk opening onto the screen. Place the light source several feet away from the screen (the best distance depends upon the light beam). Now hang a tennis ball in the path of the light (see Figure 5A).



INVESTIGATING SHADOWS
Fig. 5

In your notebook, describe the observed shadow. Note especially Figure 5-B, above.

2) Repeat observation 1, above, but double the distance of the light source from the screen. Again, describe the observed shadow.

3) Repeat observations 1 and 2, above, using a smaller ball (such as a ping-pong ball), a filing card in place of a ball, and, finally, a card cut in the shape of a triangle (see Figure 5-C). In your notebook, describe the shadow of:

(a) Ping-pong ball -

(b) Filing card -

(c) Triangular card -

Below is a drawing of a lunar eclipse (Figure 6). The earth is the opaque object between the sun (light source) and the moon (screen). The earth's shadow blots out the moon in whole or in part. Now, make a drawing similar to this one, showing what you have observed in your investigation of shadow production for 5-A, 5-B, or 5-C on page 16.

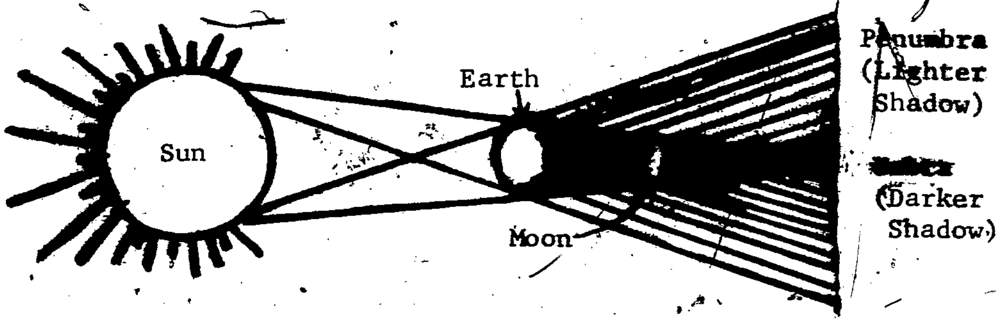
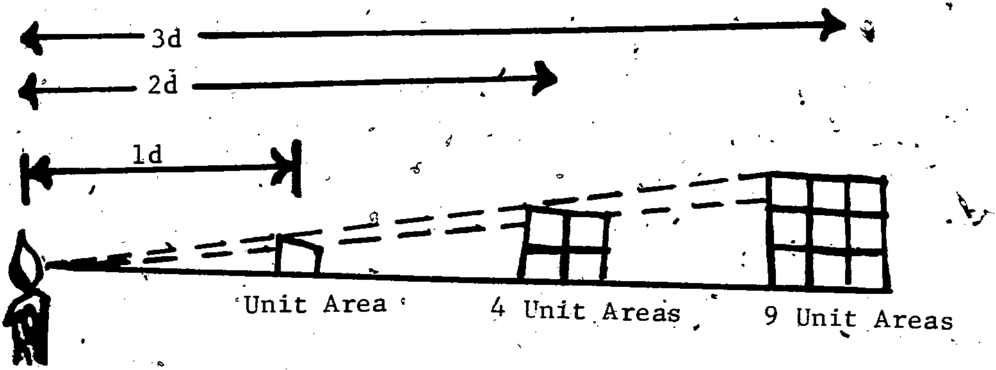


Fig. 6

Another interesting property of light is the change of its intensity (brightness) with distance: "The intensity of illumination varies _inversely_ as the _square_ of the distance from the source of light." This means that at twice the distance, the light intensity is cut to one-fourth. This is best understood if one considers that the same quantity of light at distance _d_ must cover four times the area at distance _2d_; and at three times the distance, the intensity is only one-ninth, because the area exposed is 3^2, or 9 times the area at distance _d_ (see Figure 7 below).



VARIATION OF LIGHT INTENSITY WITH DISTANCE
Fig. 7

$I \propto \frac{1}{d^2}$:

when $d = 1$, $I = \frac{1}{1^2} = 1$;   when $d = 2$, $I = \frac{1}{2^2} = \frac{1}{4}$;   when $d = 3$, $I = \frac{1}{3^2} = \frac{1}{9}$.

Historically, the amount of light on a surface one foot away from a standard candle was defined as one foot candle. The standard candle has been replaced by a more precise source, and is now defined as one-sixtieth of the luminous intensity of a square centimeter of a black-body radiator* maintained at the temperature of freezing platinum (2046° K.)

You should see by now that to illuminate a surface or object at a far distance requires a much more intense light source than is needed if the object is near. The Law of Intensity of Illumination is an inverse square law, in terms of a standard candle:

$$\text{Illumination (in foot candles)} = \frac{\text{candles of power}}{\text{square of the distance from the source}}$$

If driving at night is the illumination consideration, then the intensity of the road lights necessary to see a distant object does not follow the theoretical inverse square law. In fact, when distance is doubled, the intensity required may be twelve times (rather than the theoretical four times) because of many extraneous factors, including size, color of object, kind of viewing background, condition of the observer's eyes, and the fact that light has to reach the object and then be reflected back to the observer's eye (has to travel twice the distance from the observer to the object).

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* A theoretically perfect radiator of energy.

INVESTIGATION:

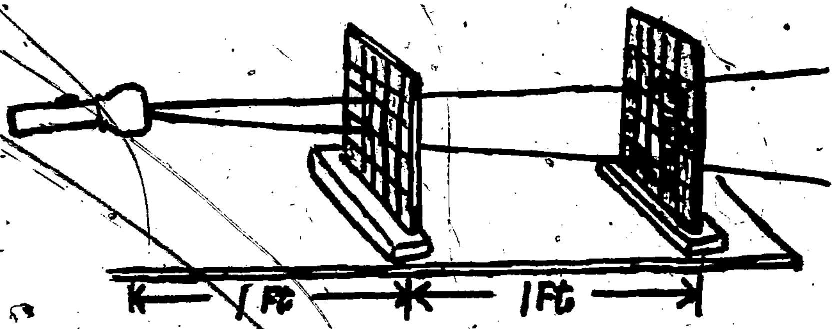
THE EFFECT OF DISTANCE UPON INTENSITY

<u>Purpose</u>: To show that light intensity decreases sharply as distance increases.

<u>Materials Needed</u>: Light source; cardboard piece 7 x 7 inch and marked off in square inches (with the center square cut out); cardboard 7 x 7 inch piece marked off in square inches; and a yard stick.

<u>Procedure</u>:

Darken the room and place the light source one foot from a cardboard piece that has a 1-inch square hole at its center (see Figure 8, below). Allow the light to pass through the hole in the first cardboard and to strike the second cardboard, which is marked off in square inches and which is placed two feet from the light source.



INVESTIGATING INTENSITY
Fig. 8

Record in your notebook a sketch of the apparatus and how many square inches the beam of light covers on the second cardboard.

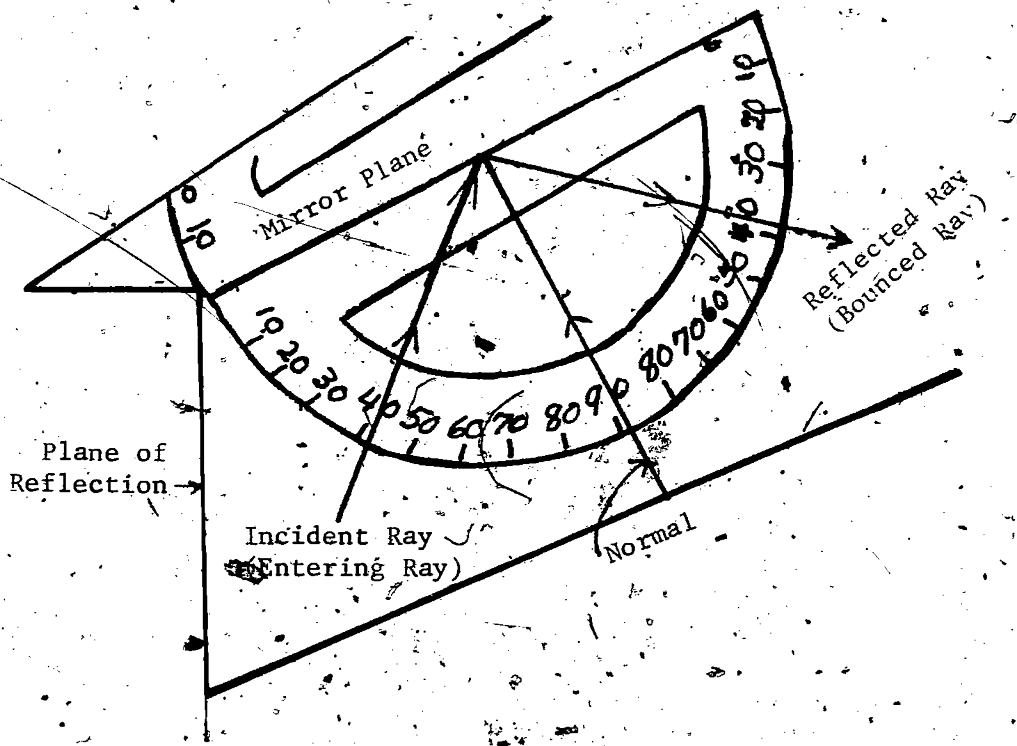
Now, move the second cardboard three feet from the light source. Record how many square inches of space are covered by the beam of light.

From these investigations, you can see that the intensity of light becomes less as the distance from the source increases. You should also see results compatible with the theory that the light is only one-fourth as intense at a distance of two feet as it is at a distance of one foot. You should be able to relate the results and the theory to perceive that light two feet from a source must be distributed over four times as much area as at one foot from the source.

As a technical example, if at 20 inches an electric lamp would supply 20 foot candles of illumination, then at 40 inches the same electric lamp would provide only 5 foot candles of illumination. Such consideration is always necessary when illuminating reading areas, recreation areas, living spaces, etc.

REFLECTION

Another important property of light is reflection. When a ray of light strikes a smooth surface, it can reflect (bounce back). If it strikes at an angle, the light is reflected in such a way that the angle of incidence is equal to the angle of reflection (see Figure 9 on next page).



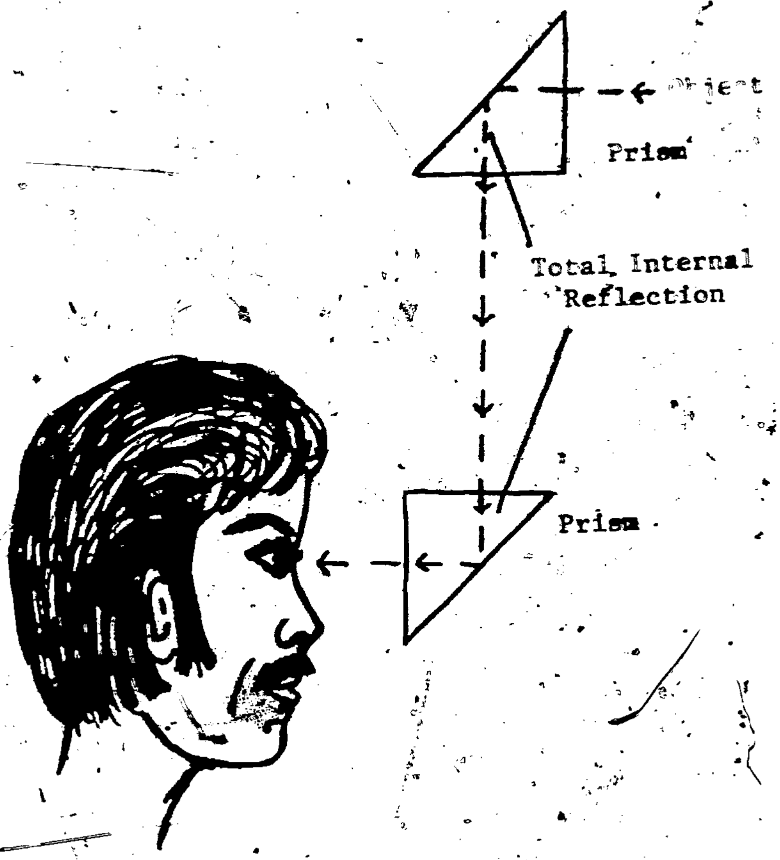
REFLECTED RAY
Fig. 9

Laws of Reflection:

1) The angle of incidence is equal to the angle of reflection.

2) The incident ray, the reflected ray, and the normal to the reflecting surface all lie in the same plane.

The reflection property and the refraction property of light are used in the design of optical instruments. For example, nearly all of the large astronomical telescopes in the world are reflecting telescopes which employ concave mirrors instead of lenses to gather the light from stars. Submarine periscopes (see Figure 10) use the reflective properties of two right-angle prisms, as do high-quality binoculars; and rods of clear, colorless plastic use reflection as the basis for piping light.



THE PERISCOPE
Fig. 10

INVESTIGATION:

THE PLANE MIRROR

Purpose: To verify the laws of reflection.

Apparatus Needed: Plane mirror; rectangular wooden block; ruler; protractor; pins; sheets of drawing paper (or equivalent); and rubber bands or cellulose tape.

Introduction: The laws of reflection state:

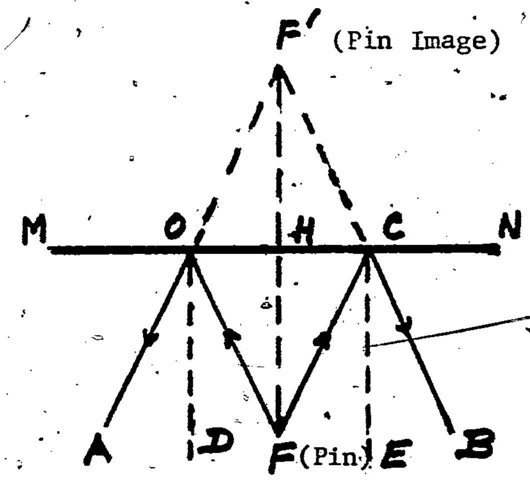
1) that the incident (incoming) ray, the reflected (outgoing or bounced-off) ray, and the normal to the reflecting surface lie in the same plane; and

2) that the angle of reflection of light is equal to the angle of incidence.

This investigation is designed to enable you to verify both of these laws.

Procedure:

Draw a line, MN, across the middle of a sheet of white unlined paper (See Fig. 11, below). Place the mirror on this line, so that the edge of its reflecting surface coincides with the mirror line. The mirror must stand vertically (it can be fastened to a rectangular support block by means of a rubber band or cellulose tape). Lay the ruler on the paper at some point A, far enough from the point F, so that angle AOF will be 30° or more. Sight along the ruler edge at the image of the pin, F, as you see it in the mirror. Now draw a sight line along the edge of the ruler, using a sharp-pointed pencil. Next, locate a second sight line for the pin, F, but from an entirely different angle (from some point, B). Draw the sight lines until they meet at the point, F'. Be sure to dot all lines extending behind the mirror plane MN. Draw lines FO and FC (which represent incident rays of light from the pin to the mirror). The lines AO and CB represent rays of light reflected from the mirror. Draw the lines OD and EC perpendicular to the mirror line, MN. Measure the distances HF and HF' to the nearest millimeter. By using a protractor, measure the angles of incidence (FOD and FCE) and the angles of reflection (angles AOD and BCE). Record these data in your notebook and in a chart similar to the one below:



INVESTIGATING REFLECTION
Fig. 11

INVESTIGATION DATA

Length of Line FH ______ mm	Angle FOD ______ °	Angle FCE ______ °
Length of Line F'H ______ mm	Angle AOD ______ °	Angle BCE ______ °
Difference	Difference	Difference

Last, answer these questions in your notebook:

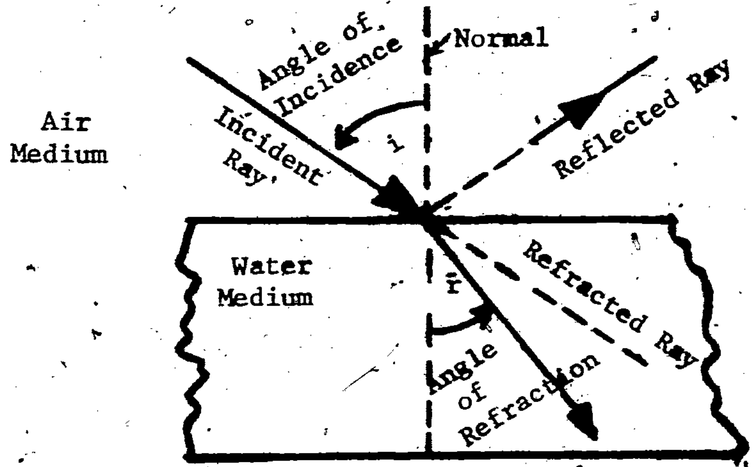
1) How do the angles of incidence compare with the angles of reflection?

2) What observation did you make in this experiment which confirms the first law of reflection?

3) How do the distances of the object and image from the mirror compare with each other?

REFRACTION OF LIGHT

Refraction is a property of light that is widely used in technological applications. Refraction is the bending of light when it passes obliquely ("at an angle") from one medium into another medium of different optical density. Optical density is a phrase referring to the relative speed with which light moves through a medium (see Figure 12).



REFRACTION
Fig. 12

Whenever light enters a different medium normal to that medium (at right angles to, "head on", or coming in straight-on) no bending occurs. But when light enters a medium at an oblique angle, bending does occur. If the light enters a more dense medium, it is bent toward the normal; if it enters a less dense medium, it bends away from the normal. This bending is due to the change in speed of light as it passes into a medium of different density (see Figure 13).

A useful concept in light technology is that of the index of refraction, which is defined as the ratio of the speed of light in a vacuum to its speed in another medium. For example, the

$$\text{Index of refraction (glass)} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in glass}}$$

$$\text{or, N (Index of refraction)} = \frac{\text{Sin i}}{\text{Sin r}} = \frac{\text{sin of angle of incidence}}{\text{sin of angle of refraction}}$$

The refractrometer, an optical instrument used to determine the index of refraction, is used in modern technology; you might be surprised to learn that one such application is in food testing laboratories.

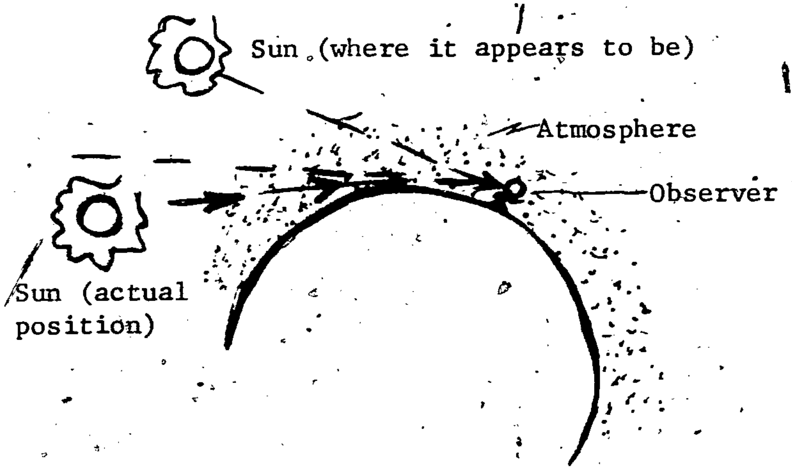
Laws of Refraction:

1) The incident ray, the refracted ray, and the normal to the surface at the point of incidence all lie in the same plane.

2) The relative index of refraction for any two media is a constant; it is independent of the angle of incidence.

3) When light passes obliquely from a medium of lesser optical density to one of greater

optical density, it is bent towards the normal; and the converse applies when light passes from a more dense medium to a less dense one.



The sun is actually visible before sunrise and after sunset, because of atmospheric refraction.

REFRACTION
Fig. 13

INVESTIGATING REFRACTION

Purpose: To determine the index of refraction of glass by means of refracted light rays.

Apparatus Needed: Glass cube or glass plate; ruler; pencil compass; pins; protractor; and white drawing paper.

Introduction: The index of refraction of a medium (substance) is defined theoretically as the ratio of the speed of light in a vacuum to its speed in that substance. The speed of light in air is only slightly different from the speed in a vacuum. Willebrord Snell was the scientist who first provided a simple and direct method for measuring the index of refraction, by defining it in terms of the angle of incidence and the angle of refraction. This mathematical relationship has come to be known as Snell's Law:

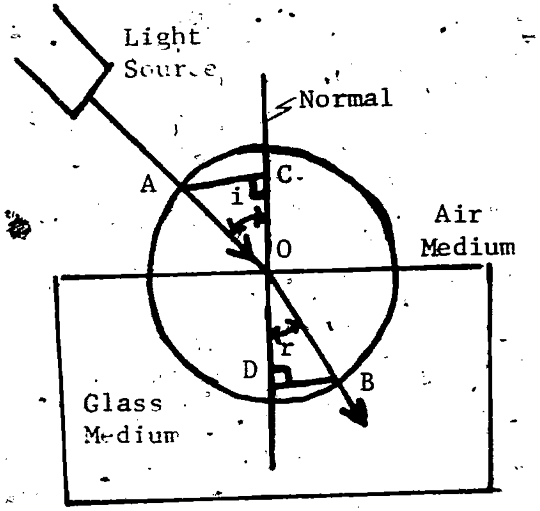
$$N = \frac{\text{Sin } i}{\text{Sin } r}$$

where N is the index of refraction, i is the angle of incidence, and r is the angle of refraction. In Fig. 14 below, Snell's Law would apply as follows:

$$\text{Sin } i = \frac{AC}{AO}$$

AND

$$\text{Sin } r = \frac{DB}{OB}$$



SNELL'S LAW
Fig. 14

Since AO and OB are radii of the same circle, they are of equal length. Therefore, if Snell's Law requires the sin ratio, we can substitute for sin c and sin r, to get:

$$N = \frac{\text{Sin } i}{\text{Sin } r}$$

$$= \frac{AC}{AO} \div \frac{DB}{OB}$$

Then, since AO = OB,

$$\frac{AC}{AO} \times \frac{OB}{DB} = \frac{AC}{DB} .$$

The index of refraction of a glass medium varies with its particular composition, and with the wavelength of the light under consideration. Crown glass, for example, when illuminated by white light, has an index of refraction of 1.52; whereas, a medium flint glass has an index of 1.63. If illuminated by light of various colors, these indices of refraction would be different for each different color. This is because different colors (wavelengths) of light have different speeds in a given medium. It turns out that blue travels slowest and red fastest.

Procedure:

Place the glass cube (or plate) on the center of a blank white sheet of paper and outline it with a sharp-pointed pencil. Approximately 1 cm from the lower left-hand corner of the glass cube, place a pin, A, as close to the cube as possible (see Figure 15). At B, about 2 cm from the upper right-hand corner of the glass cube, stick a second pin as close to the glass cube as possible. At C (a point at least 7 cm from Pin B), stick a third pin, so that Pin A is in line with Pin B when viewed from a position behind Pin C, while looking through the glass cube plate. Be sure that your eye is at about the same level as the table top.

Remove the glass cube and draw straight lines joining points A and B; in like fashion, join points B and C. Those two straight line segments represent the path of light traveling from Pin C through the air to Pin B and then through the glass to Pin A. Now identify the incident ray and the refracted ray.

Next, at Pin B, construct the normal to the surface (line DE); label the "air normal" NB and the "glass normal" BN'. Use a radius of length BC to draw a circle with Point B as its center. This circle will intersect four line segments, BA, BN', BC, and BN. From the point of intersection of the circle with the incident ray, CB, draw a line perpendicular to BN. Label it x.

DATA CHART

Trial	Glass Object	Side X (mm)	Side Y (mm)	Index of Refraction $N = \frac{X}{Y}$	i (°)	r (°)	Index of Refraction $\frac{\sin i}{\sin r}$

(You should run two trials, if you have time.)

QUESTIONS

1) From your data, would you infer that the glass cube (plate) is made of flint glass, or crown glass, or?

2) What would the size of the angle of refraction be, if the angle of incidence were 0°?

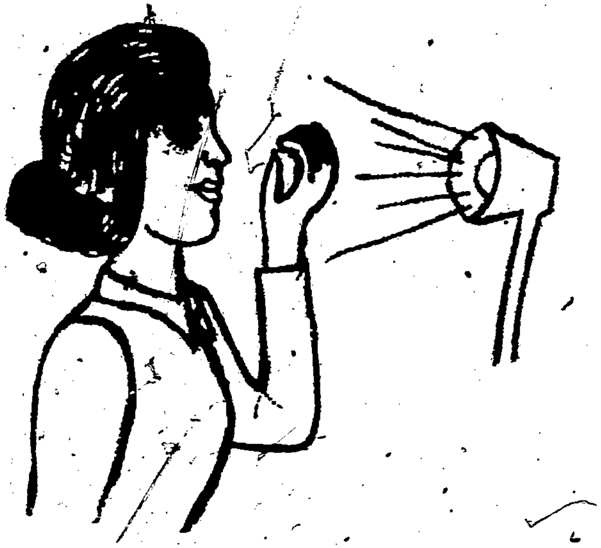
3) What is the angle of refraction, if the angle of incidence is 90°? Measure this to determine the value.

Another property of light which is useful in technology is known as interference. Interference occurs when two light waves meet under special circumstances. This meeting is known as superposition, and it results in the loss of light intensity in certain regions (called destructive interference) or in the reinforcement of light intensity in other regions (called constructive interference). These alternate regions of lightness and darkness are called interference patterns.

INVESTIGATING INTERFERENCE

This is something you can do at school or at home, without any technical equipment.

Squint your eyes at a light, aiming at it between your thumb and first finger as you bring them closer and closer together. See Figure 16, below. Just before your finger and thumb touch, you should see light and dark bands. With a little practice, you can spot the same interference patterns from between the fingers of your outstretched hand. You can also look at a street light at night through a thin handerkerchief, and see interference patterns. The light bands correspond to regions where the waves are reinforced; and the dark bands to the regions where the waves are canceled. You have just observed interference patterns caused by <u>diffraction</u> (See the next section).



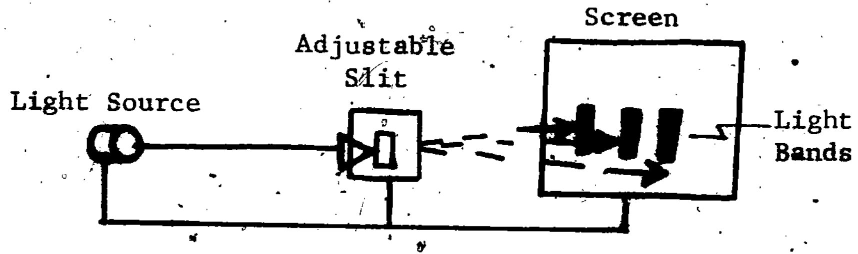
VIEWING INTERFERENCE
Fig. 16

<u>Diffraction</u> is another useful property of light.

Diffraction is a term for the bending of light by sharp edges or small openings, or the spreading of light <u>into</u> an area <u>behind</u> an opaque obstruction.

INVESTIGATING DIFFRACTION

It is relatively easy to see diffraction effects when light passes through a narrow slit or a very small hole. The narrower the slit, the more the light spreads out in diffraction patterns. Arrange a light source and adjustable slit apparatus as shown in Figure 17. If you put a screen behind a slit which is illuminated from the front side, and then proceed to make the slit narrower, the diffraction pattern bands seen on the screen will get narrower and narrower, until a certain point is reached. Then, if you continue to make the slit still narrower, the bands on the screen will get wider apart. They will widen out and move farther apart, if you narrow the slit even more. This is a pure diffraction effect.



ADJUSTABLE SLIT APPARATUS
Fig. 17

RESOURCE PACKAGE 1-2

SELF-TEST QUESTIONS

1) The fundamental differences between visible light, radio waves, and X-rays are wavelength and frequency. Compare the wavelengths and frequencies of (a) visible light waves and radio waves and (b) visible light waves and X-rays.

2) State two observations from everyday life that indicate that light tends to travel in a straight line.

3) What is the illumination in lumen/ ft^2 of the pages of a book held 3 ft directly below a source with an intensity of 75 candles?

4) List three factors which have a significant effect on the amount of light an object will reflect?

5) Define: (a) refraction, (b) index of refraction, and (c) angle of refraction.

6) State the principal idea in the following theories of light: (a) corpuscular (Newtonian) (b) wave, (c) quantum, and (d) dual nature.

7) Distinguish between umbra and penumbra.

8) Give the meaning of the following: (a) critical angle and (b) total internal reflection.

9) Give some practical applications of the index of refraction.

RESOURCE PACKAGE 1-3

ANSWERS TO QUESTIONS

1) (a) visible light wavelengths are much shorter, and the frequencies are much higher than radio waves. Radio waves have much longer wavelengths and far lower in frequency.

(b) X-rays have shorter wavelengths and higher frequencies.

2) Answers will vary.

3) $E = \frac{I}{d^2}$ where, I = intensity; d = distance; and E = illumination (density of luminous flux on a surface)

$$E = \frac{75 \text{ candles}}{(3 \cdot \text{ft})^2} = \frac{75 \text{ candles}}{9 \text{ ft}^2}$$

$$E = 8.3 \text{ lumens/ft}^2$$

4) The amount of light an object reflects can depend upon the kind of material of which the object is made, the smoothness of the surface, the angle at which the light strikes the surface, etc.

5) (a) Refraction is the bending of light as it passes obliquely from one medium into another medium of a different optical density.

(b) Index of refraction is the ratio of the speed of light in a vacuum to the speed of light in another substance.

(c) Angle of refraction is the angle between the refracted ray and the normal.

6) (a) Luminous bodies emit light as minute particles (corpuscles).

(b) Light is energy which travels as a wave form.

(c) The transfer of energy between light and matter occurs only in discrete units (quanta) and quantum of light energy is called a photon.

(d) Light is dualistic in nature. Under certain conditions, its behavior is best described in terms of its wave properties; while under certain other conditions, its behavior is best described in terms of its particle-like nature.

7) Umbra is that part of a shadow from which all rays of light are excluded; while penumbra is the lighter part of the shadow, from which only part of the light rays are excluded.

8) (a) The critical angle is that particular angle of incidence onto a denser medium, which results in an angle of refraction of 90°.

$$N = \frac{\sin 90^\circ}{\sin i_c} \quad \text{or} \quad \sin i_c = \frac{1}{N}$$

(b) Total internal reflection occurs at particular angles of incidence onto a less dense medium, which results in reflection at the media interface, with almost all light being reflected internally back into the more dense medium. Almost no loss of light occurs.

9) Answers will vary. For example, to determine purity of transparent substances, to distinguish butter fat from margarine, and to positively identify diamonds.

RESOURCE PACKAGE 2-1

SO YOU "GOTTA" WEAR GLASSES
(Lenses and Lens Combinations)

Why You May Need to Wear Glasses

We learn to interpret much of the outside world by the light which enters the eye. This visible light energy can vary in three fundamental ways: (1) in intensity or brightness; (2) in wavelength or color; and (3) in the angle at which it enters the eye, or something about general location of the light source.

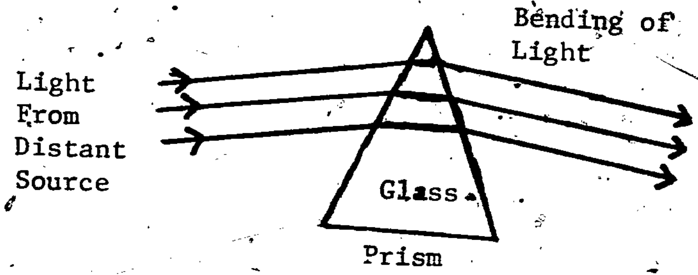
We are constantly changing optical environments--rain, wind, sleet, snow, cold, heat, fog, air-conditioned buildings, bright lights, dim lights, etc., require constant visual adjustments. In addition, infrared and ultraviolet light can damage eye tissues. The range of brightness outdoors on a sunny day can be so great as to require protection from the glare. The range in brightness from the deepest shade to the brightest sunlight can be as much as 10,000 fold! Thus, at certain times, if outdoors, everyone needs glasses (even if they have 20/20 vision). Remember, glasses are often merely aids for the body's optical system; glasses simply enable it to do a better job.

You will enjoy reading "The Sportsman's Eye" by James Gregg, Winchester Press, New York, in which you will find many reasons why nearly everyone should wear glasses.

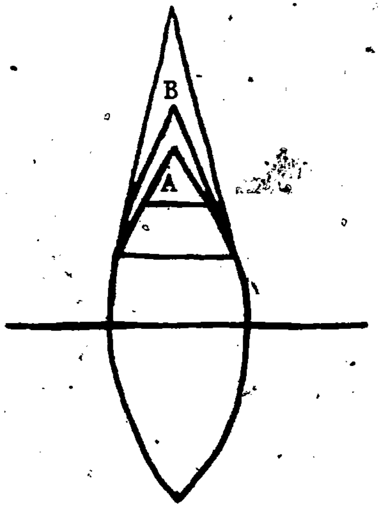
Lenses

Before you study about glasses, it will be helpful to examine some principles of lenses. First, notice how a glass prism affects light (See Fig. 18). In going through the prism, light emerges in a direction different from the one in which it entered the prism, because each of the two surfaces (incident surface and emergent surface) is tilted differently with respect to the original direction of the light. The amount of deviation (bending of the light) depends upon such things as the angle between the two surfaces and the differences in optical density of the prism and its surrounding medium (usually air). For purposes of this minicourse, we will assume that the lenses are of greater optical density than the air which surrounds them, unless specifically noted otherwise.

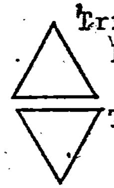
Now look at the convex lens in Fig. 19; the angle between the curved external surfaces for a convex lens having a thin shape (See shape A in Fig. 19) is much less than this same angle for a thick lens (See shape B, Fig. 19).



PRISM REFRACTION
Fig. 18



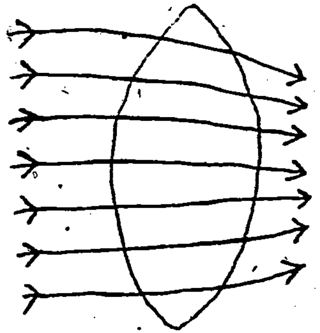
CONVEX LENS
Fig. 19



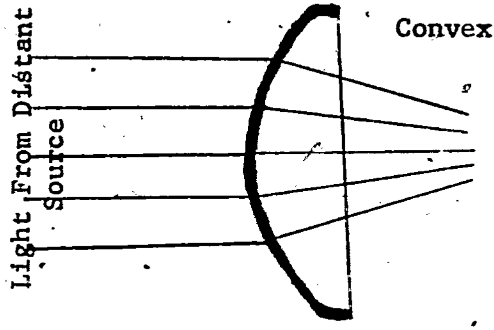
TWO PRISMS ACTING
AS A CONVEX LENS
Fig. 20

Such a convex lens can be compared to two triangular prisms placed base-to-base, with the thickest edges toward the center (see Figure 20). The deviation strength (bending ability) of a prism or a lens depends upon the angle between the external surfaces; therefore, a thick lens having the shape of A in Figure 19 would deviate (refract) light more than would a lens of the shape of B in Figure 19.

Light which enters a lens is always refracted (bent) <u>toward the thicker part of the lens</u>. Further, the light bends more at the <u>thinner portion</u> than near the thicker portion of such a lens (see Figure 21 below); and, to be more precise, the bending effect depends upon the nature of the two (the incident and emergent) surface curves. Figure 21 illustrates the effect of a <u>single</u> curved surface; in practical applications, one considers the bending effects of both surfaces. You



BENDING TOWARD THICKER
PART OF LENS
Fig. 21



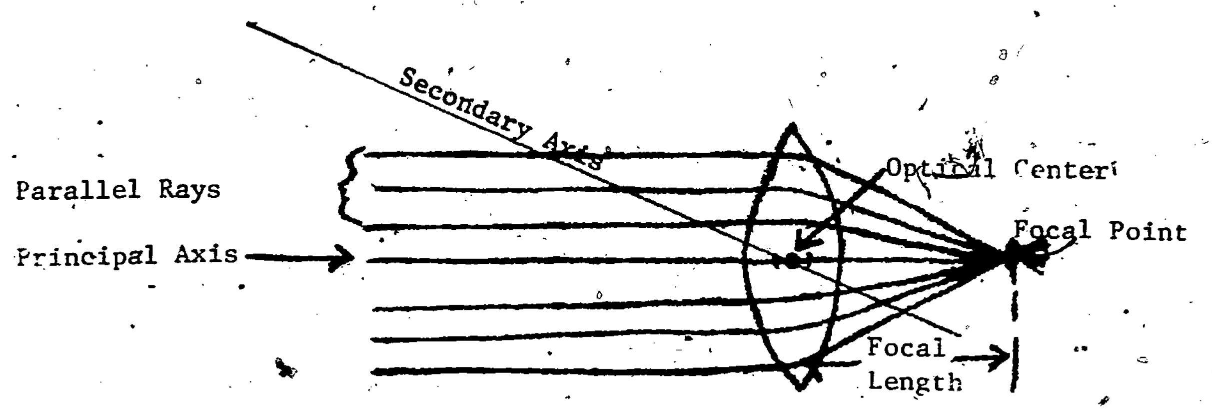
EFFECT OF A SINGLE CURVED SURFACE
Fig. 22

will learn to do this later in the minicourse, when you work with the Lens Maker's Formula.

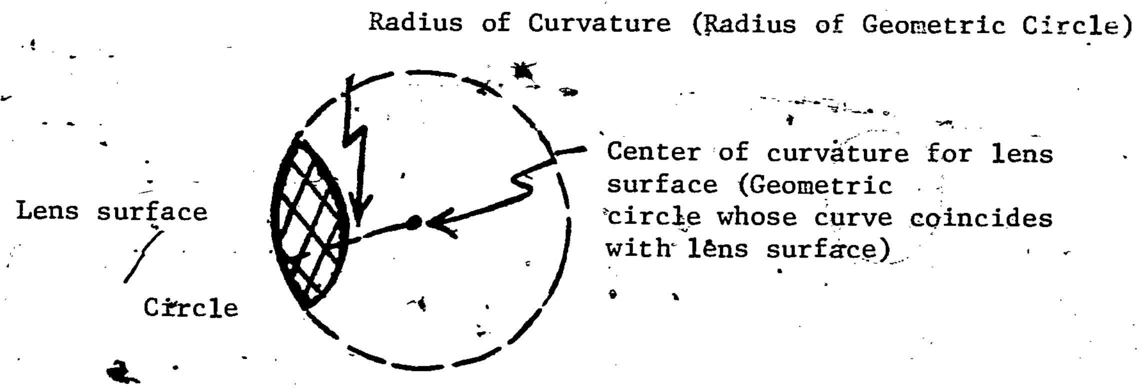
Some Technical Terms

The art of lens making is a sub-set of the physics of geometric optics. You can think of geometric optics as "ray optics," where light is represented as a straight line ray which changes direction when refracted or diffracted. Listed in this section are some technical terms, mostly from geometric optics.

The center of curvature of a lens surface is the point about which a geometric curve (circle, parabola, etc.) could be drawn, so as to coincide with the lens surface (see Figure 23).



SOME TERMS IN GEOMETRIC OPTICS
Fig. 23

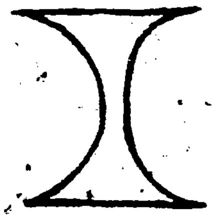


CENTER OF CURVATURE OF A LENS
Figure- 24

When a lens is thicker near its center, one can oversimplify a little and say it is then called a convex lens; and when thicker at its outer edges, it is called a concave lens.

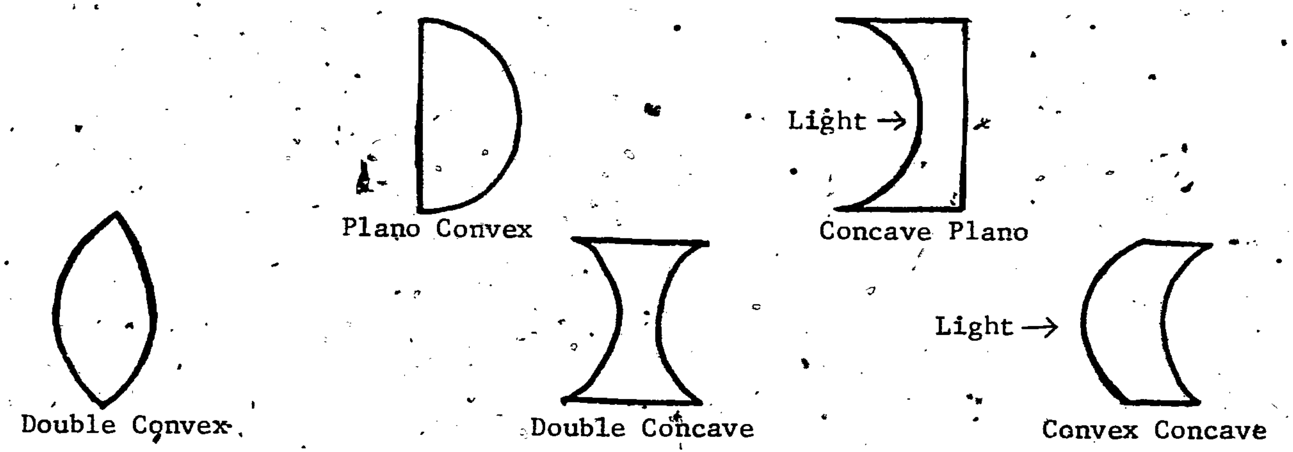
Figures 25 (a) and 25 (b) show convex and concave lenses.

Convex Lens
Figure 25 (a)



Concave Lens
Figure 25 (b)

Some other lens surface combinations are shown in Figure 26, on the next page.

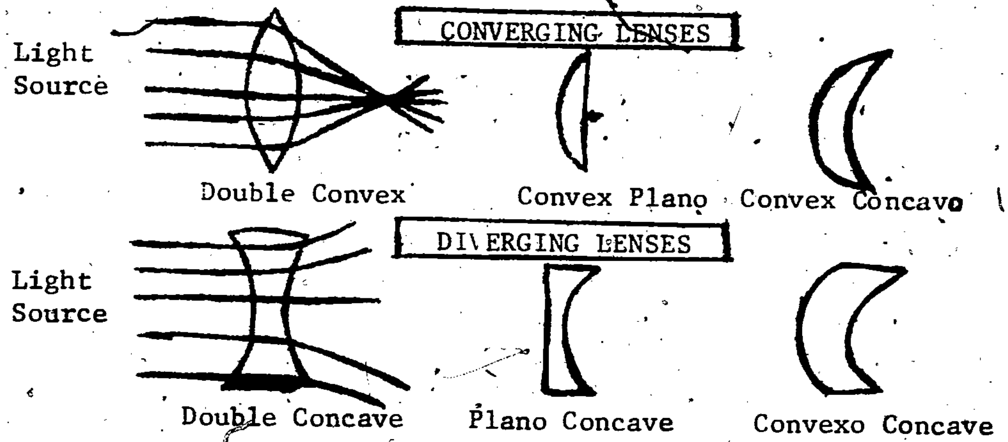


OTHER LENS COMBINATIONS
FIG. 26

Lenses can gather light from a subject (object) and bend it so as to form a picture (image) of the subject. If the light actually passes through the region of the image, the image is real; if not, the image is virtual. Images can be upright (erect) or inverted; they can also be reversed left-to-right (perverted); and images can be enlarged (magnified) or reduced (diminished) in size.

More Types of Lenses

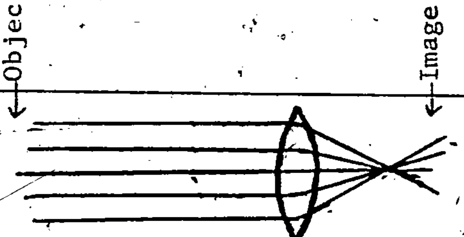
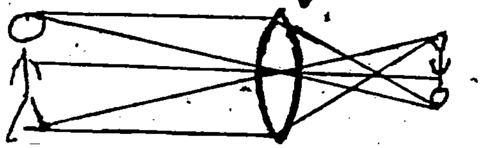
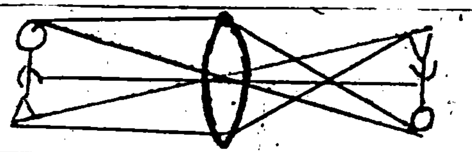
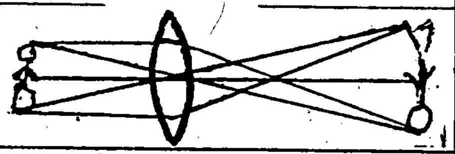
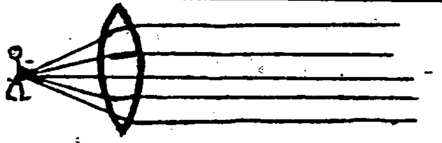
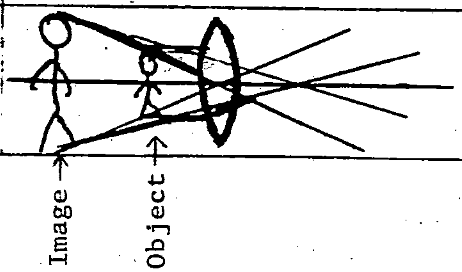
Lenses are generally of two types. Converging lenses are thicker through the middle than at the edges (see Figure 27) and tend to bring together or bend light so as to "concentrate" it. Diverging lenses are thinner through the middle than at the edges and tend to spread light so as to "dilute" it (see Figure 27). Remember, as a rule, light is bent toward the thick part of the lens (see Figure 27).



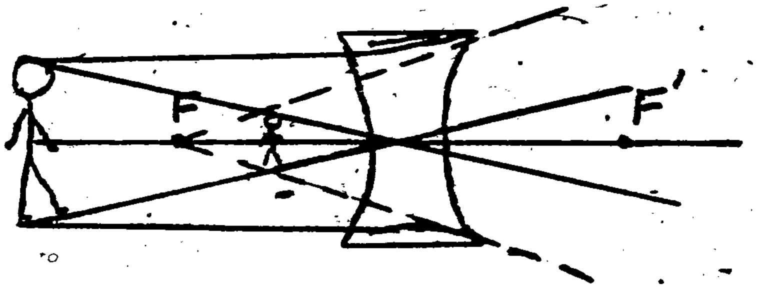
CONVERGING AND DIVERGING LENSES
Fig. 27

For object location, image formation, image location, type of image, and some technical uses for images formed by convex lenses, see the chart entitled "Chart of Six Cases and Uses (For Convex Lens)" on the next page.

CHART OF SIX CASES AND USES (For Convex Lens)

Object Location		Properties of Image	Uses
Case 1 At Infinity		The image is a point at the principal focus	Obtaining images of heavenly bodies; starting fire by a lens
Case 2 Greater Than Two Focal Lengths		Real, inverted, reversed, smaller than the object and closer to lens	The ordinary camera
Case 3 At Two Focal Lengths		Real, inverted, reversed, same size as object and same distance from lens	The copying camera
Case 4 Between Two And One Focal Length		Real, inverted, reversed, enlarged, and farther from the lens	Projectors, motion picture machines, and enlarging camera
Case 5 At Principal Focus		The parallel rays produce no image	The searchlight
Case 6 Less Than One Focal Length		Virtual, upright, not reversed, enlarged and farther from the lens	The simple microscope (magnifying glass)

Notice that parallel lights (light from an infinitely distant source is always considered to be parallel) focus at the focal point of a convex lens. But notice that the concave lens spreads or diverges light. It turns out that parallel light rays from an infinite distance can never meet after passing through a concave lens because they are diverged. It turns out also that the image a concave lens forms of a nearby object will always be virtual (see Figure 28).



The concave lens produces a virtual, upright and reduced image.

VIRTUAL IMAGE
Fig. 28

Lens Formula (Object and Image Relations Formula.): The curvature of the lens determines the location of the principal focus, as well as the kind of image, image size, and image distance for any given object, object size and object distance. All of these can be expressed mathematically as follows:

$$\frac{1}{F} = \frac{1}{Do} + \frac{1}{Di}$$

where: F = focal length of lens
Do = distance of object
Di = distance of image

When a negative value is obtained for Di (image distance), the image is virtual.

Also $\frac{So}{Si} = \frac{Do}{Di}$

where: So = size of object
Si = size of image

Sample Problems:

(a) A child is photographed with a camera held 6 feet away, what is the focal length of the camera lens if the image is formed on a film pack 6 inches behind the lens?

Solution:

$$\frac{1}{F} = \frac{1}{Do} + \frac{1}{Di}$$

$$\frac{1}{F} = \frac{1}{72\ \text{in}} + \frac{1}{6\ \text{in}}$$

$$\frac{1}{F} = \frac{1}{72\text{in}} + \frac{12}{72\ \text{in}}$$

$$\frac{1}{F} = \frac{13}{72\ \text{in}} \qquad \text{Therefore,} \quad 13\ F = 72 \cdot \text{in}$$

$$\text{and} \quad F = \frac{72\ \text{in}}{13} \quad \text{or} \quad F = 5.54\ \text{in.}$$

(b) How tall is the image, if the child is 3 feet high?

Solution:

$$\frac{S_o}{S_i} = \frac{D_o}{D_i}$$

$$\frac{36\ \text{in}}{S_i} = \frac{72\ \text{in}}{6\ \text{in}}$$

$$72\ \text{in}\ S_i = 216\ \text{in}^2$$

$$S_i = \frac{216\ \text{in}^2}{72\ \text{in}}$$

$$S_i = 3\ \text{in.}$$

The Lens Maker's Equation: The Lens Maker's Equation is so-called because it allows computation of the focal length of a lens in terms of the radii of surface curvatures and the index of refraction of the lens material; the equation can be written:

$$\frac{1}{F} = (N - 1)\left(\frac{1}{r} + \frac{1}{r'}\right)$$

where: F = focal length

N = index of refraction of lens

r and r' = radii of curvature. Radii must be considered positive (+) for convex surfaces and negative (-) for concave surfaces for this form of the Lens Maker's Equation.

Problem:

The symmetrical lenses shown in Fig. 29 have radii of curvature equal to 40 cm; and they are made of glass having N = 1.65. Compute the focal length.

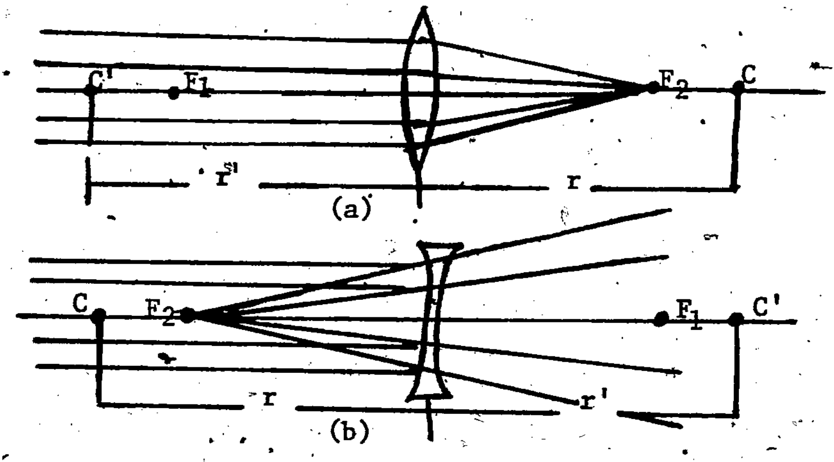
Since F_2 is on the right side of the lens in Fig. 29(a), r is positive and equals +40 cm and r' is negative and equals -40 cm.

$$\frac{1}{F} = (N - 1)\left(\frac{1}{r} + \frac{1}{r'}\right)$$

$$\text{So, } \frac{1}{F} = (1.65 - 1)\left(\frac{1}{+40\text{ cm}} + \frac{1}{-40\text{ cm}}\right)$$

$$\frac{1}{F} = .65 \times \frac{2}{40\text{ cm}}$$

$$F = 30.7\text{ cm or } 31\text{ cm}$$



USING LENS MAKER'S EQUATION
Fig. 29

a) Parallel light passes through the principal focal point F_2 of a converging lens; F_1 would be the principal focal point if the light emerged from the right side of the lens.

b) Parallel light, passing through a diverging lens, seems to originate at the second focal point F_2. C and C' are centers of curvature for the lens surfaces.

In Fig. 29(b) r is negative (= -40 cm). Since r' is positive (= +40 cm), the answer (using the same formula) will be: F = -31 cm.

It is customary in optometry and opthalmology to express the focal length of a lens in diopters. The power of a lens is its bending ability, which is related to its focal length; therefore, power is customarily referred to in diopters, given by the reciprocal of the focal length expressed in meters:

$$\frac{1 \text{ meter}}{\text{focal length in meters}} = \text{diopters}$$

Example:

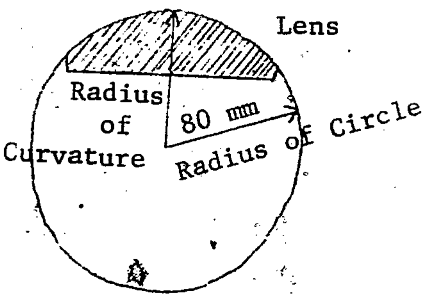
A lens with a focal length of 50 cm would have a power of + 2 diopters:

$$\frac{1 \text{ meter}}{.5 \text{ meter focal length}} = +2\text{ D}$$

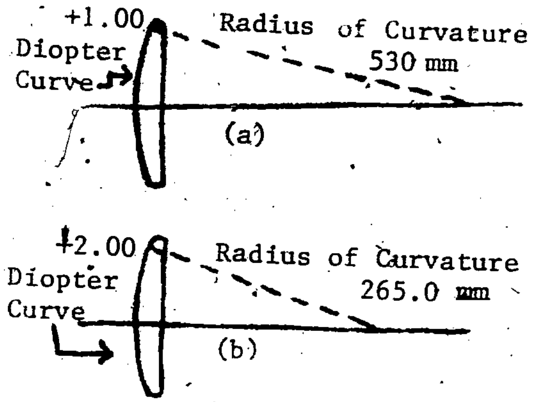
where the positive (+) sign indicates magnification.

Eyeglasses

The power or strength of a simple lens or of a combination of lenses fitted together (compound lens) is related to the combination of curves on the lens surfaces. As discussed earlier, if the curve of a certain lens surface matches the curve of a particular circle, then the lens surface and the circle have the same radius. So when we say that a lens surface has an 80 mm radius of curvature, we mean that it has the same curvature as a circle with 80 mm radius (see Figure 30-A). However, a customary way to measure curvature (and thus the power) of eyeglasses is in diopters. As shown earlier, the diopter is a unit of measurement which can be used to describe the curvature of a lens surface. It has real importance in eyeglass prescription practice, as it is the customary unit by which surface curves are measured and prescribed. The radius of curvature of one diopter surface is 530 mm. The ordinary range of curvature for eyeglasses is from 0.01 to 20.00 diopters. It turns out that the shorter the radius of curvature, the greater will be the strength of the lens (the higher its dioptic power).



RADIUS OF CURVATURE
Fig. 30-A



DIOPTER AND RADIUS OF CURVATURE
Fig. 30-B

Concave and Convex Surfaces

As has already been stated, lenses may either be concave or convex. To distinguish the surfaces, you can use a negative sign (-) in front of a number representing the curvature of a concave surface and a positive sign (+) for the curvature of a convex surface. It is common in technical practice to use D as the symbol for the word, "diopter." Thus, a concave surface with 6 diopters curvature is written as - 6.00 D, while a convex surface of the same curvature is written as + 6.00 D.

Eyeglass Power: The strength or power of an eyeglass lens is dependent upon the curvature of the two lens surfaces and upon the kind of lens material used. For practical, technical purposes, lens power is found by properly combining the diopter values of the two surfaces. (There are exceptions in case

Partial Table

Radii of Curvature of Diopter Tools

Diopter	Radius	Diopter	Radius	Diopter	Radius
0.12	4240.0	6.00	88.3	11.87	44.6
0.25	2120.0	6.12	86.5	12.00	44.2
0.37	1413.0	6.25	84.8	12.12	43.7
0.50	1060.0	6.37	83.1	12.25	43.3
0.62	848.0	6.50	81.5	12.37	42.8
0.75	706.7	6.62	80.0	12.50	42.4
0.87	605.7	6.75	78.5	12.62	42.0
1.00	530.0	6.87	77.1	12.75	41.6
1.12	471.1	7.00	75.7	12.87	41.2
1.25	424.0	7.12	74.4	13.00	40.8
1.37	385.4	7.25	73.1	13.12	40.4
1.50	353.3	7.37	71.9	13.25	40.0
1.62	326.2	7.50	70.7	13.37	39.6
1.75	302.9	7.62	69.5	13.50	39.3
1.87	282.7	7.75	68.4	13.62	38.9
2.00	265.0	7.87	67.3	13.75	38.6
2.12	249.4	8.00	66.2	13.87	38.2
2.25	235.6	8.12	65.2	14.00	37.9
2.37	223.2	8.25	64.2	14.12	37.5
2.50	212.0	8.37	63.3	14.25	37.2
2.62	201.9	8.50	62.4	14.37	36.9
2.75	192.7	8.62	61.4	14.50	36.6
2.87	184.3	8.75	60.6	14.62	36.2
3.00	176.6	8.87	59.7	14.75	35.9

of very thick lenses). Let's consider the power of spherical lenses. Consider a lens having a concave surface of - 2.00 D on one side and - 4.00 on the other side. By finding the algebraic sum of these two numbers (adding the effect of one surface to that of the other), the total power of this lens is - 2.00 plus - 4.00 = - 6.00. The partial chart of diopters and radii of curvature tells us that an equivalent radius of curvature would be 88.3 mm (see page 53).

Most eyeglass lenses are made with a concave surface on one side, and a convex surface on the other; they are crescent shaped, like a new moon. To determine the strength of such a lens, you find the algebraic sum of the dioptic powers of the two surfaces. Since one side of the lens is concave and one convex, you simply <u>subtract</u> the smaller from the larger of the two numbers and keep the algebraic sign (+ or -) of the larger number.

In Figure 31(a), you can see a lens with a - 6.00 D spherical curve on one side and a + 8.00 D spherical curve on the other. By combining algebraically the + 8.00 D and the - 6.00 D, one gets:

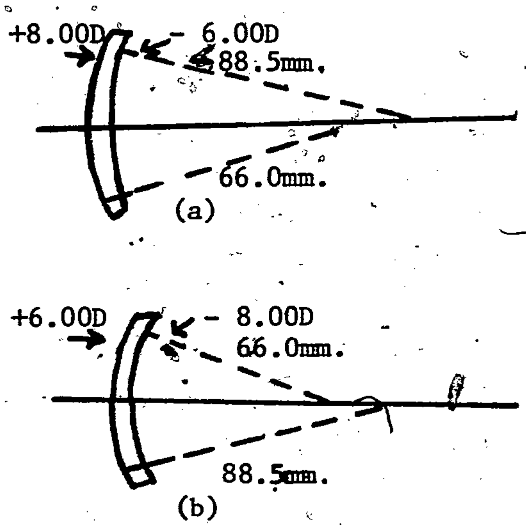
$$\begin{array}{r} +\ 8.00\ \mathrm{D} \\ \underline{-\ 6.00\ \mathrm{D}} \\ +\ 2.00\ \mathrm{D}. \end{array}$$

The result is +2.00 D. Therefore, the power of the lens is two diopters (+ 2.00 D), and in technical jargon this lens is called a "plus sphere" because the final total power is positive.

We can also have a "minus sphere," when the concave surface has greater curvature than does the convex surface. In Figure 31 you can see a lens with - 8.00 D spherical curve on one side and a + 6.00 D curve on the other. The total power is, obviously, a negative two diopters (- 2.00 D).

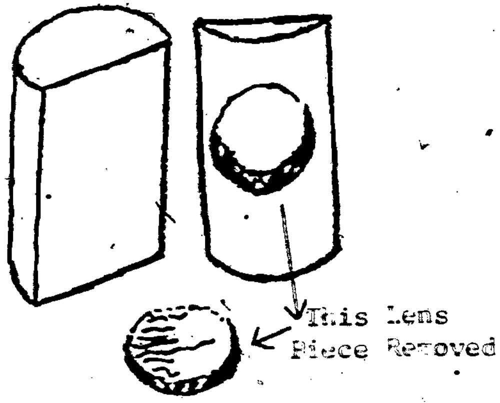
From these two examples we see that a "plus lens" is one in which the total power is shown by a positive sign (+), and a "minus lens" is one in which the total power is shown by a negative sign (-). The "plus lens" will always be thicker at its center than at its edge. A "minus lens" is always thicker at its edge than at its center.

Sometimes lenses are not spherically surfaced, but are cylindrically surfaced (see Figure 31(b)). Let us now consider the power of a lens having one cylindrical surface and one flat surface. See Figure 32 on page 56 for a picture of a cylindrical lens, which is shaped as though it is cut from a sliced cylinder slab. Therefore, it has a flat surface on one side, and a cylindrical surface on the other. You can guess from looking at Figure 33 (see page 56) that the power is not the same in all directions (meridians). If the cylinder surface of this lens has a power of + 4.00 D, the power is effective only in the horizontal meridian (level). In the vertical meridian (up-and-down) of this cylinder surface, there is a zero diopter power because the surface is flat. This meridian of zero power is known as the axis of the cylinder. The technician would write the power of this lens as "+ 4.00 D cylinder, axis vertical."

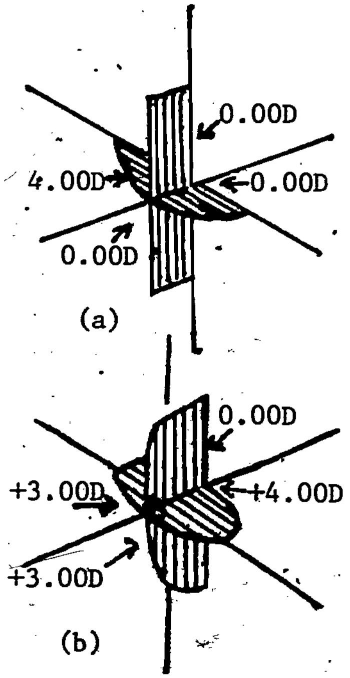


EYEGLASS LENSES
Fig. 31

By combining a spherical surface with a cylinder surface, one gets the lens type combination shown in Figure 33(b). An interesting lens surface form is the Toric Lens, a lens with different curves in different directions (meridians). In Figure 34 you can see a representation of a Toric Lens with curvature of + 3.00 in the vertical meridian and with a curvature of + 7.00 D in the horizontal meridian. If a toric surfaced lens were formed with a flat surface on the other side, all of the power of this lens would result from the side having the toric surface. Therefore, the power of this lens can be written as + 3.00 D power in the vertical meridian and as + 7.00 D in the horizontal meridian.

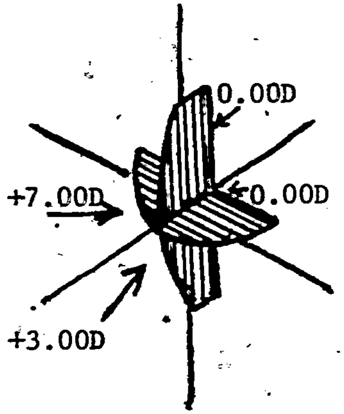


CYLINDRICAL LENS
Fig. 32



LENS MERIDIANS
Fig. 33

Eyeglasses and the Eye. Now that you have some knowledge of lenses, you can better understand that the kind of imperfection the eye may possess will determine the type of lens needed to correct the imperfection. Essentially, then, one uses lenses to aid the refractive power of the eye itself.

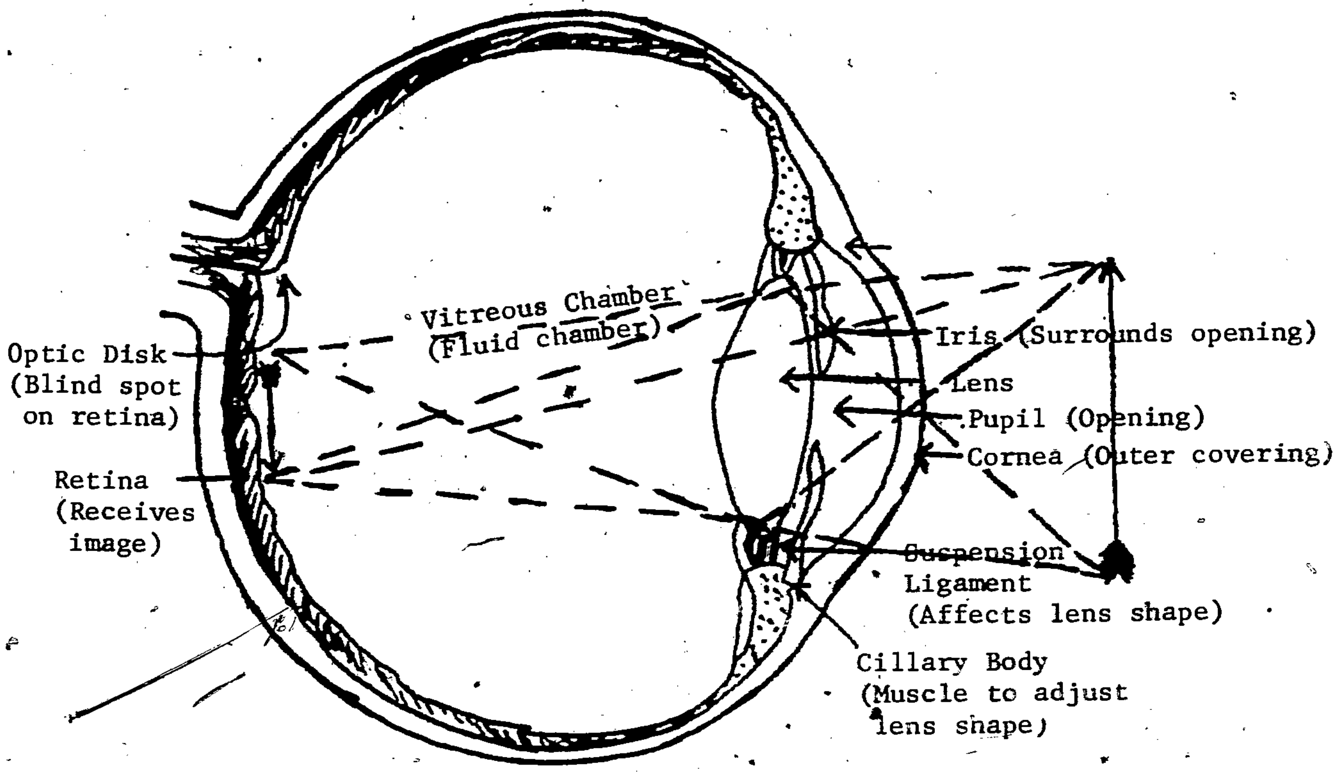


TORIC LENS
Fig. 34

The Normal Eye

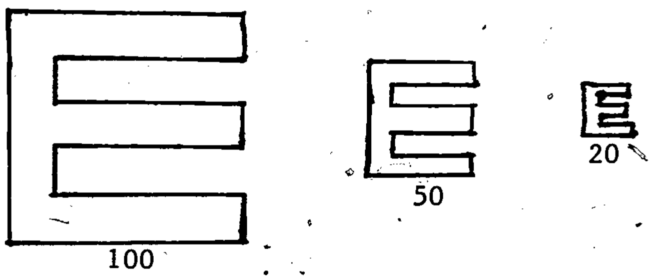
The normal eye forms a satisfactory image on the proper area of the retina (see Figure 34). When light from a distant object passes through the lens system of the eye, it is refracted and brought to a focus on the retina. A real, but inverted, image is formed on the retina. It is amazing to some people that while all retinal images are inverted (see Figure 34), they are interpreted automatically by the brain as being erect.

Good visual "sharpness" can be rated on a vison scale. For example, the term "20/20" refers to the size of letters which the average eye can read twenty feet away. If the letters (objects) must be made larger to be read, the denominator of the fraction becomes bigger: for example, 20/40, 20/50, 20/100, etc. In other words, the smaller the fraction of the vision rating scale, the



HUMAN EYE CROSS-SECTION
Fig. 35

larger the letters (objects) must be to be seen clearly from twenty feet (see Figure 36). The letter marked 20 is readable twenty feet away if you have 20/20 vision. If at twenty feet you barely make out the one marked 50, you have 20/50 vision. If only the large letter is readable, you have 20/100 vision. The letter marked 100 is five times as large as the one marked 20; but if your vision is 20/100, it does not mean that it is five times worse than 20/20; but it is worse. Visual acuity ("sharpness") is only one factor in determining eye condition.

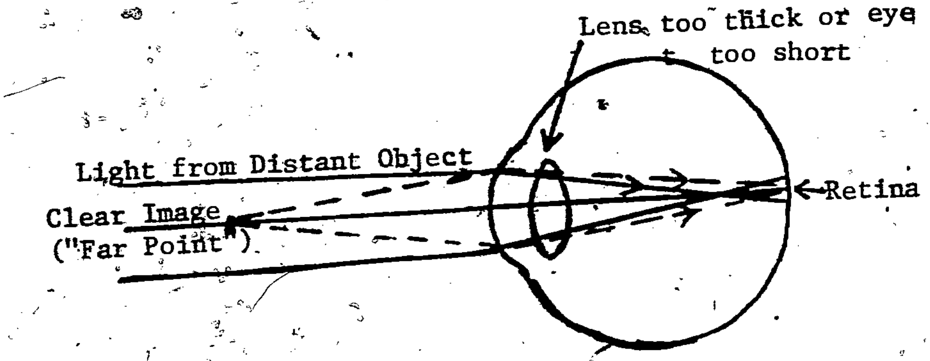


VISION SCALE LETTERS
Fig. 36

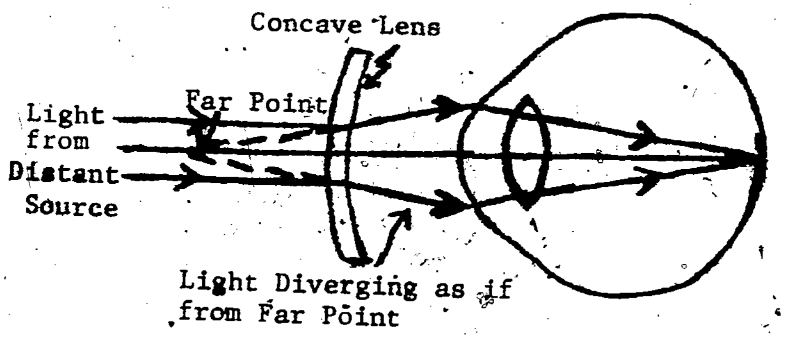
The eye's ability to bring near and far objects into focus is called accommodation. In focusing a camera to accommodate near and far objects, the lens is moved away from or towards the film. In the human eye, the relative position (distance) of lens to retina ("film") is fixed, so focusing is effected by changing the shape of the flexible lens. This change of shape (thickening or thinning of the lens) is accomplished by a system of ligaments and muscles. Due to a tension which exists in the lens capsule, the flexible crystalline lens, if completely free, would tend to become spherical in shape. But the edge of the lens is surrounded by the ciliary muscles which, by contracting, can cause the lens to bulge (thicken at the center). This reduces the focal length of the lens, bringing nearby objects into focus on the retina; and when the ciliary muscles relax, the suspensory ligaments, being under tension, pull the edges of the lens, thus tending to flatten it. Under these conditions, the focal length increases, bringing distant objects into focus on the retina. The normal eye is most relaxed when it is focused for parallel light (on far away objects). To relax your eyes, it is a good idea to gaze occasionally at distant objects. On the other hand, to read and to study fine details, an object must be brought closer to the eye (to permit accommodation); a distance of about 10 inches is usually close enough.

Vision Correction With Spectacle Lenses

The Myopic or Nearsighted Eye. If an eye is myopic (nearsighted), the rays of light coming from a far distant object will converge to a focus before they reach the retina. In Figure 37, you can see that the distant object rays focus in front of the retina (solid lines). You can also observe the point in front of the retina where an object could be placed for the myopic eye lens to form a clear image (dotted lines). On the retina of the myopic eye, there is a blurred image instead of a sharp image.



MYOPIC EYE
Fig. 37



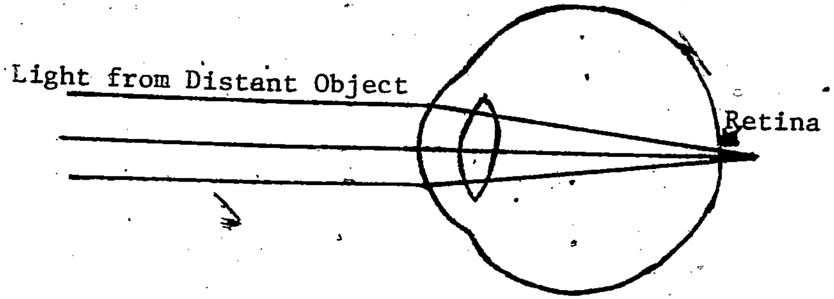
CORRECTING MYOPIC EYE
Fig. 38

By bringing an object closer to this nearsighted eye, a point is finally found where it is possible to see clearly. Because the image of that point will be focused sharply, this is called the "Far Point" (see Figure 37). All other points farther away will produce blurred images.

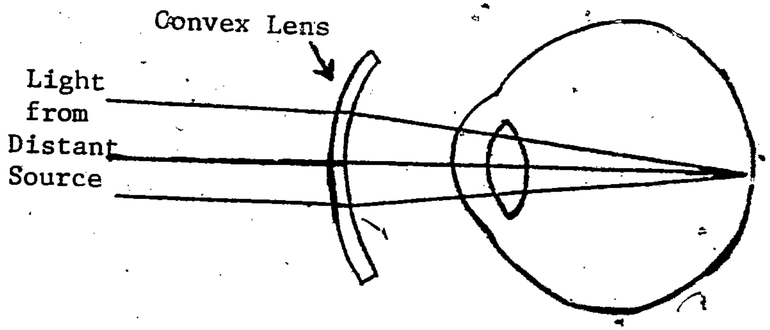
The nearsighted or myopic eye lens must be helped to see far objects; this can be done by placing a concave lens in front of the eye (see Figure 38). This lens can change the direction of the rays of light from a distant object, making them divergent before entering the eye. The power of the concave lens must be precisely such that just the correct divergence occurs; then the rays will seem to have originated at the "Far Point" for that eye and the image will be focused sharply on the retina.

The Hyperopic or Farsighted Eye. In this case, light coming from a distant source will come to a focus behind the retina; consequently, a blurred image will be formed on the retina (see Figure 39). By selecting a convex lens of correct power, it will (in combination with the lens of the eye) focus rays on the retina and form a sharp image (see Figure 40).

Astigmatism. Astigmatism is a defect in vision caused by an irregularly curved cornea, which results essentially in the focus of the eye being different for different meridians (directions). Astigmatism



HYPEROPIC EYE
Fig. 39

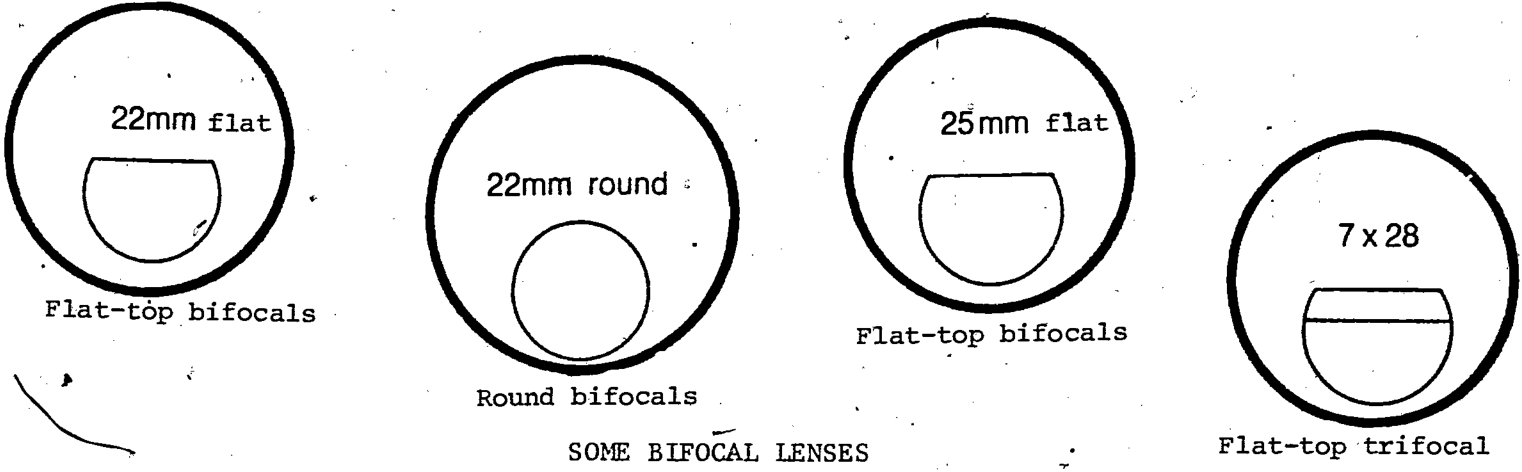


CORRECTION FOR HYPEROPIC EYE
Fig. 40

is usually corrected by using cylinder or sphero-cylinder shaped lenses. With such lenses (Toric lens, for example), the focus of one meridian of the eye can be different from that of a meridian 90° away. Therefore, the lens can have a different power in one meridian from that in another. The combined effect of the proper lens and the astigmatic eye will give a sharp image on the retina.

Bifocal and Trifocal Lenses

Bifocals. The bifocal is actually two lenses combined in one (see Figure 41). The primary purpose of the bifocal lens is to furnish additional power in one portion of the area of the lens which will assist the user in seeing objects nearer to the eye. The remaining area of the lens can be used for focusing on distant objects; hence, the term bi ("two") focal. The portion of the lens in which this extra power is furnished is often referred to in technical terms as the "segment" or "reading addition," or simply, "add." The bifocal lens is widely used as an aid to people over 40 years of age who, because of the



SOME BIFOCAL LENSES
Fig. 41

loss of accommodative power of the eye (reduced lens flexibility), are no longer able to read small print up close. This condition is known as presbyopia.

The most common type of bifocals have the part with added power located in the lower portion (see Figure 41, above). This makes it possible for the wearer to look over the top of the segment when looking at distant objects.

The fused bifocal segment is fused onto the basic lens; this is essentially embedding a piece of glass of greater optical density into the given lens. The denser glass has a greater refractive index and bends the light rays more for focusing nearby objects.

Trifocals. Except for one major difference, the manufacturing process of the bifocal and the trifocal are similar. In the trifocal, two pieces of glass of different densities are fused to the given lens.

Each glass has a refractive index for producing a different focal length. Trifocals can thus furnish a focus for nearby work, another for intermediate distance work (arm length work, for example), and a third for far distance viewing.

Who Else "Gotta" Wear Glasses?

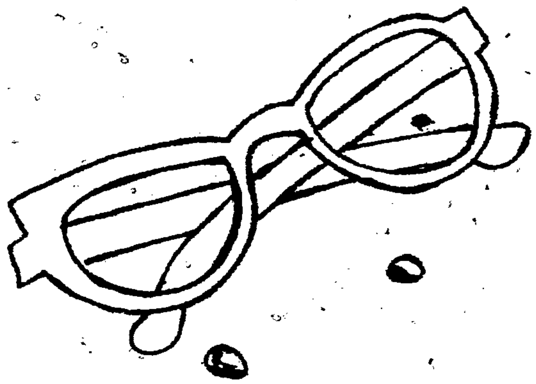
Wearing glasses which are properly fitted will neither ruin eyes nor weaken them, as some people think. Further, the majority of people should wear either corrective vision glasses or protective vision glasses. Eyeglasses are usually thought of as being used for correction; but so-called safety glasses are fitted with special lenses designed to protect eyes under hazardous industrial conditions and, of course, to protect the eyes from glare (sunglasses).

Special Kinds of Glasses

Contact lenses are prescribed often for people with relatively great visual defects (see Figure 42). But many people prefer contact lenses for cosmetic reasons (you can change "eye color" when you change the color of your clothes!), and others because the frame problem is eliminated.

Because some eyes do not achieve good visual sharpness with contact lenses, and because some people are hypersensitive to the eye pressure which contact lenses can effect, not everyone can wear them.

Sunglasses should be worn by people who spend much time in the sun, to protect their eyes from the infrared (long wave, heat radiations) and the ultraviolet (short wave, tanning radiations) of the sun-



SIZE COMPARISON OF CONTACT LENSES
AND ORDINARY EYE GLASSES
Fig. 42

light's spectrum; these radiations tend to damage the eyes. In addition, glare can cause annoyance, fatigue, headache, discomfort, etc.

Sportspersons often need special glasses for fishing, boating, flying, skin diving, skiing, racing, and other sports. Where magnification is needed, binoculars and telescopes are often useful or necessary. For example, many modern guns have telescopic gun sights.

RESOURCE PACKAGE 2-2

IMAGE FORMATION BY EYEGLASS LENS

Purpose: (1) To find the focal length of an eyeglass lens.

(2) To show how eyeglasses form images.

(3) To show the relationship between object distance, image distance, and focal length of a lens.

(4) To show the relationship between the size of an object, the size of an image, the distance of the object from the lens, and the distance of the image from the lens.

Materials Needed: Object screen, light, meter stick and supports; candle; eyeglasses (if not available, substitute a convex lens and holder); cardboard screen with metric scale.

Introduction: This section of investigations should provide you with some first-hand knowledge of lense formation of images.

Investigating Focal Length and Eyeglass Image

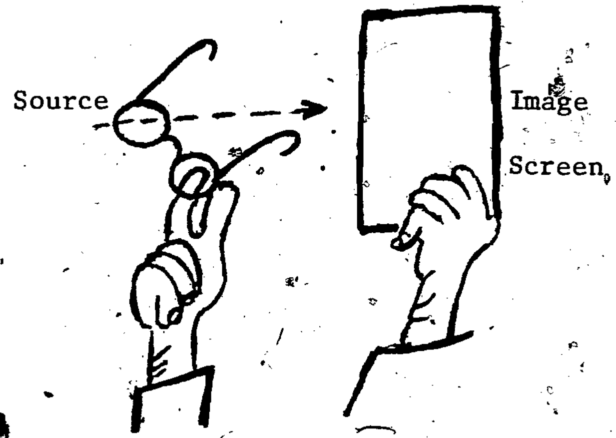
Look at a printed page through a lens of some eyeglasses. Slowly move the lens back from the print, until the print starts to blur. Measure the distance from the print to the lens, when this blurring of the print first occurs. This is the focal length of the lens. In your notebook, describe the image produced and record this distance. Also, answer this question: Does the image become larger or smaller as the lens is drawn back from the print?

Investigating a Real Image

Now hold the lens of some eyeglasses in a path of light, where the source is a known distance away. (an optical bench is convenient here). Fig. 1 shows the setup without optical bench; this requires several people working together. Place the lighted candle (or electric equivalent) in its holder on the meter stick (or in hand) opposite the lens and screen. The distance of the candle (source) to the lens should be slightly more than the lens focal length.

Darken the room. Move the screen back and forth slowly, to find a sharp focus of the image of the candle (source) on the screen. Make a data table in your notebook, similar to the one on the next page. Record the required data.

Now move the candle (source) to a position twice the focal length (2F). Focus to a sharp image and record the data in the table. Move the source beyond 2F and repeat the procedure.



INVESTIGATING A REAL IMAGE
Fig. 1

DO NOT WRITE IN THIS BOOK. REPRODUCE THIS TABLE IN YOUR NOTEBOOK.

IMAGES FORMED BY EYEGLASS LENS

Position of Object	Position of Image	Characteristics of Images		
		Real or Virtural	Larger, Smaller or same size	Upright or Inverted
Between Fand 2F				
At 2F				
Beyond 2F				

RESOURCE PACKAGE 2-3

SELF-TEST QUESTIONS

1. Name two general types (classifications) of lenses?
2. What is a diopter?
3. What is meant by the following (a) + 6.00D and - 6.00D?
4. If a lens had + 8.00D on one side and - 4.00D on the other, what is its power in diopters?
5. Explain the following vision scale ratios: 20/20, 20/50 and 20/100.
6. What is a myopic eye?
7. What kind of corrective lens is used to assist the myopic eye?
8. What is the hyperopic eye?
9. What kind of lens is used to assist the hyperopic eye?
10. List some examples of optics applied to correct or to protect vision.
11. A converging lens has a focal length of 15 cm. If it is placed 50 cm from an object, at what distance from the lens will the image be?
12. What is the focal length of the human eye lens when a person is looking at a person standing 50 ft away? Assume the distance from the lens to the retina is 0.75 inches.

RESOURCE PACKAGE 2-4

ANSWER TO SELF-TEST

1. The two general types of lenses are convex and concave.

2. A diopter is a measurement used to describe the (converging or diverging) power of a lens:

$$D = \frac{\text{1 meter}}{\text{focal length in meters}}$$

3. (a) +6.00D means that the lens has a convex surface curvature of 6 diopters.

   (b) -6.00D means lens has a concave surface of 6 diopters.

4. +8.00 diopters
   -4.00 diopters
   +4.00 diopters

   Answer +4.00D

5. $\frac{20}{20}$ = refers to the average size of the alphabet letter which the average eye can read 20 feet away.

   $\frac{20}{50}$ means that at 20 feet, the eye can barely make out the letter marked 50 on the vision scale; $\frac{20}{100}$ means the eye can barely make out the letter marked 100 on the vision scale, when at a distance of 20 ft.

6. A nearsighted eye.

7. concave lens

8. Farsighted eye

9. convex lens

10. Answers vary

11. $\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$ $\qquad D_i = \frac{D_o f}{D_o - f}$

$$D_i = \frac{50\ cm \times 15\ cm}{50\ cm - 15\ cm}$$

$$D_i = \frac{750\ cm^2}{35\ \cancel{cm}}$$

$$D_i = 21.4\ cm$$

12. $\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$

$$f = \frac{D_o D_i}{D_o + D_i}$$

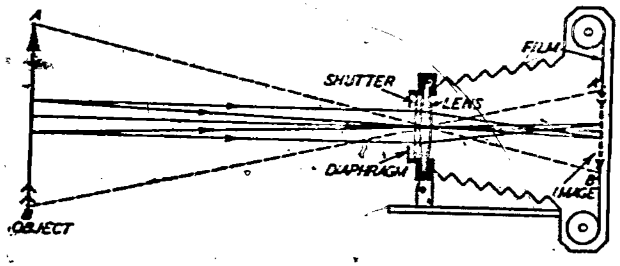
$$f = \frac{50\ \cancel{ft} \times 12\ \cancel{in}/\cancel{ft} \times 0.75\ \cancel{in}}{50\ \cancel{ft} \times 12\ in/\cancel{ft} \times 0.75\ in}$$

$$f = 0.75\ inches$$

RESOURCE PACKAGE 3-1

APPLICATION OF LENSES AND LENS SYSTEMS

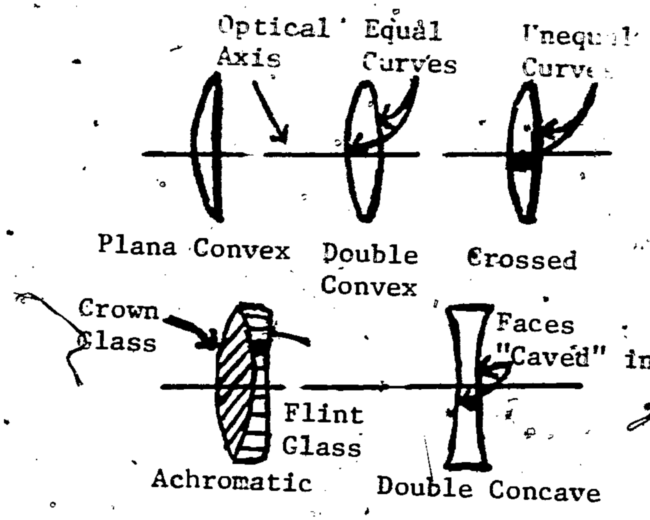
<u>The Camera</u>. The camera is a light-tight box with a convex lens in front, and with a light-sensitive photographic film back and slightly beyond the lens' focal length. See figure 1 . The object being photographed is beyond 2F., Inside, the lens casts a real, inverted, (small) diminished image upon the photographic film. The length of time light is allowed to pass through the lens can be varied by shutter speed, and can ary from a thousandth of a second up to several minutes in extreme cases; the brightness (illumination) of the object to be photographed and the light sensitivity (speed) of the film are two of the factors in determining shutter speed.



THE CAMERA
Fig.1

A fixed or movable opening, called a <u>diaphram</u> or <u>stop</u>, is put in front of the lens to regulate the size of the pencil of light entering the camera. A camera is susally made so that the lens to film distance can be adjusted to permit focusing on objects at varying distances.

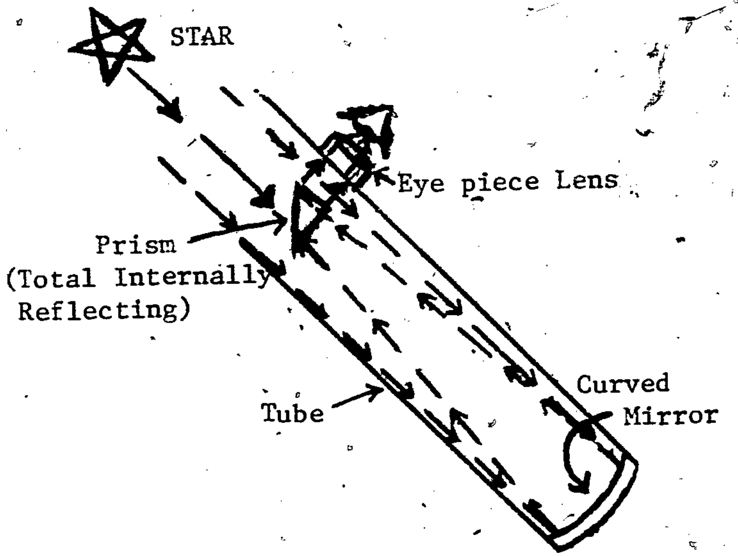
<u>The Telescope</u>. The lenses needed to make a simple telescope are shown in Figure 2 . A converging lens ~~is~~ commonly used for the objective or front lens. If it is a <u>compound</u> lens it may consist of two lenses cemented together and called a <u>cemented doublet</u>; and if this combination is corrected for



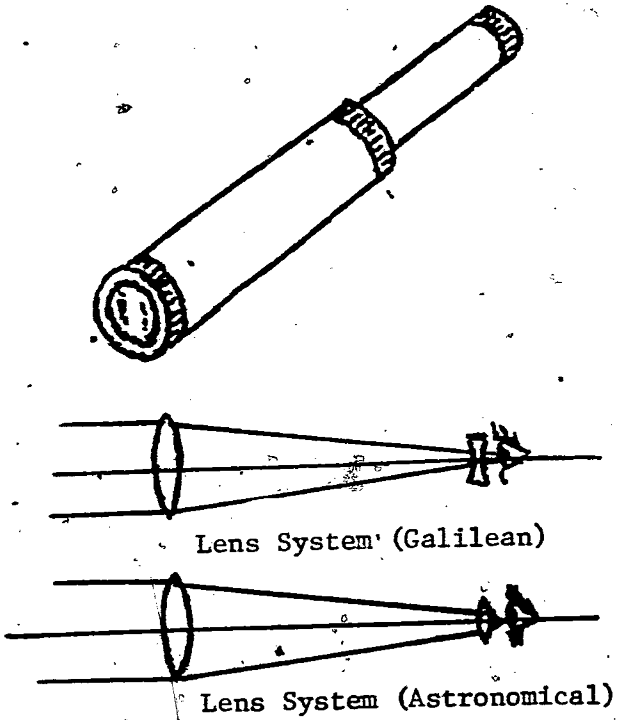
TELESCOPE LENSES
Fig. 2

color aberration (color aberration is the unequal bending of different colors, or light wavelengths, resulting in a blurred image because each color bends somewhat differently and thus focus at different focal points), it is called achromatic. The plano convex lens of Fig. 2 is one kind of non-compounded (single) lens that may be used as an objective on less expensive telescopes. In more expensive telescopes, double-convex and crossed lenses are used instead of the plano convex. The double concave lens is a negative lens and is used as the eyepiece (not the objective) for what is called the Galilean telescope. Galileo is credited with having made the first modern telescope over 300 years ago!

There are two main kinds of telescopes, refractor telescopes and reflector telescopes. The refracting type (Fig. 4) picks up light from the object viewed by means of a lens or a combination of lenses; the reflector telescope does the same job with a curved mirror (See Fig. 3). The reflector type telescope is used almost exclusively in astronomy; while the refractor telescope, though used in astronomy, has many other uses.



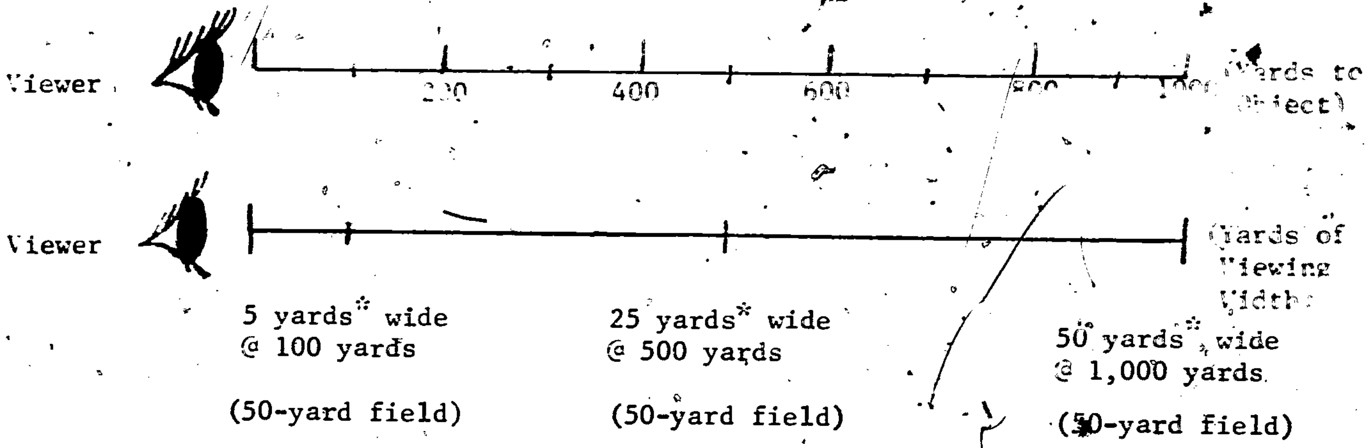
REFLECTING TELESCOPE
Fig. 3



REFRACTING TELESCOPE
Fig. 4

Some Features Of Telescopes. Some features of any telescope include field, magnification and illumination. These will be discussed separately.

Field refers to how broad a scene can be viewed through the telescope. Field is a technical word, and it is usually expressed in yards per 1000-yard distance. For example, a 50-yard field is equivalent to a 25-yard field at 500 yards, or to a 5-yard field at 100 yards. See the sketch below.



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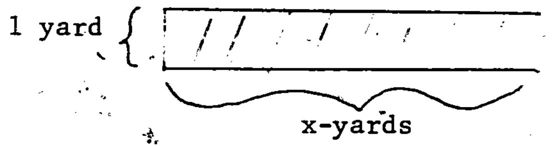
* If the view is only a yard wide:



Because field refers to cross sectional area.

In other words, a 5-yard field encompasses an area of any shape which totals 5 square yards; a 25-yard field would view 25 square yards, etc.

Magnification refers to how much bigger or how much smaller the image becomes. A telescope which magnifies ten times (10X) actually makes the object look ten times as big as seen by the unaided eye. Because the object viewed is larger than when seen by eye alone, it appears to be closer. The converse is true when the magnification is negative (object appears farther when the image size is smaller).

Illumination refers to how much light reaches the eye or how brightly the object looks as seen through the telescope. The pupil of the eye is reduced to about 5 mm in diameter in daylight. If a beam of light of this same diameter comes through the telescope, this is equivalent to getting the same illumination as with the eye alone in daylight. If the beam in daylight is less than 5 mm diameter, the brightness will be less that that gathered by the unaided eye. On the other hand, a daylight beam larger than 5 mm is partly wasted because it is larger than the pupil of the eye. In the dark, the pupil of the eye expands to about 7 mm, therefore the ideal night viewing scope should pass a beam of 7 mm. In practice, these maximun illumination values for daylight or for night viewing are seldom attained. However, about 50 percent, or less, is satisfactory for most viewing purposes. In fact, 10 percent of the illumination of bright sunlight is sufficient for us to see reasonably well.

In the telescope business, you cannot have your pie and eat it too. If you build a telescope, you must compromise magnification against field and illumination. You can't maximize all three. It turns out that the higher the magnification, the smaller the field; further, it is usually the case that the higher the magnification, the poorer the illumination. In technical applications, the telescope's intended use determines which factor is given preference. For example, if you plan to build an astronomical telescope, you can safely sacrifice both field and brightness for greater magnification. But for many other purposes, one may need both a large field and good illumination: this means that one must accept less magnification.

INVESTIGATING THE GALILEAN TELESCOPE

Purpose: To construct and to use a Galilean telescope.

Materials Needed: An optical bench (A meter stick with supports and lens holders will do.)

Assortment of lenses (objective lenses of 25 to 64 mm in diameter, of focal length 95 to 304 mm, of E/4 to F/6 stop values, and plano concave.)

Introduction. Galileo (1664-1647) perfected this type of telescope; its good features are simple construction, a sharp field, and an upright image. The poorest feature is that the field of view is small and decreases rapidly with increased magnification; therefore, Galilean telescopes are usually confined to a magnification of six times or less, with a top of perhaps 8X. Two Galilean telescopes can be combined to make field glasses or opera glasses and are so-called to distinguish them from prismatic binoculars.

Procedure. Notice the normal values of the chart on the next page: that is, the objective lens has a certain range of diameters and focal lengths, the magnification has certain limits, etc. Examine the chart carefully.

NORMAL VALUES FOR GALIEAN TELESCOPES	
Diameter of object Lens - 25 to 64mm (1 to 2½in)	Dia. of Eye Lens - 10mm or over
Focal Length of 95 to 384mm (3 3/4 to 15 1/8in) Objective.	Dia. of Eye hole 5/16 to 3/8
Focal length ÷ Diameter of objective=f/number Objective should be f/4 and not over f/6.	Eye Relief 5/16 inch
Magnification - not over 8X	Field 30 to 100 yards at 1000 yards
Focal Length of 12 to 38mm (½to1½in) Eye piece	**Illumination - 100% or better**

Illumination will not need to be taken into account if the scope is well designed. An important "Normal Value" is the f/value of the objective lens; it must be f/4 or under in order to obtain a reasonable field of view.

It is good for you at this point to do some calculations which are simple. Carefully peruse (study) the calculations and definitions on the next few pages.

DEFINITIONS

$$\text{Magnification} = \frac{\text{f(length) of objective lens}}{\text{f(length) of eyepiece lens}}$$

$$\text{f(length) of eyepiece lens} = \frac{\text{f(length) of objective lens}}{\text{magnification}}$$

$$\text{Field of view} = \frac{\text{diameter of objective lens X 1000}}{\text{f (length) of objective lens X magnification}}$$

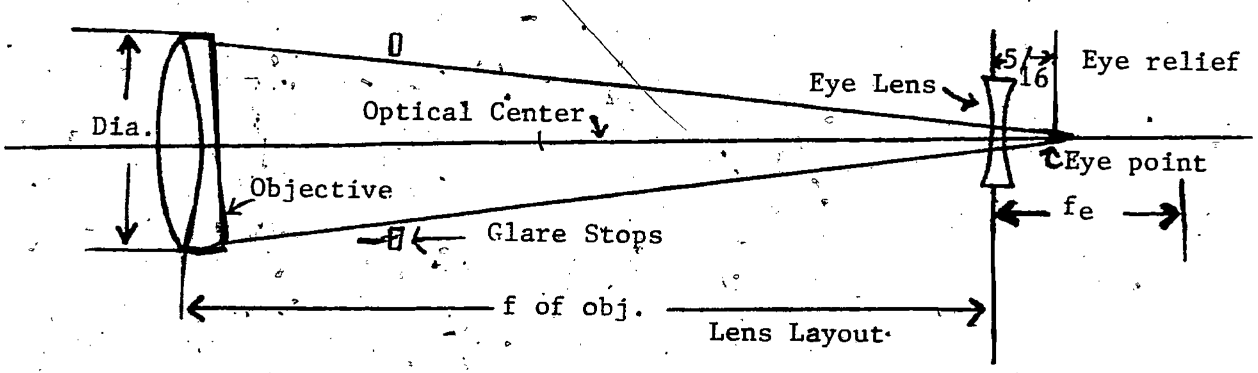
$$\text{f/value of objective lens} = \frac{\text{f(length) of objective lens}}{\text{diameter of objective lens}}$$

HOW TO USE DATA

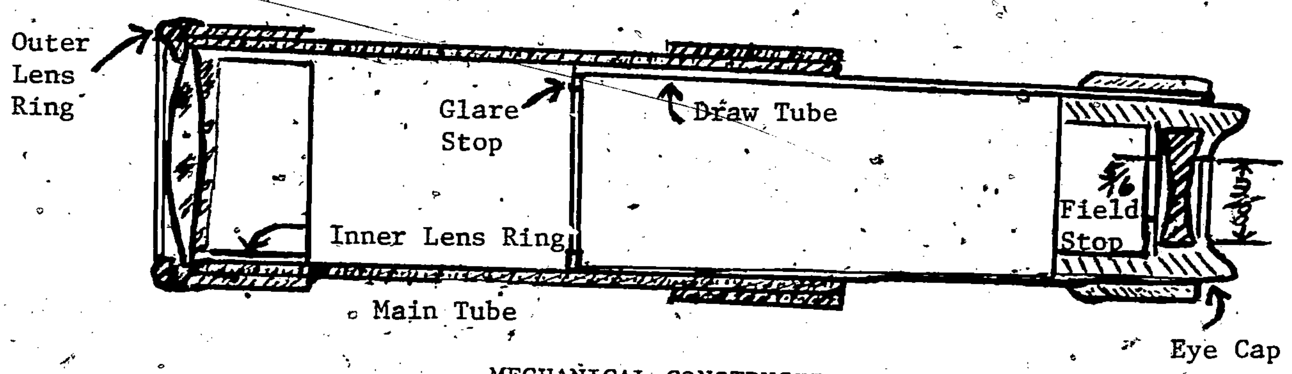
Data	Calculations
Objective - 52 mm diameter; 193 mm focal length	Magnification = $\frac{\text{f of obj. lens}}{\text{f of eyepiece lens}} = \frac{193\text{mm}}{28\text{mm}} = 7\text{x}$ (This is about the limit) Higher power makes the field too small.
Eyepiece - 19 mm diameter; 28 mm focal length	Field in yards at 1000 yds. = $\frac{\text{dia. or obj. lens x 1000}}{\text{f of obj. lens x mag.}} = \frac{\text{52mm x 1000 yd.}}{\text{193 mm x 7}}$ = 38.5 yds.
Length 7 3/4 inches extended, 5½ closed	f/value of objective = $\frac{\text{f of obj. lens}}{\text{dia. of obj. lens}} = \frac{193\text{mm}}{52\text{mm}}$ = f/3.7

After you get the swing of calculating the "Normal Values" for a telescope, your next move is to make one.

Designing your Telescope. Examine Figure 5 to get an idea for the layout of your lens system, with focal lengths and spacing for lens as they will be when the telescope is focused at infinity (an object about 300 yards away will serve as one at infinity). The telescope is at its shortest draw (collapsed length) when focused at infinity. To focus on a close object, you will pull the draw tube out about a half-inch or so.

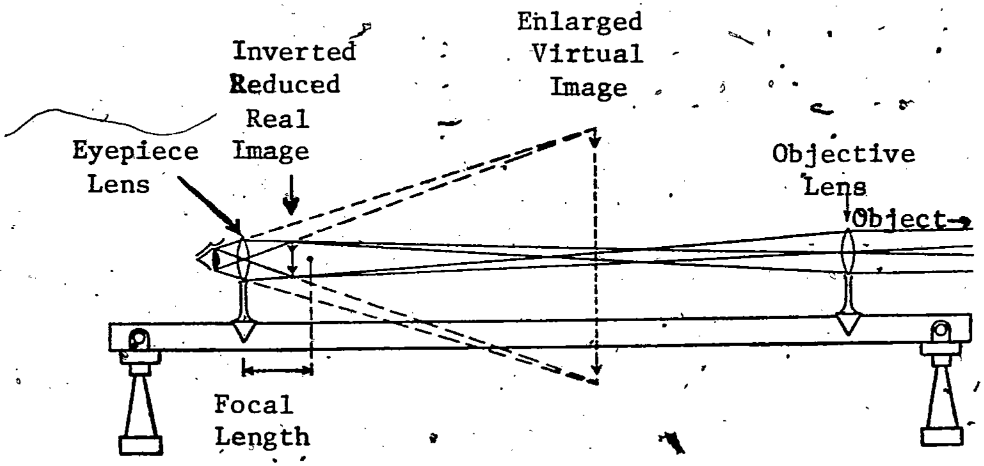


GALILEAN TELESCOPE



MECHANICAL CONSTRUCTION
Fig. 5

You really don't have to do calculations to build a simple [illegible]ope. Try this direct method described next. First, set up the lenses on an optical bench, with the objective lens about 20 feet from the object (use a printed sheet for the object copy). Move the eyepiece back and forth until you get the copy in exact focus. Once you get proper lens setting,



(Change Eyepiece Lens to Double Concave To Make Galilean Telescope)

METER STICK TYPE OPTICAL BENCH
Fig. 6

proceed with sketching in the construction details to suit yourself using Figures 5 and 6 only as guides.

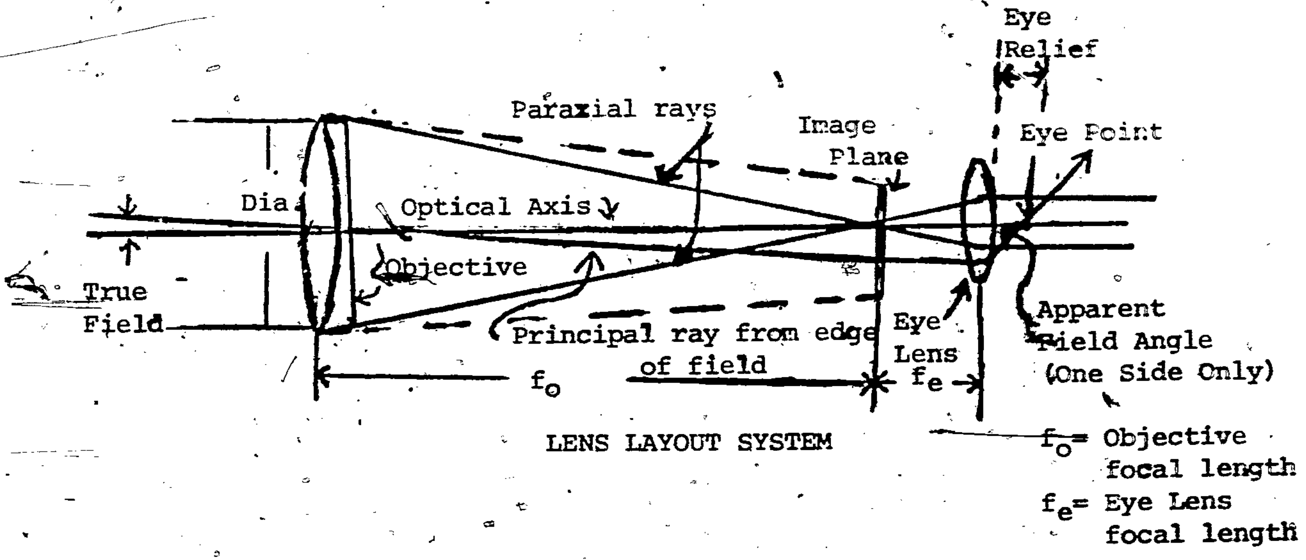
The eye point for the Galilean telescope should be close behind the eyepiece lens because the closer your eye is to this lens, the more you see. It is best to be about 5/16-inch from the eyepiece to avoid distortion. In designing, the lines drawn from the eye point to the edges of the objective can be used as a guide for diameter of glare stops. Glare stops are round disks made of cardboard fitted inside the telescope, whose purpose is to cut off stray light. The glare stop near the eyepiece should be of 5/6-inch diameter for all Galilean telescopes.

Fig. 6 shows a good design of a 7x Galilean telescope, with some calculations worked out for you. The construction calls for cardboard tubes, thoroughly blackened inside with black paint. The field of this instrument is about 38½ yards.

INVESTIGATING THE ASTRONOMICAL TELESCOPE

In the astronomical telescope, light first passes through the objective lens, then it forms an inverted image of the objected viewed, and then this image is looked at and magnified by the eyepiece lens. See Fig. 7.

Lens spacing is simply the focal length of the objective plus the focal length of the eye lens. Unlike the Galilean telescope, the diameter of the objective has no bearing on the size of the field, you will be able to see just as much through a small lens as a large one. However, diameter of the objective lens does control the illumination. Notice in Fig. 7 that the principal ray from the edge of the field crosses the optical axis at a point behind the eye lens. This point of crossing is the eye point, and marks the proper position for your eye when looking through the telescope.



ASTRONOMICAL LENS
Fig. 7

The first thing you do is to make calculations. Start by checking normal values in the charts on the following page:

Normal Values For Astronomical Telescope

Diameter of Objective Lens: $1\frac{1}{2}$ to 4 in.	f/value of Objective: f/10 to f/15
f of Objective Lens: 20 to 60 inches	True Field: 15' to 1° Angle
Magnification: 1[illegible]X to 60X per inch of objective diameter	Apparent Field: 40°
Exit pupil: 1/64 to 1/6 inch (The image of the objective as seen at the eye lens).	Eye Relief: 5/16 to 3/4 inch
f of eye lens: $\frac{1}{4}$ to $1\frac{1}{4}$ in.	

Calculation Formulas

$$\text{Magnification} = \frac{\text{f of obj. lens}}{\text{f of eye lens}}$$

$$\text{f of Eye Lens} = \frac{\text{f of obj. lens}}{\text{magnification}}$$

$$\text{Exit of Pupil} = \frac{\text{dia. of obj. lens}}{\text{magnification}}$$

$$\text{f/value of Objective} = \frac{\text{f of obj. lens}}{\text{dia. of obj. lens}}$$

Diameter of Eye Hole = .72 x Eye relief

This preliminary calculation work is necessary to tell whether or not you are on the right design track. For example, if you have a $2\frac{1}{2}$ inch diameter by 36-inch focal length lens, this will give a magnification of 36X, which with a $\frac{1}{2}$-inch eyepiece will give a magnification of 72X. At 72X, the exit pupil will be (2.5 ÷ 72) or .034 (about 1.32 inch). Then one can go ahead and set up the test on the optical bench.

Set up the telescope components on the optical bench. Next, make a <u>Lens Layout</u>, which is a check to see if you are getting the full field and all the light you can through the telescope. This is done by drawing a diagram beginning with an optical axis (a centerline). Then cross the centerline with lines to represent objective, image plane, eye lens and eye point. Make the drawing full size from dimensions or from marks you have made on the optical bench. Finish your drawing and plans for making a telescope at home. Work out the diameter of the stops (glare stops or field stop). Fig. 8 has a chart of image size, and Fig. 9 shows calculations and drawings of an astronomical telescope.

The telescope in Fig. 9 is just a suggestion, to give you an idea of how you may design your own telescope at home, if you desire to do so.

<u>Eyepieces</u> Most telescopes, with the exception of Galilean telescopes, have eyepieces consisting of two lenses. In the two-lens eyepiece, the front lens is called the <u>field lens</u> and is used to collect the light and direct it to a smaller eye lens. The purpose of the eye lens is to magnify. Fig.10 shows four common types of eyepieces.

IMAGE SIZE

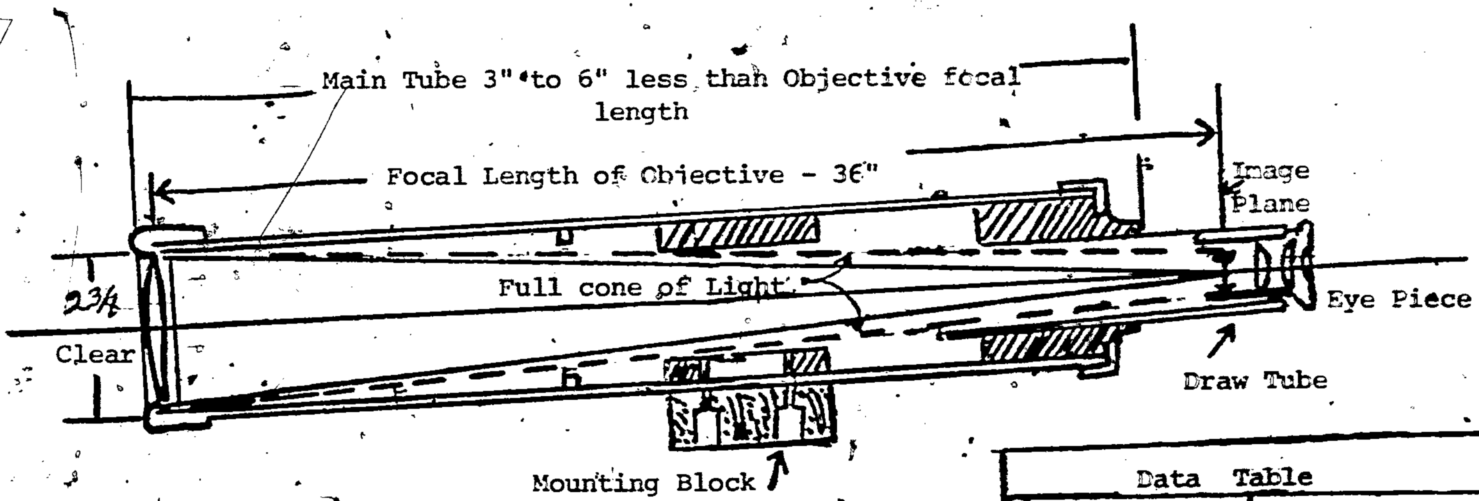
Opposite magnification of Telescope find Multiplying Factor. Multiply Factor by focal length of objective (in inches) to get image size (in inches).

M	True Field	Factor	M	True Field	Factor	M	True Field	Factor
4	10°	.176	19	2°1'	.036	34	1°11'	.021
5	8°	.141	20	2°	.035	35	1°9'	.020
6	6°36'	.116	21	1°55'	.033	36	1°7'	.019
7	5°42'	.099	22	1°48'	.031	37	1°5'	.019
8	5°	.087	23	1°44'	.030	38	1°3'	.018
9	4°26'	.077	24	1°42'	.029	39	1°2'	.018
10	4°	.070	25	1°36'	.028	40	1°	.017
11	3°38'	.063	26	1°32'	.027	45	54'	.015
12	3°20'	.058	27	1°29'	.026	50	48'	.014
13	3°6'	.054	28	1°26'	.025	55	44'	.013
14	2°51'	.050	29	1°23'	.024	60	39'	.011
15	2°42'	.047	30	1°20'	.023	75	32'	.009
16	2°30'	.044	31	1°18'	.023	100	24'	.007
17	2°21'	.041	32	1°15'	.022	125	20'	.006
18	2°12'	.038	33	1°13'	.021	150	16'	.005
						200	12'	.003

Fig. 8

Field of View: To find Field of View, find magnification of telescope and read multiplying factor as yards at 1000 yards.

Ex. 12x magnification = 58yd Field



2 3/8" ASTRONOMICAL TELESCOPE

(Magnification -36X to 144X)

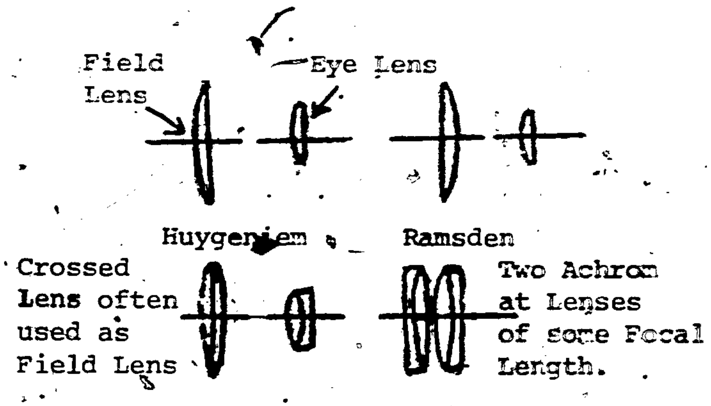
Fig. 9

Data Table	
Objective	2½" Dia. 36" F.L.
f/ Objective	36÷2.5= f/14
Eye Piece	¼" to 1" F.L.
Magnification*	36 x with 1" Eye Piece
Exit Pupil	1/16" (1-7mm.) at 36x
True Field	1° 10' (at 36x)
Image	11/16" (at 36x)

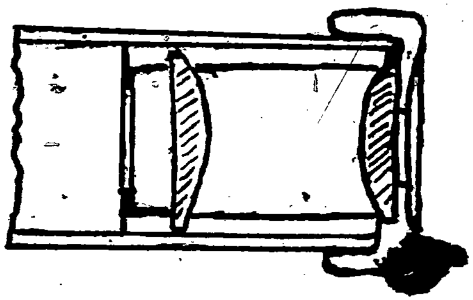
* To increase magnification use shorter focus eyepiece.

The Huygeniem Eyepiece differs from the others in that the image plane is between the two lenses; therefore, it cannot be used directly as a magnifier. However, it is well corrected for color, and image definition is good over a wide field.

The Ramsden Eyepiece is popular and easy to make. It is a better corrected eyepiece than the Hygenian eyepiece in all respects, except for color. (See Fig. 10 and 11).

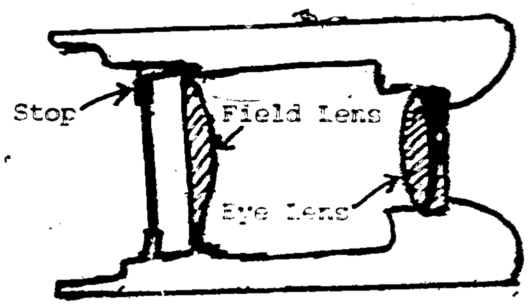


COMMON EYEPIECES
Fig. 10



RAMSDEM EYEPIECE
Fig. 11

The Kellner Eyepiece (Fig. 12) has less chromatic (color) aberration than the Ramsden, but it has slightly more spherical aberration (inexact focus due to different distances of lens surface points to the lens focal point); therefore, this eyepiece is the first choice for prismatic instruments (because with the prisms, both the chromatic and spherical aberrations are inherently reduced almost to zero). The Kellner Eyepiece is a symmetrical eyepiece used almost exclusively for riflescopes.

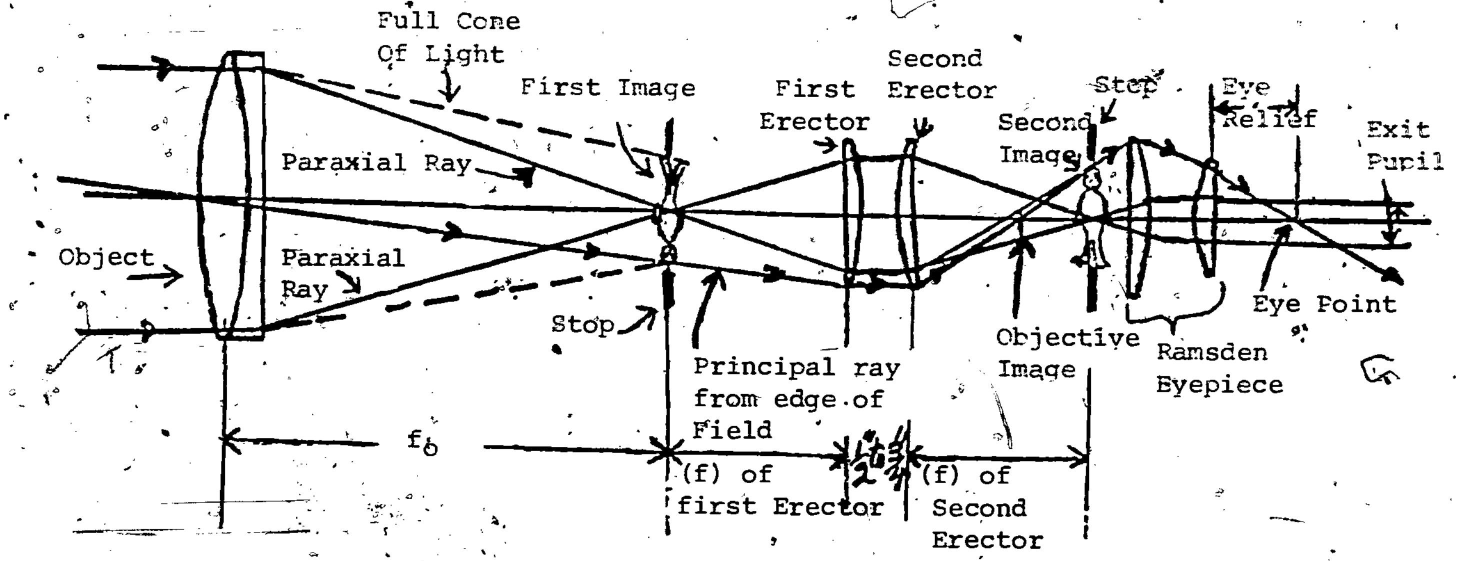


KELLNER EYEPIECE
Fig. 12

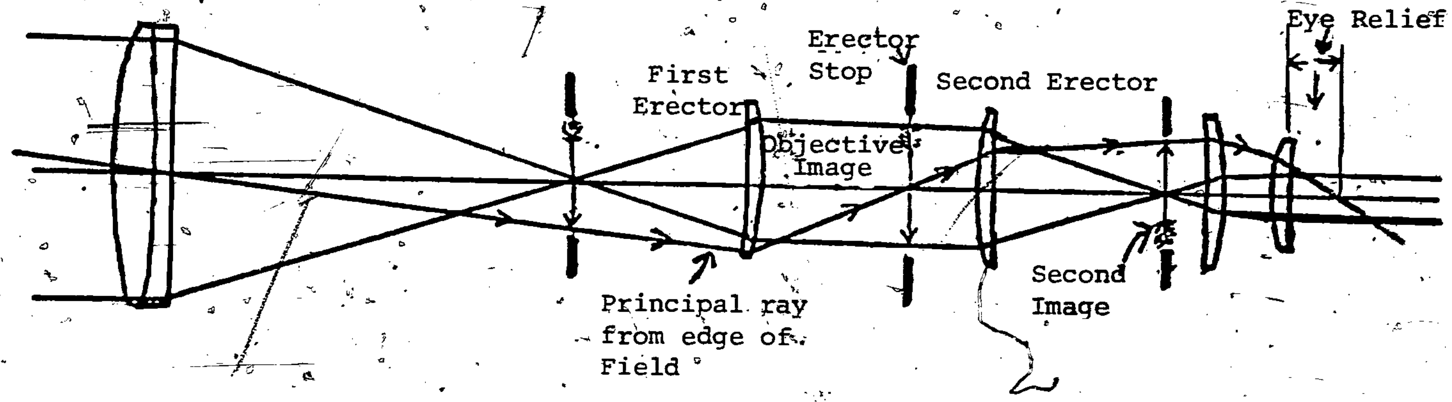
Terrestrial Telescopes. A terrestrial telescope is one designed for viewing objects on land. It shows an upright image, and in order to do this it uses two lenses placed between the object lens and the eyepiece. This makes for greater magnification as well as for an upright image. An 8 or 10-inch focal length objective can be increased to 30X or better. But with higher magnification, a sacrifice of both illumination and field occurs. The average terrestrial telescope is hand-supported and has a top practical magnification limit of 15x; above 15x a stand is required to keep the magnified field from blurring because of telescope movement.

The normal lens system may contain an objective that is plano-concave, although a good scope always uses an achromat. The lenses which place the image upright are called erectors; erector lenses may be plano-convex or acromatic. Erector lenses may be spaced close together or wide apart; wide spacing ~~is~~ best, since it lessens distortion. Figures 13 and 14 present an idea of how these lenses are used.

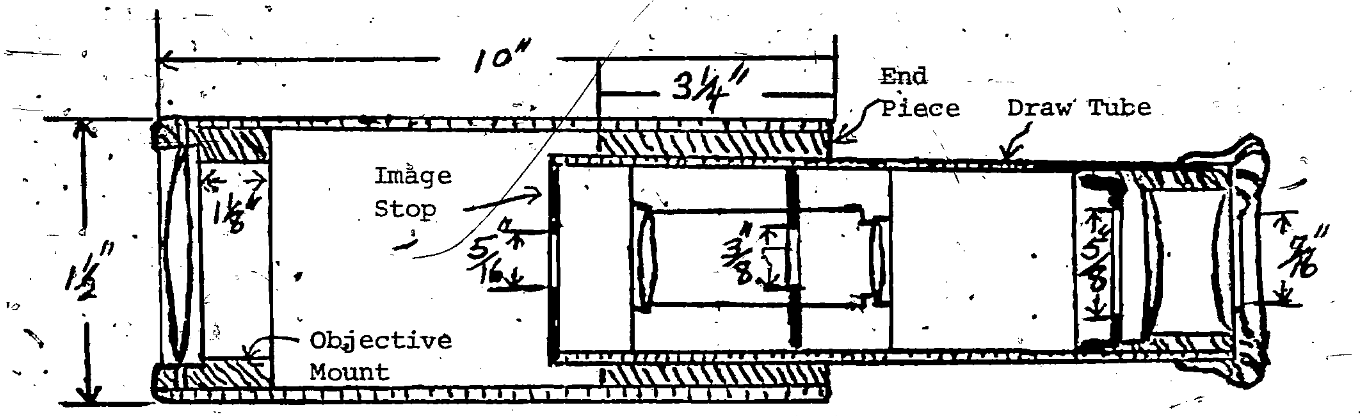
With your present knowledge, and using the illustrations and data in Figs.13 and 14 you can make an optical bench setup and layout for terrestrial telescope. If you desire to make a terrestrial telescope at home, Fig. 15 shows one you can buy in kit form from Edmund Scientific Co., Barrington, N.J.



LENS SYSTEM OF
TERRESTRIAL TELESCOPE
Fig. 13



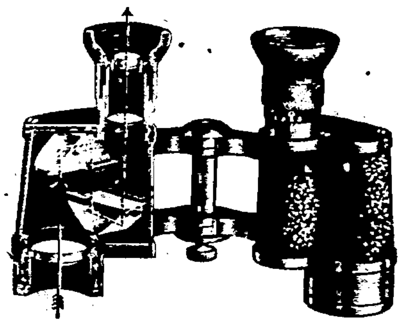
TERRESTRIAL TELESCOPE
WITH WIDE SPACING OF ERECTORS
Fig. 14



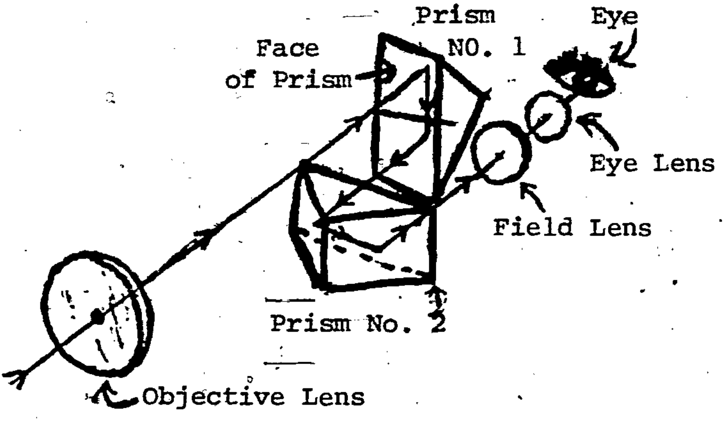
MECHANICAL CONSTRUCTION OF
TERRESTRIAL TELESCOPE (ABOUT 10X)
Fig. 15

Prismatic Telescopes. This type of telescope consists of an astronomical lens system, plus two prisms to erect the image. Noticeable advantages of the prism erecting system are compactness and little light intensity loss; this greatly reduces the length of the telescope. Magnification must be obtained solely by the ratio of the focal length of objective to the focal length of eyepiece. Telescopes of this type give a brilliant image due to the little light intensity loss in the total reflection of light by prisms. See Fig. 16.

The "Normal Values" for the prismatic telescope are the same as those for the terrestrial telescope, so all calculations are essentially the same.



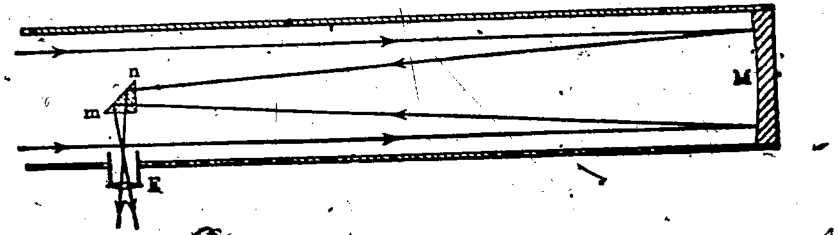
PRISM BINOCULAR



PRISM TELESCOPE
Fig. 16

Reflector Telescopes. In this type of telescope, a large concave mirror is used to collect the light and produce an image of some distant object, such as a planet. The mirror in Figure 17 is labeled M. In many reflector telescopes, the image is viewed from the side as shown here. A totally Internally reflecting prism (mn) turns the light through a right angle and brings the image to the eyepiece, E. The eyepiece produces a magnified virtual image of the object.

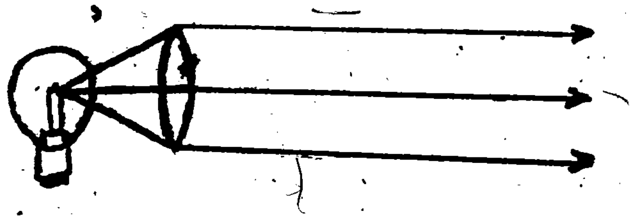
If you wish to build a four to ten-inch reflecting telescope, you can get plans from *Popular Mechanics* for about 50¢ or you can write Edmund Scientific Co., Barrington, New Jersey, where you can purchase necessary materials to build one.



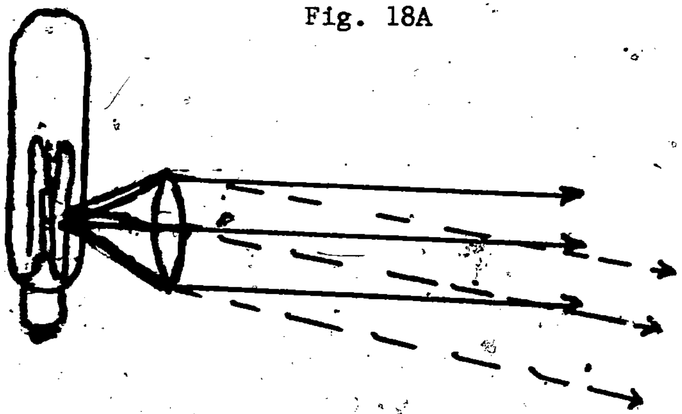
REFLECTING TELESCOPE
Fig. 17

Projector Systems. A projection system usually has two distinguishing features: (1) It forms a real image (2) It contains a light source of high brightness. Some image projection systems are the slide and motion picture projectors; these form an image of the film on a projection screen. Other non-image projection systems, such as spotlights, searchlights and signal lights, are designed to project only an image of the light source.

Some principles of any projection system are illustrated in Fig. 18A. A source of light is located at the focal point of the lens, thus

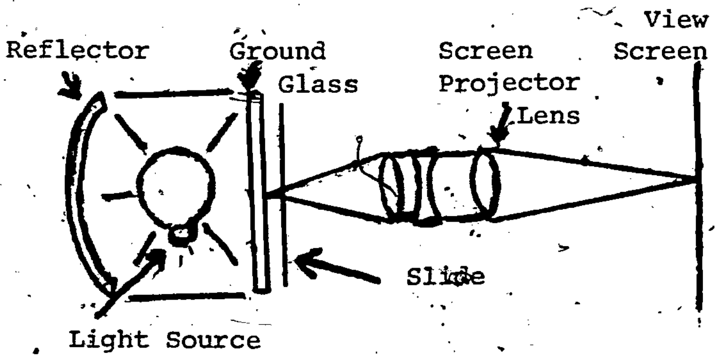


Basic Projection System
Fig. 18A



Effect of Increasing Size of Light Source.
Fig. 18B

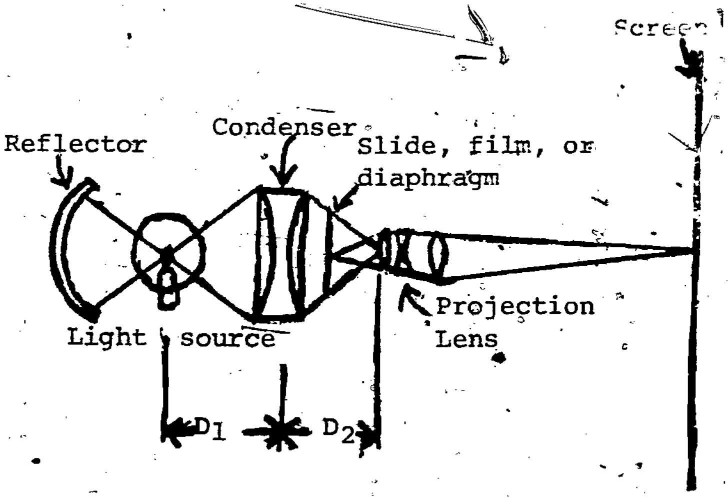
forming an image of the source at infinity. Illumination at any point along the axis of the projector light path obeys the Inverse Square Law. Therefore, the illumination may be found by dividing the candle power of the lamp by the square of the distance to the point (plane) under consideration. For example, a 100-candle lamp, at a distance of 5 feet, produces an illumination of 100/25, or 4 candles. This intensity of illumination depends only on the intrinsic brightness of the light source and not at all on its dimensions. Therefore, the size of the source (as shown in Fig. 18B) merely produces a larger beam, without increasing the illumination of an object within the beam.



SLIDE PROJECTOR
Fig. 19

The Slide Projector. When you desire to project an image of something other than a light source upon a distant screen, then a projection system such as that of Fig. 19 can be used. This projector system consists of an illuminator behind the slide, and a projection lens which forms an image of the slide on the screen. In the Figure illustration, a source of light and a concave mirror are used to illuminate a piece of ground glass (which because of its diffusing properties, becomes a secondary source of illumination). The brightness of the receiving screen depends only upon the brightness of the ground glass, and the coverage area of the projection lens.

When it is necessary to project an intense beam of light, the source of light can be imaged on the aperture of the projection lens by means of a condensing system. See Fig. 20. The function of the condensing systems is to project the image of a light source into the aperture of a projection lens, but in doing this it also performs as a magnifier. The amount of magnification needed to completely fill the lens aperture with light is found by dividing the diameter of the projection lens aperture by the diameter of the lamp filament. For example, if the aperture of the projection lens is 20mm and the longest dimension of the lamp filament is 5mm, the required condenser magnification then is 20/5 = 4. Also the aperture or diameter of the condenser will be determined by the object to be projected.



CONDENSING SYSTEM
Fig. 20

If the image of the light source completely fills the entrance pupil (aperture) of the projection lens of a condensing system projector, then the aperture stop of the lens becomes the aperture stop of the whole system. Under these conditions the size of the light source is not important. Such a system provides a broad, uniformly-bright area in which a slide or other framing device can be placed.

In order to determine the exact location of a condensing system, one can use the following procedure:

1. The distance D_1 is found by the relation

   $$D_1 = f(1 + 1/M) \text{ millimeters}$$

2. The distance $D_2 = f(1 + M)$ millimeters

Where M is condenser magnification, D_1 is the distance from the light source to the condensing system, D_2 is the distance from the condensing system to the projection lens aperture, and f represents the focal length of the condensing system in millimeters.

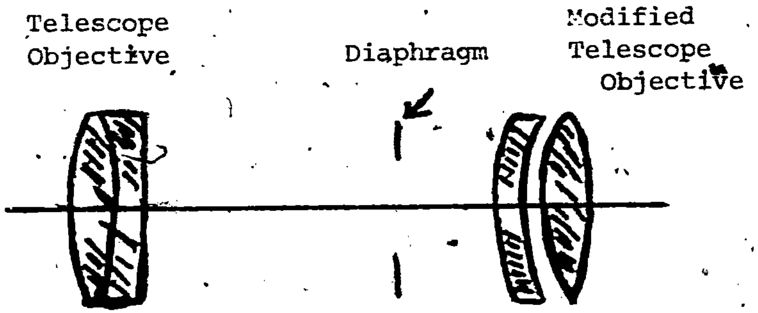
For example, if the required condenser magnification is 5 in (See Fig. 20) and the focal length of the system is 50mm, then the distance D_1 becomes 50mm (1 + 1/5) or 60mm. The distance D_2 will be 50mm(1 + 5), or 300mm. (Naturally, if it is desired to express D_1 and D_2 in inches, then the focal length of the condensing system must also be expressed in inches).

Projection Lenses. Projection lenses are in general designed to fill two main requirements:

(1) They must pick up a large cone of light (they must have a large aperture to focal length ratio, or small f/number).

(2) They must be well corrected for spherical aberration, in order to give sharp or well-defined images on the screen.

Other requirements include good color correction and a relatively flat field (field free of depth distortion).



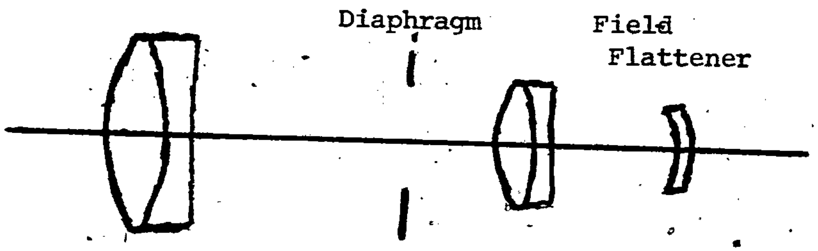
PETZVAL PORTRAIT LENS
Fig. 21

The majority of lenses used for projection work have been developed from the Petzval Portrait Lens. See Fig. 21. Such a lens consists of a telescope objective in front, and a second modified telescope objective widely spaced from the front objective. The definition of the central field of view of this type of lens is excellent, and it is used whenever the required field is small and a high aperture is desired.

The field of a Petzval Lens may be flattened by the addition by a negative lens located close to the focal plane (See Fig. 22). The addition of this lens extends the field without any loss of aperture or definition in the projected image.

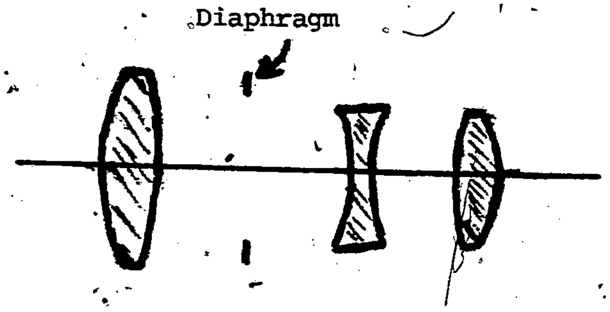
A triplet lens system is commonly found in projectors where the required field is moderately large and an aperture of f/3.5 or f/4.5 are most generally used (See Fig. 23).

The easiest type of projection lens to construct would be one of the duplets; these are lens types which are symmetrical about a central diaphram. The advantages of this type of lens are an almost

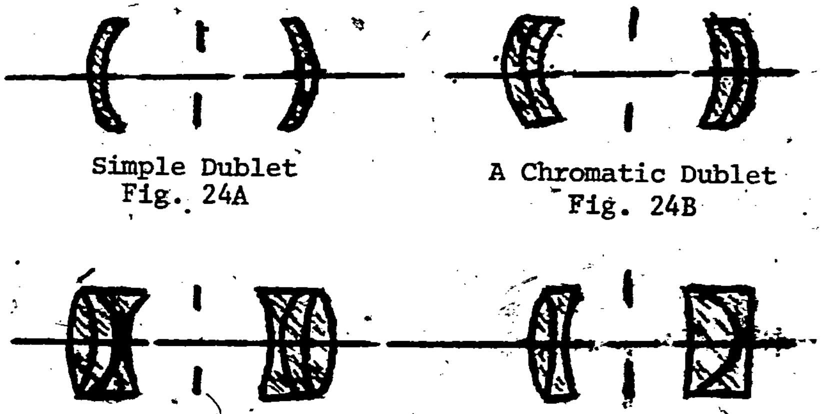


FLATTENED PETZVAL LENS
Fig. 22

complete reduction of certain color distortions, but spherical and chromatic aberration (as well as astigmatism) are present to some degree, although the use of achromatic lenses can eliminate most of these spherical and chromatic aberrations. See Fig. 24.



TRIPLET LENS
Fig. 23


Simple Dublet
Fig. 24A

A Chromatic Dublet
Fig. 24B

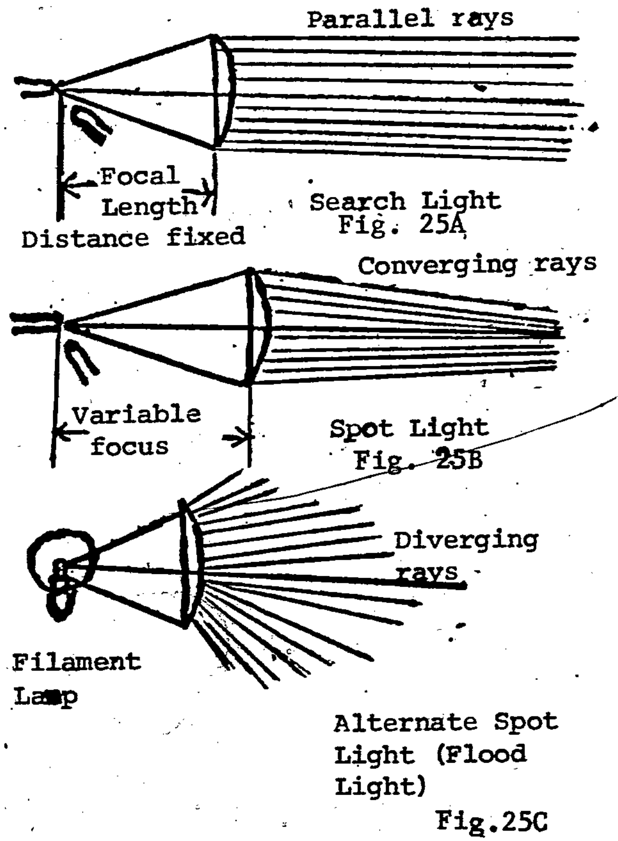
Achromatic Triplets
Fig. 24C

Un Symmetrical
Dublets
Fig. 24D

DUPLET LENSES
Fig. 24

The simplest type of symmetrical lens consists of two lenses arranged on either side of a diaphram (See Fig. 24A). Figure 24B is used for color aberration correction. Figures 24C and 24D show other possible combinations, using better type lenses will give better, more-sophisticated optical results.

Flood, Spot and Search Lights. These lights are all grouped together, since only one lens is normally used in the optical system of each of these types of light projectors (See Fig. 25). A search light system is illustrated in Fig. 25A; the light source is located in a fixed position at the focal point of the lens. This light source should be as small as possible in order to provide a very narrow beam.



Search Light
Fig. 25A

Spot Light
Fig. 25B

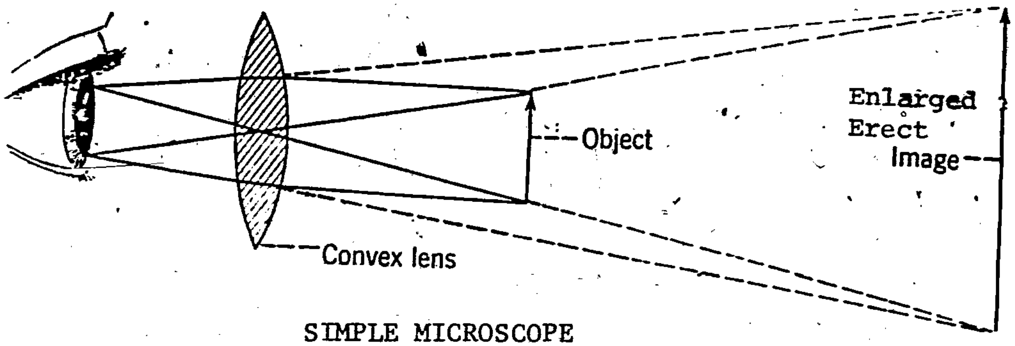
Alternate Spot
Light (Flood
Light)
Fig.25C

SINGLE LENS PROJECTORS
Fig. 25

In Fig. 25B, an image of the light source is actually focused on a nearby object by the spotlight. A spotlight needs a uniform light source. An alternate spotlight system (Fig. 25C) can operate with almost any type of light source, since the lens is used to diverge the image of the light source uniformly over a circular area. This is identical to a flood light when a frosted projection bulb is used instead of a clear projection lamp.

MICROSCOPES

The Simple Microscope (Magnifying Glass). Simple microscope (magnifying glass) operation is illustrated in Fig. 26. You may remember that the distance of most distinct vision is about 25 cm (10 inches). If an object is placed at a greater distance than this, the image on the retina of the eye is smaller, and the details of the object are not seen so distinctly. If the object is placed nearer than 25 cm, the image on the retina is blurred because the eye cannot accomodate to this extent.



SIMPLE MICROSCOPE
When the object is placed nearer the convex lens than its focal length, the image formed is virtual.
Fig. 26

If you hold your eye near a double convex lens, often called a magnifying glass (simple microscope), and place the object to be examined on the other side and a little nearer the lens than the principal focus, you will see a magnified, erect image (See Fig. 26). If the object distance is adjusted until a clear image is formed, the image distance will be found to be 25 cm (10 inches) or more. The magnifying power of a simple microscope is the ratio of the size of the image to the size of the object.

Magnification is thus also equal to the distance of the image divided by the distance of the object; in this example, magnification is $25/D_o$, where D_o is the distance of the object (in centimeters) from the lens. As another example, if for distinct vision a magnifying glass is held 2.5 cm from an object, the magnification will be 10 diameters.

Magnifying power can also be expressed in terms of focal length. Let M = magnifying power; and M is also the ratio of image to object distance: $M = \frac{D_i}{D_o}$. But for this magnifier, the image is virtual, so we use the virtual image equation $1/D_o - 1/D_i = 1/f$ or $D_o = \frac{D_i \times f}{D_i + f}$

Now substituting D_o in the equation,

$$M = \frac{D_i}{D_o} = \frac{D_i + f}{f} = \frac{D_i + 1}{f}$$

Assume that $D_i = 25$ cm then $M = \frac{25 + 1}{f}$, where f = focal length in centimeters.

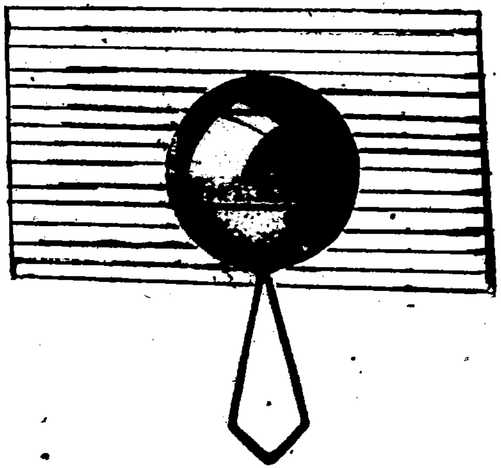
To apply such calculations to combination of lenses, use this simple rule. Calculate the position of the image for the first lens (forgetting the second lens for the time); then use this first <u>image</u> as the <u>object</u> of the second lens, and compute the image position, etc., due to the second lens. This process can be continued for a series of lenses.

INVESTIGATING MAGNIFYING POWER

Purpose. To learn a simple method for measuring approximate magnification.

Materials Needed. 1-hand lens; piece of lined paper.

Procedure. Focus a hand lens over some lined paper. (See Fig. 27) Now compare the number of spaces seen outside the field of the lens with a single space seen through the lens. For example, the lens shown in Fig. 27 magnifies five times. Using the same method make a diagram in your notebook of your investigation and record the magnifying power of your lens.



MEASURING MAGNIFYING POWER
Fig. 27

Repeat this investigation using the lens of some eyeglasses.

Answer this question in your notebook:

Are eyeglasses like simple microscopes?

Compound Microscope. The compound microscope consists of two lenses (or lens systems) placed at the end of a tube (See Fig. 28). The object in Figure 28B, is put just outside the principal focus of the smaller lens L (called the objective) which forms an enlarged real image A'B'. This real image is examined through the eyepiece E, which acts as a magnifying glass, giving a still larger but virtual image at A"B", 25 cm or more from the eye.

The eyepiece image, A"B", magnifies the size of the object BA by a factor approximately equal to the distance of BA from the lens L times the focal length of the lens. Then, the magnification produced by the eyepiece E is equal to the image distance (25cm) divided by the object distance, that is the distance from A"B" to lens E. Finally, the total magnification of the system is the product of these two magnifications. Usually a distance A"B" from L is about 150 mm; therefore, if the lens has a focal length of 5mm, the image A"B" is 30 times as long as the object BA. If the eyepiece still further magnifies the image 10 times, the magnifying power of the combination is 10 x 30 or 300 diameters. Microscopes magnifying as much as 2500 diameters are sometimes used.

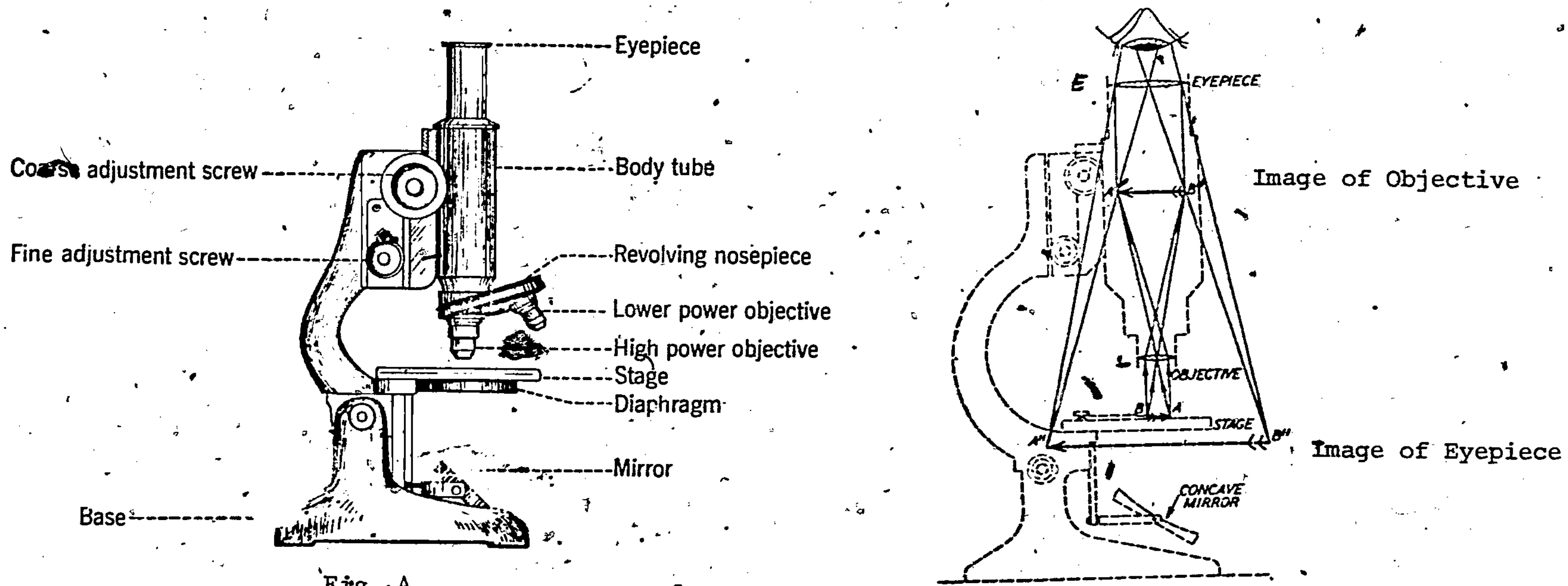
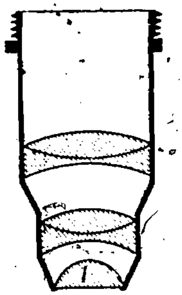


Fig. A

Fig. B

COMPOUND MICROSCOPES
Fig. 28



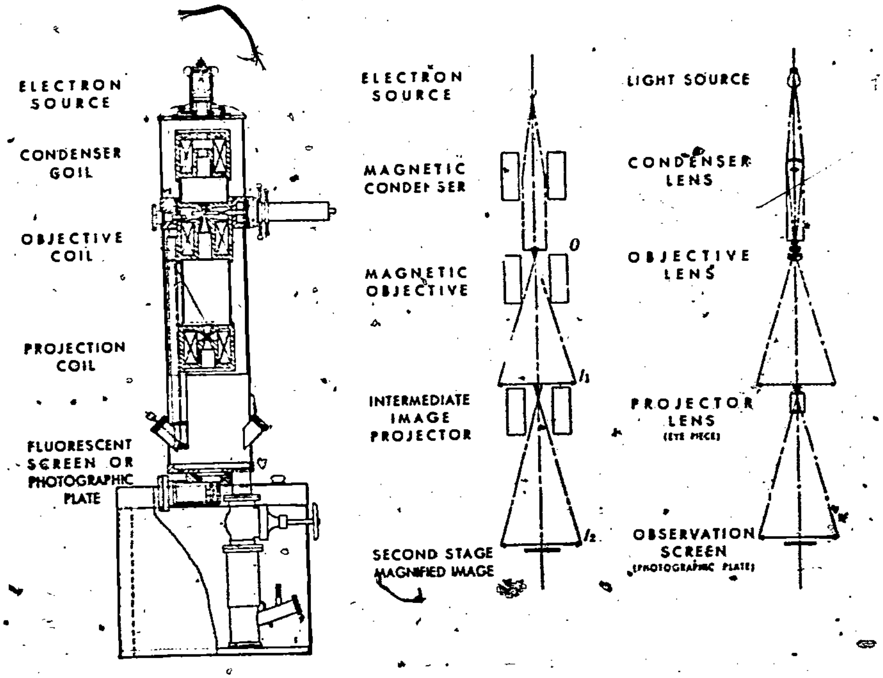
CROSS SECTION OF
MICROSCOPE'S OBJECTIVE
Fig. 29

Microscope Objective. The typical objective (see Fig. 29) of a compound microscope is not a single short focus lens, but is a complicated system of lenses so designed that they correct for spherical and chromatic aberration over the entire aperture. Some microscopes have objectives giving magnification of over 100 diameters, and with eyepieces giving magnifications of 20; therefore, the total magnification can be 2000 diameters or more.

One way of increasing the power of the microscope is to use an oil-immersion lens. With this method, a drop of cedar oil is placed between the outside lens of the objective and a cover glass over the object to be viewed. The oil has about the same refractive index as the cover glass, and the result is that the objective can then collect light rays over a wider angle in the outside lens.

The Utramiscope is used to get higher magnification than even the oil-immersion scopes. It can be proved mathematically that the limit of magnification (the resolving power of a microscope) depends upon the wavelength of the light used. For this reason, microscopes have been made using ultraviolet light, which has a shorter wavelength than visible light. For this kind of microscope, the lenses have to be made of fused quartz and the image is formed on a fluorescent screen (or photographic plate), because the eye cannot detect ultraviolet light and glass is opaque to ultraviolet light.

Going Beyond Light Magnification. In order to get still greater magnification than is possible with



THE ELECTRON MICROSCOPE AND THE CORRESPONDING PARTS OF AN ORDINARY MICROSCOPE
Fig. 30

ordinary light, or even with ultraviolet light, scientists have turned to electrons. It is possible to focus electrons by means of magnetic and/or electrostatic fields; these fields thus act as lenses for electrons, and the result is called an <u>electron microscope</u>. The method of operation of the electron microscope is shown in Figure 30, above, which compares the electron microscope with its optical counterpart. The object is put on a transparent film at 0; the first image is formed at I_1, and the final image is viewed at I_2 on a fluorescent screen. Such an instrument can provide magnification of 20,000 diameters, and up! Of course, even the electron microscope has limits to its magnifying power.

INVESTIGATING THE COMPOUND MICROSCOPE

Purpose: To construct the lens system of a compound microscope and to determine its magnification.

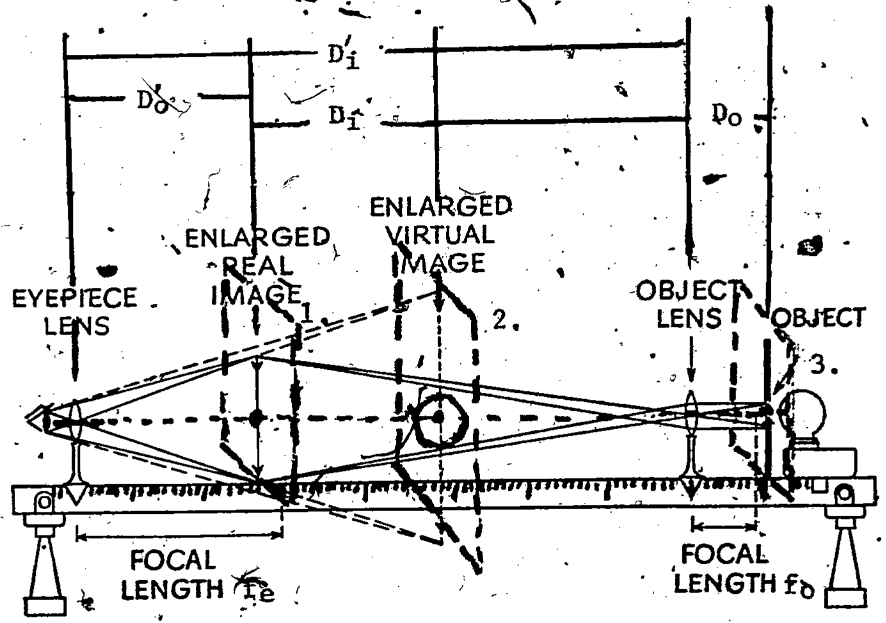
Materials Needed: Optical bench; light source; 3 screen holders; 3 lens holders; 2 converging lenses, 5 cm focal length; object screen; black Bristol board with 4 mm diameter aperture covered with wire gauze; first image screen, white Bristol board 10 x 12.5 cm with 3.5 diameter aperture; metric scale; and metric rule graduated in 0.5 mm.

Introduction:

The lens system of the compound microscope consists of two highly-corrected short focal-length converging lenses. The objective is located slightly more than its focal length from the object O and produces a real, inverted, and enlarged first image I in front of the second lens (eyepiece), as shown in Fig. 31. This real image becomes the object for the eyepiece, and is located slightly less than its focal length. The eyepiece is therefore used as a simple magnifier to form a virtual, erect, and enlarged second image I.

In this investigation, you shall determine experimentally the separate magnifications of the objective and eyepiece lenses, using both size and distance ratios. Then determine the magnification of the lens system using both size ratio calculations and the product of the individual lens magnification calculations.

Procedure: Be sure you know the focal length of each lens. Using a precise metric rule, measure the diameter of the object-screen aperture (estimating to the nearest 0.01 cm). Record this value as S_o in the data table reproduced in your notebook from page 111. Set up the optical bench as shown in Fig. 31. Mount one short focal lens near the left end of the bench to serve as the eyepiece and adjust the position of the first image screen (1) approximately one focal length away. Mount the second screen (2) approximately 25cm from the eyepiece lens. The remaining short focal length is to be used as the object lens, and is to be located 5cm from second screen (2); and the object screen (3) is to be slightly more than a focal length away from this object lens. The object screen aperture, its luminous source, the two lenses, and the second image screen aperture must be centered on a common principal axis.



COMPOUND MICROSCOPE
Fig. 31

Be sure to darken the laboratory and to illuminate the object. Then adjust the position of the first screen (1) and the object lens, to give a sharply defined real image; keep the image distance about 5 times the object distance. Shift the position of the object aperture slightly with respect to the principal axis (if necessary) to center the image on the first-image screen; this screen is in the front of the eyepiece lens. Make your final focus by slight adjustment of the object lens. Shift the first-image screen (1) in the holder so that the image falls on the millimeter scale. Read the diamenter of the image, estimating to the nearest 0.01 cm and record as S_i in your data table. In like manner, record the object distance D_o and the first image distance D_i to the nearest 0.01 cm.

Put one eye close to the eyepiece lens and view the back of the first-image screen and adjust the eyepiece slightly to bring it to sharp focus. Remove the screen (1) from its holder. Reset screen (2) (if necessary) so as to place it approximately 25 cm from the eyepiece lens. With one eye close to the eyepiece, and looking along the principal axis, view the virtual second image of the object.

Focus the other eye on the second image screen (2), and adjust the object screen slightly in its holder to superimpose the virtual second image symmetrically about the aperture of the second-image screen. Adjust the position of the eyepiece slightly to yield the best definition of the wire gauze image on the screen. With the image positioned on the metric scale, read the image diameter to the nearest 0.01 cm, and record it as S_i'. In like manner, find and record D_o' and D_i'.

One trial is probably enough; but if you have time to run a second trial, increase the object distance D_o about 0.5 cm by moving the objective lens 0.5 cm to the right and the object 1 cm to the right; then repeat the entire procedure and record the required data.

DATA

OBJECTIVE				EYEPIECE			M			M			M		
S_o (cm)	S_i (cm)	D_o (cm)	D_i (cm)	$S_{i'}$ (cm)	$D_{o'}$ (cm)	$D_{i'}$ (cm)	$\frac{S_i}{S_o}$	$\frac{D_i}{D_o}$	AVE	$\frac{S_{i'}}{S_i}$	$\frac{D_{i'}}{D_{o'}}$	AVE	$\frac{S_{i'}}{S_o}$	$M_o M_e$	AVE

Calculations:

1. Magnification of Objective. Compute the magnification M_o of the objective lens for one trial from both size and distance according to this equation:

(1) $\boxed{M_o = \frac{Si}{So} = \frac{Di}{Do}}$ where S_i is the diameter of the first image, S_o is the diameter of the object aperture, and D_i is the distance from the objective lens to the object screen. Record your results in the data table.

2. Magnification of Eyepiece. Compute the magnification M_e of the eyepiece lens for one trial, using the data according to this equation:

(2) $\boxed{M_e = \frac{Si'}{Si} = \frac{Di'}{Do'}}$ where Si' is the diameter of the second image, Di' is the distance from the eyepiece lens to the second image screen (2), and D_o' is the distance from the eyepiece lens to the first-image screen (1). Record your results in the data table.

3. Magnification of Lens System. To compute overall magnification M of the conpound lens system, you will calculate the ratio of the second image size to object size. That is

(3) $\boxed{M = \frac{Si'}{S_o}}$ We may use this equation to derive yet another useful equation.

From (1): $S_i = M_o S_o$

Substituting in Equation (2): $M_e = \frac{Si'}{M_o S_o}$

Solving for S_o, $So = \frac{So'}{M_e M_i}$

Substituting in Equation (3):

(4) $\boxed{M = M_o M_e}$

Use Equations 3 and 4 for computation, and record results in your data table.

RESOURCE PACKAGE 3-2

SELF TEST

1. Helen wishes to make a camera.

   (a) What three essential parts must she obtain?
   (b) What is the function of each part?

2. John observes that the inside of his camera (and of the optical instruments in the laboratory) are painted black.

   Why is this?

3. Name two main types of telescopes, and tell how they differ from each other.

4. What do you mean when you say that a telescope has a field of view of 50 yards at 1000 yards?

5. To have 100% brightness, what should the diameter of the beam of light coming through the telescope be: (a) in daylight (b) at night.

6. How does the Galilean telescope differ from the astronomical telescope?

7. What are some advantages of the prismatic telescope?

8. What are the two basic features of a projection system?

9. What lens system is necessary when an intense beam of light is to be projected?

10. What two requirements must be met in the design of all projection lenses?

11. What is the difference between a spotlight, floodlight, and searchlight?

Completion Questions

12. A ________________ lens is used in a camera.

13. In the astronomical telescope, the lens farther from the eye is called the ________________.

Problems

14. If an objective has a diameter of 64 mm and a focal length of 384 mm, and if the magnification of the telescope is 7x, what is the field of view?

15. If f_o is 384 mm and f_e is 38 mm, what is the magnification of the telescope?

16. If an objective has an f_o equal to 384 mm and a diameter of 64 mm, what is the f/value of the objective?

RESOURCE PACKAGE 3-3

ANSWERS TO SELF-TEST

1. (a) Light-proof box, converging lens, shutter, and film.

   (b) <u>Light-proof</u> <u>box</u> to keep out light.

   <u>Converging</u> <u>lens</u> to form an image of the object on the film.

   <u>Film</u> - to record the image.

2. To prevent glare; to absorb all stray light.

3. They are refractor telescopes and reflector telescopes. The refractor telescope picks up light from the object by means of a lens; the reflector telescope collects light by means of a curved mirror.

4. It means the field of view (or how large an area you can see through the telescope) at 1,000 yards is an area of 50 yards cross section.

5. (a) About 5 mm in daylight.

   (b) About 7 mm at night.

6. The Galilean telescope is the only telescope that uses a negative lens as an eyepiece, and is also the only two-lens system that gives an upright image. The astronomical telescope is made up of two lenses, or two lens systems. The light passes through the objective, forms an inverted image of the object viewed; and this image is looked at and magnified by the eyepiece lens.

7. Inverting the image, compactness, and little light loss.

8. (1) Formation of a real image.

(2) A source of high intensity.

9. A condenser system.

10. (1) They must pick-up a large cone of light (they must have a large aperture).

(2) They must be well corrected for spherical aberration. Other secondary requirements include good color correction and flat field.

11. A spotlight has a light source focused so that light is converged on some nearby object. A floodlight has a light source located in relation to the lens, so that light is diverged. A searchlight has a light source so located in relation to the lens, that it sends out a parallel beam of light.

12. Convex

13. Objective

Problems

14. $\text{Field of View} = \frac{\text{Dia. of objective} \times 1000 \text{ yd}}{\text{focal length of objective} \times M}$ $\text{Field of View} = \frac{64\text{mm} \times 1000 \text{ yd}}{384\text{mm} \times 7} = \frac{64000 \text{ yds}}{2688}$

Field of View = 23.4 yds.

15. $M = \dfrac{fo\ \text{(focal length of objective)}}{fe\ \text{(focal length of eye lens)}}$

$M = \dfrac{384}{38} =$ approx 10 x, or 10.1 x

16. $\text{f/value of objective} = \dfrac{fo}{\text{Dia. of objective}}$

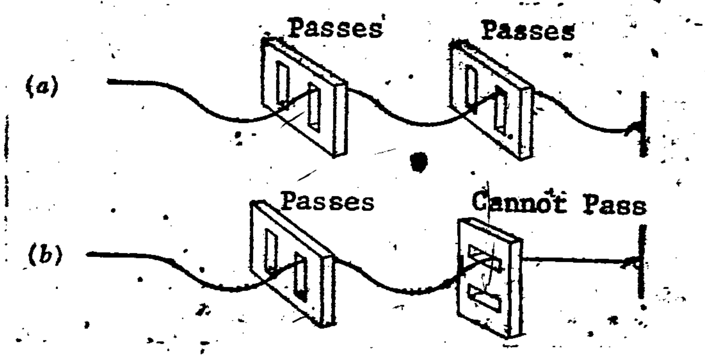
$\text{f/value of objective} = \dfrac{384\ \text{mm}}{64\ \text{mm}} = \sim f/6.0$

RESOURCE PACKAGE 4-1

POLARIZED LIGHT

Introduction. Historically, the corpuscular theory of light had to yield to the wave theory in order to explain diffraction and interference effects. But early believers in the wave theory assumed that light was a longitudinal form of wave motion, similar to sound, but with much faster and shorter waves. It was around 1808 when the phenomenon of polarization was studied, and this study forced science to adopt a transverse-vibration wave theory of light. It turns out that the wave behavior of light shows ordinary light to be a mixture of transverse vibrations which are randomly oriented in all possible directions in space.

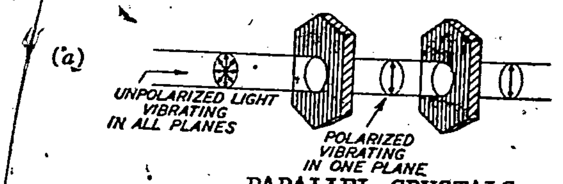
Polarization of Light. There are various means by which the light waves vibrating in one particular plane may be sorted out of the random vibrations of natural light. When all, or most, of the vibrations except those in some plane have been eliminated, the light is said to be plane polarized. Polarization may be illustrated as follows: If you string a rope so that it passes through two parallel grates, and if a hand that is holding the unattached end of the rope is given an up-and-down motion, vertical waves will pass through both grates, as shown in Figure 1-a. But if the second grate is rotated so that its grate openings are at right angles to those of the first, the vertical waves



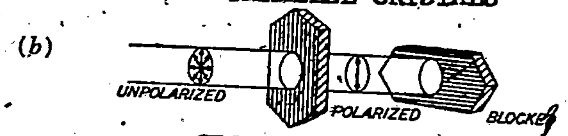
TRANSVERSE WAVES PASS THROUGH PARALLEL GRATES
Fig. 1

cannot pass through the second (horizontal) grate, as shown in Figure 1-b.

In a similar manner, if a beam of light is sent through two tourmaline crystals set with their optical axes parallel to each other, the light will go through both crystals. It can be shown that after the light passes through the first crystal, it is polarized. Instead of vibrating in all directions at right angles to the direction of the wave, it now vibrates in only one plane (parallel to the optical axis of the crystal). Since the optical axis of the second crystal is set parallel to the first, the light waves pass through (Figure 2-a). But if the optical axis of the second crystal is rotated so that it is at a right angle to the first crystal, the polarized light will not pass through (Figure 2-b). Tourmaline is not used in optical instruments because the crystals are yellow in color and do not transmit white light.



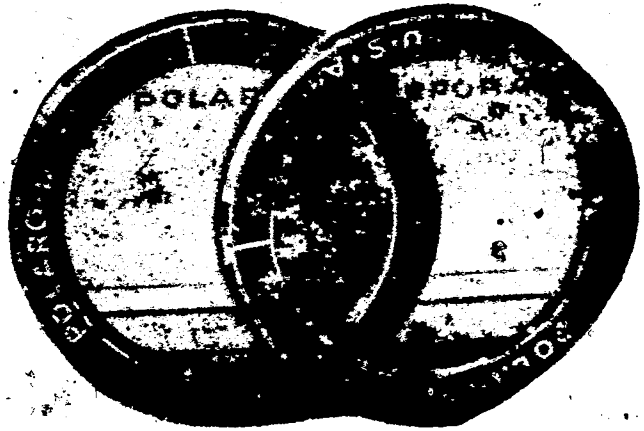
PARALLEL CRYSTALS



CROSSED CRYSTALS
Fig. 2

Polarization by Selective Absorption. There are certain materials that allow waves of a particular orientation to pass through and that absorb other wave orientations, resulting in polarization of the passed (transmitted) light.

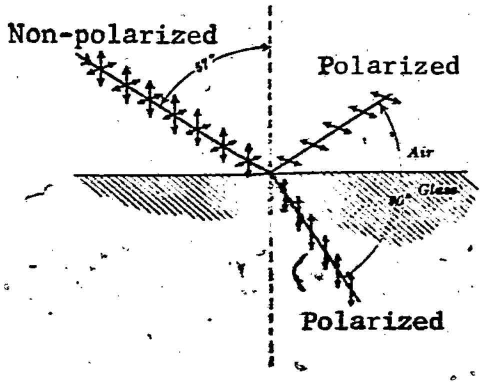
A satisfactory substance which does transmit white light is an organic compound iodosulfate of quinine. It is used in very thin layers in the production of Polaroid sheets (Fig. 3). The tiny crystals of compounded iodine are distributed densely in a celluloid film, which is then mounted between glass or transparent, flexible plastic sheets; such sheets transmit polarized lights by absorbing all light not oriented in a particular plane.



POLARIZERS
Fig. 3

Polarization by Reflection. When light is incident upon a transparent medium at a special angle (called the polarizing angle) the beam striking the glass is divided into two beams, one of which is refracted into the glass (See Fig. 4) and is polarized in the plane of incidence, and the other is reflected and is polarized at right angles to the plane of the first beam. Sir David Brewster, in 1815, first discovered that at the polarizing angle the orientation of the reflected and refracted rays were 90° apart.

Because the two rays are oriented at 90° with each other, the angle of refraction r are geometric complements of each other, and sin r in Snell's

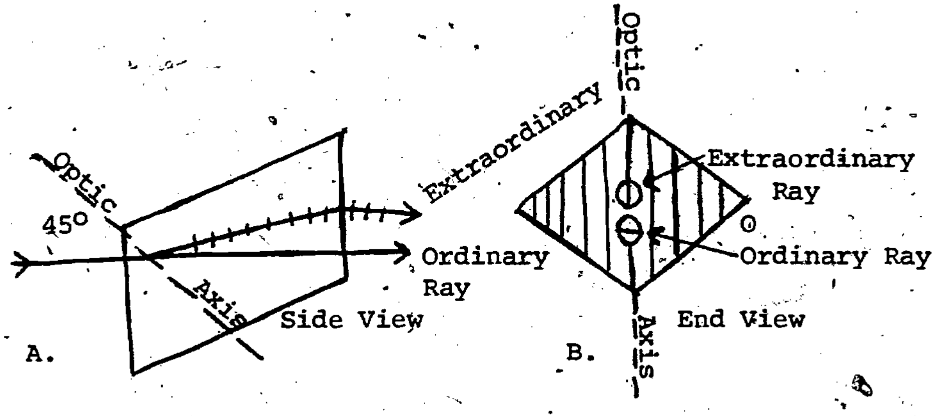


POLARIZATION BY REFLECTION
Fig. 4

Law becomes $\frac{\sin i}{\cos i} = N$, or, $\tan i = N$ (index of refraction), where cos i is the cosine of the polarizing angle. This formula is useful in calculating the angle of polarization. For example, with water, N = 1.33, angle i = 53°; whereas for glass, with N = 1.52, angle i = 57°.

Double Refraction. If a beam of light passes through a certain kind of crystal known as Iceland Spar (calcite), it is split up into two distinct beams called an ordinary (essentially non-polarized) beam and an extraordinary (polarized) beam. That is, if a line is made on a piece of paper and then covered with calcite, two images of the line will be seen through the calcite. Such a crystal is said to be double or bi-refracting (see Figure 5). One ray follows the direction to be expected from the calcite index of refraction; this is called the ordinary ray. The other ray assumes a different index of refraction and is called the extraordinary ray. Calcite has two optical densities for two possible optical paths; therefore, two different indices of refraction and two consequent refractive beams (light paths) result. In addition, one of these beams turns out to be polarized.

Extraordinary ray is refracted to one side.



DOUBLE REFRACTING CRYSTALS
Fig. 5

INVESTIGATION OF POLARIZATION OF LIGHT

<u>Purpose</u>: (1) To show some ways in which light can be polarized. (2) To illustrate some uses of polarized light.

<u>Materials Needed</u>: 2 Polaroid discs; a piece of calcite (Iceland Spar); a block of wood enameled on one side; 12 plates, each 5 cm square; cellophane strips mounted between 5 cm glass plates, or cellophane tape on a square; a U-shaped piece of plastic; glass from a broken bottle.

<u>Introduction</u>:

In this investigation you will polarize light by use of the natural crystal, calcite. Polaroid is the name of a man-made material which is used to polarize light by selective absorption; i.e., absorption of light except along a selected orientation. Polarized light can be used in identifying certain chemical compounds, in detecting strains in structural material, and in determining the thickness of crystals and fibers. Polaroid is used in sunglasses and in some types of reading lamps to reduce glare.

<u>Procedure</u>: Look through one of the polaroid discs at a wall, rotating the disc. Notice whether the intensity of the light varies. Do the other disc the same way and notice whether or not the intensity of the light varies. Now hold both discs together, one in front of the other, and rotate one of them while you look through both of them at the wall. Does the intensity vary?

In your notebook, record approximately how many degrees you have to turn one disc to go from maximum brightness to minimum brightness (almost no light). Write a brief account of why crossed polarizers (when the transmitted light is least) transmit a minimum of light.

Now look through a transparent piece of calcite (Iceland Spar) at a period mark in a book or other text. Sketch what you see; put the sketch in your notebook.

Now, hold a single Polaroid disc above the calcite and examine the images in the crystal. Rotate the Polaroid disc as you look. Record your observations.

Next, place a piece of wood painted with black enamel on the laboratory desk. Find the position where the most light (glare) from the window is reflected from the surface of the plate. Examine the glare through a single Polaroid disc and record whether or not the glare light appears polarized. Then examine the glare from a stack of 12 glass plates. Record this observation. Record the answer to this question also, "In what plane is glare polarized when reflected from a polished surface?"

Holding the Polaroid discs oriented so that their transmitting plane is at right angles to the plane in which the glare is polarized (one disc over each eye), compare the amount of glare through the Polaroid discs with the amount you can see without these Polaroid discs.

Cross the Polaroid discs and place between them a glass slide containing cellophane strips of varying thickness. Rotate the glass slide until you observe the brightest colors. Record how the brightness of color varies from the thin strips to the thick ones.

<u>Use of Polarized Light to Determine Structural Strains</u>. Examine a small V-shaped piece of transparent plastic between crossed Polaroid discs. Record what you see. Now pinch the open ends of the piece of plastic between your fingers. Record what you see now. Record how colors help to detect places where strain is the greatest. Last, examine a piece of broken glass (from a molded bottle) between crossed polarizers. Record a simple description of anything you detect in the glass.

Some Technical Uses for Polarized Light

Polarization by double refraction is used technically in the polariscope. The polariscope consists essentially of two Nicol prisms (polarizing prisms) mounted on a common axis in such a way that one may be rotated and the angle of its rotation read off a scale. Nicol prisms are separated so that an optically active material may be inserted in the space between the two Nicol prisms (see Figure 6). The polariscope in Figure 6 uses as a source of light a sodium flame (which produces a yellow monochromatic light). The light enters the first Nicol prism called the polarizer and then passes through the material to be studied, then through the second Nicol prism called the analyzer, and finally into the eye. If the analyzer is rotated so that the light is entirely cut off, we know that the Nicols are crossed. If we then introduce a solution of sugar (or some other dissolved substance) between the polarizer and analyzer, we can rotate the analyzer prism until the light passed is maximum and minimum. From this we can read the angle of rotation required to go from cutoff to transmission. This gives us the rotation of the plane-polarized light produced by the sugar solution (or other dissolved substance).

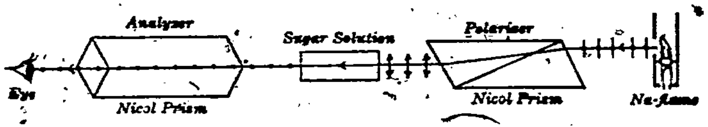


DIAGRAM OF A POLARISCOPE
Fig. 6

There are a number of liquids which have the property of twisting the plane of polarization of a beam of light. The amount of rotation depends upon the distance which the light travels through the substance, upon the wavelength of light used, the temperature of the solution, and the concentration of the solution. Further, there are two types of what are termed optically active substances: One kind produces right-handed rotation, and one kind produces left-handed rotation.

Strangely enough, some quartz crystals produce right-handed rotation, while other crystals produce left-handed rotation.

Cane sugar is dextrorotatory (right-handed), while grape sugar is levorotatory (left-handed). These differences can be explained by the differences in the arrangements of the sugar and their resultant optical densities in different directions.

RESOURCE PACKAGE 4-2

SELF-TEST QUESTIONS

Complete the following:

1. Experimentally light may be polarized by 1. ____________ 2. ____________ ____________
   3. ____________ ____________ and 4. ________________________

2. In polarized light, the waves in a beam of light vibrate ________________________
   ________________________.

3. Quartz, mica, sugar, topaz, calcite, etc. are examples of crystals that polarize light by
   ________________________.

4. There are two types of what are termed optically active substances: one which produces ________
   ________________________ and the other which produces ________________________.

5. State Brewster's law.

6. Find the polarizing abgle for clear plastic with refractive index of 1.455.

7. Give some practical uses for polarized light, or for polarizing materials.

RESOURCE PACKAGE 4-3

ANSWERS TO SELF-TEST

1. 1-reflection 2-double refraction 3-selective absorption 4-scattering

2. In planes parallel to each other.

3. Double refraction.

4. Right-handed rotation left-handed rotation

5. At the polarizing angle, the reflected and refracted rays are 90° apart.

6. $\mathrm{Tan}(i) = n$ tan for $1.455 = 55.5^{\circ}$

7. Answers may vary.