Newsletter

Of the

New York Microscopical Society

1 Prospect Village Plaza
(66F Mt. Prospect Avenue)
Clifton, New Jersey 07013-1918
GPS: Latitude 40.8648N, Longitude 74.1540W

Nov-Dec 2013 **N.Y.M.S. (973) 470-8733** **Volume 7 (27) Number 9**

Wishing you Season's Greetings and a Very Happy New Year

We welcome Guy de Baere as a pro tem member of the NYMS Board of Managers

Save a Tree: Get The Extended Newsletter: By Email Only

Board of Managers

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Andrew Winter	andrew.winter@co.middlesex.nj.us;	(732) 816-3793	June 2016	Board

For additional information contact the Editor: Mel Pollinger at (201) 791-9826, or pollingmel@optonline.net

Dues and Addresses
Please remember to mail in your Dues to:
Mary McCann,
Membership Chair
McCann Imaging
161 Claflin Street
Belmont, MA 02478

Junior (under age 18) $10 Annually
Regular $30
Student (age 18 or above) $20 Annually
Supporting $60 Annually
Corporate (includes one advertisement in NYMS News) $175 Annually
Life $300 (payable within the year)
To avoid missing notices:
Notify Mary McCann and Mel Pollinger if you have changed your address, phone or email.

Awards Given by the New York Microscopical Society
The New York microscopical Society takes great pleasure in recognizing and rewarding individuals who have contributed to either the activities of the society or to furthering microscopy. These awards are described in our website and in a pdf file for our email newsletter recipients. All members are eligible to nominate individuals for these various awards, and are encouraged to do so.
John A. Reffner, Awards Committee Chairperson

Awards Committee
Chair: John A. Reffner
Members
Jan Hinsch
Mel Pollinger
Open position

Mel Pollinger, Editor
18-04 Hillery St.
Fair Lawn, NJ 07410-5207

To Order Your NYMS Lapel Pins
Send a check in the amount of $12.00 per pin to:
New York Microscopical Society
c/o Mel Pollinger, 18-04 Hillery Street, Fair Lawn, NJ 07410. To avoid shipping & handling charges, pins may be purchased directly at any NYMS meeting for $10.00.

The Mission of the New York Microscopical Society is the promotion of theoretical and applied microscopy and the promotion of education and interest in all phases of microscopy.

Alternate Meeting Notifications
Please note that due to time constraints in publishing, some meeting notices may be available by calling Mel Pollinger at 201-791-9826, or by visiting the NYMS website, or emailing: pollingmel@optonline.net

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Dues for 2014 are due in January!

Buy and Read a Good Book on Microscopy.

NYMS at EAS 2013

Dr. Brettell and students from Cedar Crest College, PA at the NYMS booth for a picture. John Jay's Pete Diaczuk on right.

From Jean Portell

Dear fellow NYMS members,

The Holiday Banquet at Landmark Tavern yesterday was wonderful! The company was delicious, the food was very friendly, and Jan's presentation about his life in microscopy was a special treat. I hope someday Jan will write and publish his memoirs, because his personal professional history also reveals a big slice of the history of the dissemination and uses of microscopes in America --- and that eliminating middle-men-dealers is a great company policy (something I sensed long ago, but didn't really understand until Jan explained this)!

Another attendee of the NYMS the banquet also has a remarkable professional history, as I discovered when he and I walked together to Grand Central Station "for the exercise," talking animatedly all the way. (Both of us are non-stop talkers, yet we managed to share the 'stage' equitably.) Before then, I had thought of Dan Slatkin only as Heidi's father. If you Google-search his full name you will discover much more about him. http://dnslatkin.weebly.com/

Our Society is a great place to meet all kinds of people who share (for disparate reasons) a passion for microscopes, or simply want to learn how to use them better.

Long live NYMS and its much-appreciated expert microscopists!

Jean

From Jay Holmes, AMNH

The American Museum of Natural History recently opened an exhibit around some of the books in our Rare Books Collection. The exhibit spins around the recent book published by the Museum and Edited by Thomas Baione, Harold Boschenstein Director of Library Services at the Museum, called Natural Histories.
http://www.amnh.org/exhibitions/current-exhibitions/natural-histories
and there are a couple points where microscopes pop into the story.
There are of course a couple images from Hooke's Micrographia.
http://images.library.amnh.org/digital/items/show/18590
http://images.library.amnh.org/digital/items/show/18591
There is also an image of scientific instruments, including a simple microscope, from Poli's Testacea vtrivsqve Siciliae eorvmqve historia et anatome
http://images.library.amnh.org/digital/items/show/18647
Some images by Ernst Haeckel drawn based on microscope observations… I like the siphonophore images:
http://images.library.amnh.org/digital/items/show/18567
Other images from the Rare Books Collection at the AMNH are available at:
http://images.library.amnh.org/digital/items/browse?collection=8&page=5

Jay Holmes
jholmes@amnh.org

Volunteers needed at Clifton to help with the second floor cleanup. If you wish to help, please contact me at (201) 791-9826 or by email at pollingmel@optonline.net

McCrone Research Institute in Chicago

•Inter/Micro 2014Call for Papers, June 2-6.

2014 Microscopy courses.

The deadline to submit titles and abstracts is March 1, 2014.

For more information, visit our website at: www.mcri.org. Contact us at (312) 842-7100 or by email at: intermicro@mcri.org

Visitors Always Welcome to NYMS

Although most of our lecture meetings, workshops and classes are held in the NYMS Clifton facility on the last Sunday of the month, the building may be opened for special purposes at other times, by appointment only. For such an appointment, please contact Mel Pollinger by phone at (201) 791-9826, M-F noon to 9:30pm, or by email at pollingmel@optonline.net.

***From The Editor*... if you have email:** Getting the newsletter by email means you can receive an **extended pdf version** that cannot be sent by "snail mail." Even if you only continue your USPS delivery of the newsletter, NYMS needs your email address for reporting priority events and special news. Being able to contact you quickly by email means better communication between you & NYMS■■ Mel

Need to use a Microscope?

The various microscopes that are presently set up on the main floor of the New York Microscopical Society building in Clifton, N.J. are there for the use of its members.

Microscope Cleaning Kit

A complete set of tools and accessories to keep your microscope in optimum operating condition. The kit is put together by our Curator/Educational Chairman and available directly from NYMS for only $35.00 plus shipping & handling, or may be purchased at a meeting. Call or email Mel Pollinger for details (see page two for contact numbers).

Microscope, by Louis Ginsberg

With bated breath and buoyant hope,
Man bends above the microscope,
The question, pulsing deep in dark,
Splinters to many a question mark,

He looks upon a point to check,
The tiny, faint and finite speck;
And yet the more he stares and broods,
It swells into infinitudes.

The more he peers into the middle,
Of particles that shape the riddle,
The lens, for all that he can see,
But magnifies the mystery…

Louis Ginsberg, the father of Allen Ginsberg, was a poet and high school teacher.

(From "The Microscope")

Answer to Mystery Photo for October 2013

Julie Cohen answered correctly: Beak of Mute Swan. Image by Mel Pollinger

Mystery Photo for Nov-Dec 2013

Want to take a guess? Send it to me by email or call me: pollingmel@optonline.net, (201) 791-9826

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Additional Historical NYMS Supplements

Email Newsletter recipients will also be getting copies of NYMS Newsletter pdf back-Issues from 2007. Copies of older newsletters will be sent as I convert them.

Got something you want to sell, trade or publish in the Newsletter and/or on the website? Write, call or send an email message to:
201-791-9826 or pollingmel@optonline.net (images ok)
or
Mel Pollinger, Editor
NYMS Newsletter
18-04 Hillery Street
Fair Lawn, NJ 07410

Supporting Member

NYMS Newsletter Extended Section, Nov-Dec 2013

In This Section:

Directions to NYMS Headquarters

One Prospect Village Plaza
(66F Mount Prospect Avenue)
Clifton, NJ 07013

GPS: Intersection of Colfax & Mt. Prospect: Latitude 40.8656 N, Longitude 74.1531W,
GPS: Our building: Latitude 40.8648 N, Longitude 74.1540 W

From George Washington Bridge:
Take Interstate Route 80 west to Exit 57A, Route 19 South. Take Route 19 to Broad Street and continue two lights to Van Houten Avenue. Turn Left. Go to second light, Mount Prospect Avenue and turn left. Building 66F is on the left side , one and a half blocks from Van Houton.

From Lincoln Tunnel:
Follow exit road to NJ route three west. Continue to Bloomfield Avenue exit. Turn right to Circle and go three quarters to Allwood Road West. Mount Prospect Avenue is a few blocks on the right (a small street) Turn right and go to first light (Van Houton) continue. Building 66F is on the left side , one and a half blocks from Van Houton.

From North:
Take Garden state Parkway South to Route 46 Clifton Exit. On 46 Make second exit to Van Houton Ave. Continue to third light Mount Prospect Avenue and turn left. Building 66F is on the left side , one and a half blocks from Van Houten.

From Route 46 coming from west:
Take Broad Street Exit in Clifton and follow Directions above from GW Bridge.

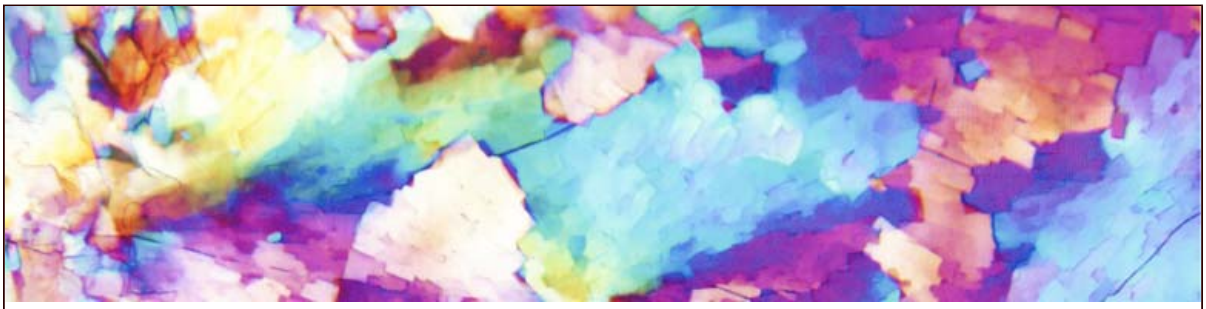
From route 46 coming from East: Take Paulson Avenue Exit in Clifton and follow to Second light, Clifton Ave turn right. Go to next light, Colfax, turn left, go three blocks and turn right on Mount Prospect Ave.. Building 66F is half block on right.

Public transportation from NY:
Take NJ Transit train from Penn Station to Secaucus Transfer Station. Change trains to Bergen Line to Clifton (call NJ Transit for schedules). From Clifton Station cross under tracks to first street and go left one block to Mount
Prospect Street, turn right and Building 66F is one half block on Right.

If you plan to come by bus or train, please copy the links below into your browser:
http://www.njtransit.com/sf/sf_servlet.srv?hdnPageAction=TripPlannerItineraryTo
http://www.njtransit.com/sf/sf_servlet.srv?hdnPageAction=BusSchedulesP2PTo
http://www.njtransit.com/sf/sf_servlet.srv?hdnPageAction=TrainTo

NYMS Booth at EAS 2013

From: "McCrone Research Institute" <intermicro@mcri.org>
To: <pollingmel@optonline.net>
Sent: Thursday, October 24, 2013 10:04 AM
Subject: Inter/Micro 2014 - June 2-6, 2014



Inter/Micro 2014

June 2-6, 2014

at McCrone Research Institute in Chicago

McCrone Research Institute cordially invites you to participate in Inter/Micro 2014 -- the premier international microscopy conference.

Papers are being solicited in micro-analytical techniques and instrumentation, environmental and industrial microscopy, and chemical and forensic microscopy.

The deadline to submit titles and abstracts is March 1, 2014.

For more information, visit our website at: www.mcri.org
Contact us at (312) 842-7100 or by email at: intermicro@mcri.org

We look forward to seeing you at Inter/Micro in Chicago!

McCRONE RESEARCH INSTITUTE CHICAGO

From: "McCrone Research Institute" <info@mcri.org>
To: <pollingmel@optonline.net>
Sent: Tuesday, September 17, 2013 10:08 AM
Subject: 2014 Microscopy Courses at McCrone Research Institute, Chicago

Register for McCrone Research Institute's

2014 Microscopy Courses

Since 1960, McCrone Research Institute in Chicago has offered intensive courses in microscopy that emphasize the proper use of the microscope and more specialized microscopy, focusing on a particular technique, material or field of application. All courses are hands-on, featuring lectures, demonstrations and laboratory practice. Click the following links to view McCrone microscopy courses by type:

Asbestos and Environmental Microscopy Courses

Forensic Microscopy Courses

Microscopical Methods Courses

Specialty Microscopy Courses

Featured 2014 Courses

Advanced Indoor Air Quality: Identification of Fungal Cultures
Culturing fungi is essential in order to identify fungi to the species level. The course will cover media, culture methods, spore identification and viable sampling methods. Emphasis is on the fungi that relate to indoor air quality and human health. more...

Digital Imaging and Photomicrography
This course covers the most important aspects of digital imaging microscopy: camera and microscope hardware, system set-up, user settings, collection of quality images, introductory image processing, storage and printing. more...

Forensic Paint Microscopy
This course is an introduction to the analysis of dust traces for trace evidence analysts. Beginning with the history of dust analysis and the work of Locard, Popp, Schneider, Heinrich, Frei-Sulzer and others, this course will explore the techniques for collecting, separating, analyzing and interpreting dust evidence. more...

Microscopy of Extraneous and Foreign Matter in Food

This course is geared towards scientists who encounter contaminants in manufactured products such as food, beverages, and pharmaceuticals. more...

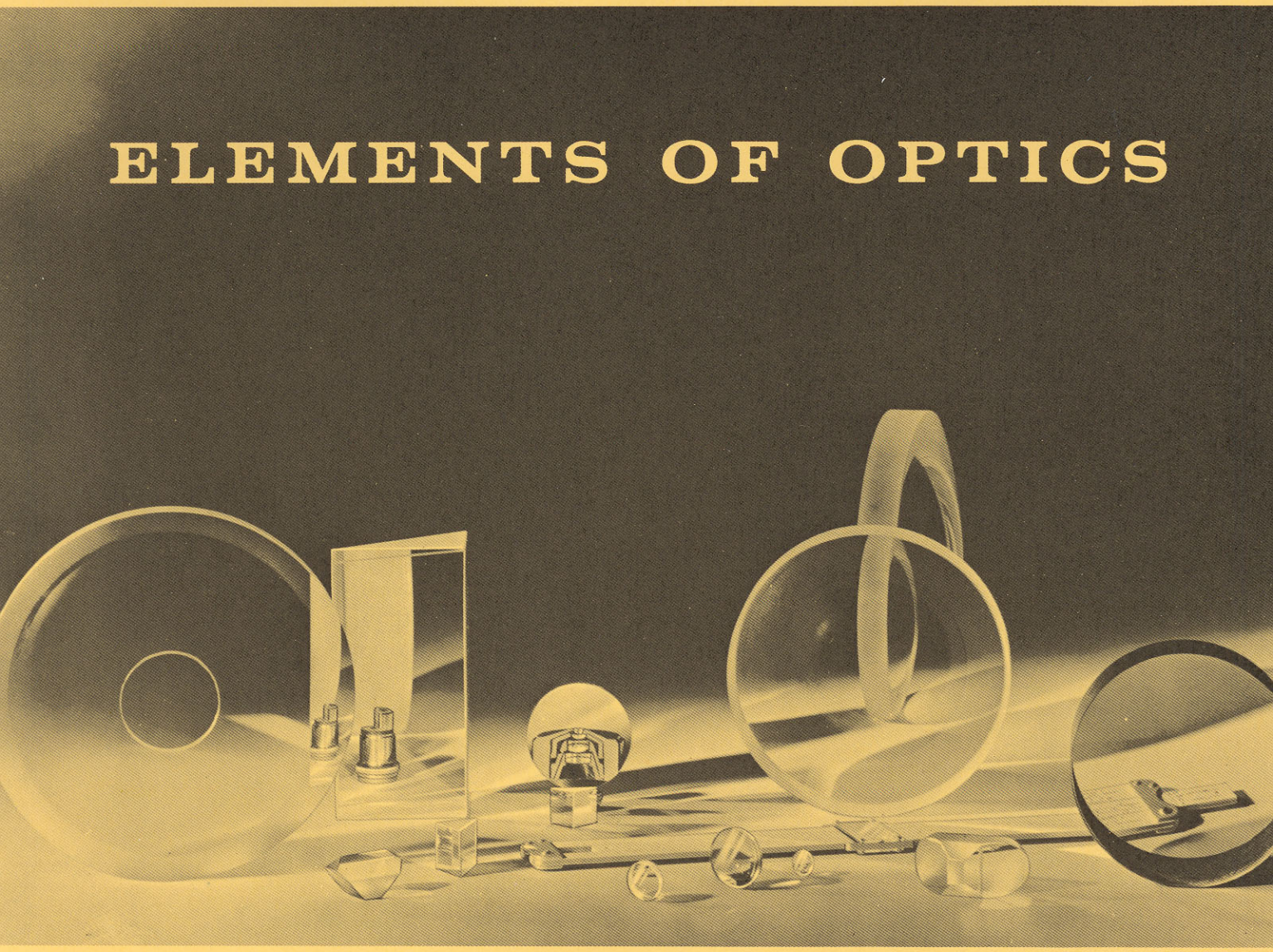
Modern Pollen Identification
Students engage in an intensive study of pollen, fern and fungal spores. Methods for identification, classification and morphological description are covered in detail.Students are shown the methodology for the extraction and isolation of pollen and spores from air samples, soils, and forensic materials. more...

Pharmaceutical Microscopy
This course focuses on two major problems in the pharmaceutical industry: identification of particle contamination and characterization of the solid state. Students learn to recognize common contaminants and to effectively characterize unknown materials. more...

Polymer Microscopy
After an introduction to the microscope as used by polymer microscopists, the optical "crystallography" of fibers and films is thoroughly covered. more...

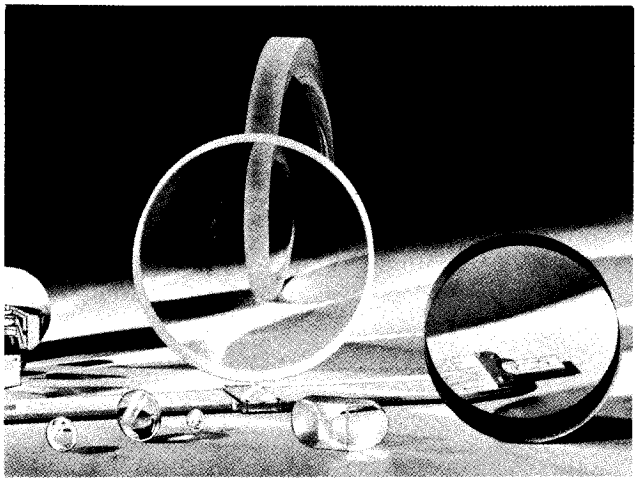
Visit www.mcri.org for full descriptions of all courses, secure online registration, hotel information and more.

ELEMENTS OF OPTICS



AO® American Optical
SCIENTIFIC INSTRUMENT DIVISION
BUFFALO, NY 14215

price: Fifty cents



CHAPTER ONE

BASIC OPTICAL CONCEPTS

Two theories, taken together, explain most fully the current understanding of light. First to be developed was the **corpuscular theory** which held that light was composed of a stream of invisible particles, or corpuscles, emitted by objects and gathered by the eye. These corpuscles were considered to be given off directly by self-luminous objects (the sun, a flame, or the white-hot filament of an electric light bulb) and to be reflected to the eye from non-luminous objects.

Electromagnetic Wave Theory

The second theory, demonstrated late in the 19th century, is that light is an **electromagnetic wave.** Following upon the corpuscular theory, it was not until the middle of the 17th century that the idea began to grow that light might be some sort of wave motion, and at first it was thought that light was a mechanical vibration of the ether (air), but later thinking brought the electromagnetic wave theory into wide acceptance.

Physicists now accept and apply both the corpuscular theory and the electromagnetic wave theory, since one satisfactorily explains many light phenomena, and the other satisfies other phenomena. In general and for our use here, however, the **propagation of light** (travel, extension or spread) is best explained by the electromagnetic wave theory and we will concern ourselves mainly with this theory in these courses.

Wave Motion

Toss a pebble into a pool of quiet water and you create a series of waves, all traveling outward from the center, while each drop of water in the wave separately moves up and down. This up and down motion of the individual drops in combination with the line of travel of the complete wave itself is called a transverse motion. Electromagnetic waves of light emitted from a light source travel in much the same way. They are **transverse** waves in which the direction of vibration (up and down motion) is at right angles to the direction of propagation (travel).

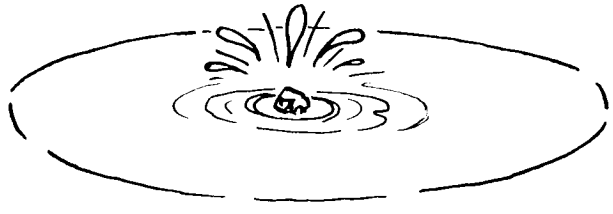


Illustration 1.

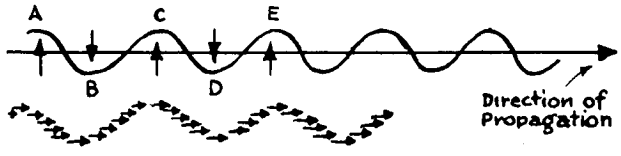


Illustration 2.

Now, if we were to take a small arc from any one of these waves, as shown here, we have determined a **wave front:**

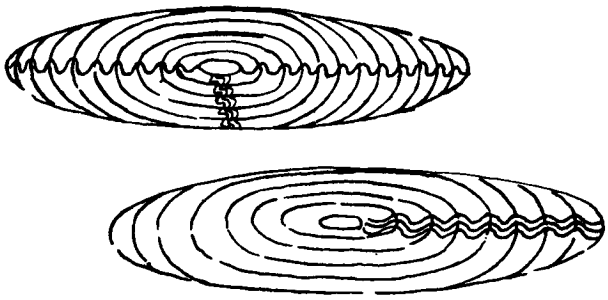


Illustration 3.

Wave Length

This wave concept gives us a convenient method of measuring for different colors of light: **Wave Length.** The wave length is simply the distance traveled forward by the light as it goes through one complete vibration: A to C, B to D, or C to E, etc. (in Fig. 2).

Frequency

The longer wave lengths will vibrate fewer times in a given time interval than will the shorter ones, and thus we hit upon a second measuring factor: **Frequency.** Frequency is the number of vibrations of a given wave length in one second.

Both Wave Length and Frequency are of high importance in determining a very basic measurement of light—the speed or **Velocity** at which it travels. Many of our instruments are constructed to utilize the varying velocities of light in different mediums so that a formula for determining this velocity is a part of an adequate background for our study. This is the formula:

$$V = f \times \lambda$$

V = Velocity
f = Frequency
λ = Wave Length

Now that we have determined theoretically how light moves and how that movement is measured with regard to velocity, our problem becomes one of understanding **direction** of motion.

Rectilinear Propagation Of Light

Light given off from a light source travels in all directions from this source and travels in straight lines. This characteristic is known as the Rectilinear Propagation of Light (Rectilinear = moving in a straight line)

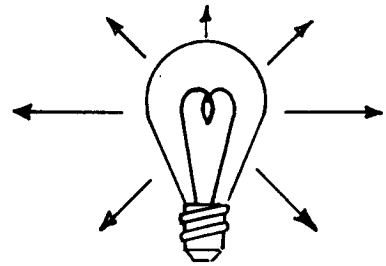


Illustration 4.

For example, if we place an object in the way of light coming from a very small source, a sharply defined shadow is formed on a nearby screen.

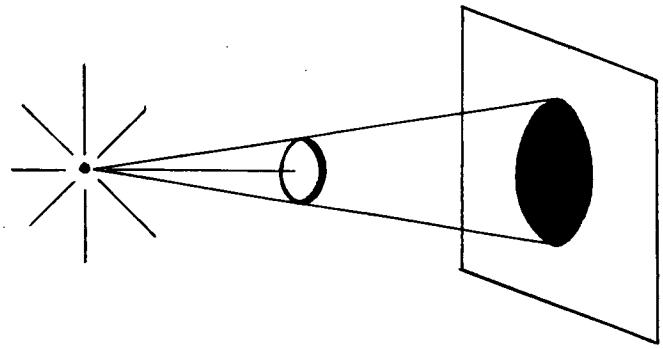


Illustration 5.

The edges of the shadow are formed by the continuation of straight lines drawn from the light source to the edges of the object. Similarly, if light from two small sources falls on the same object, two shadows, partially over-lapping, will result:

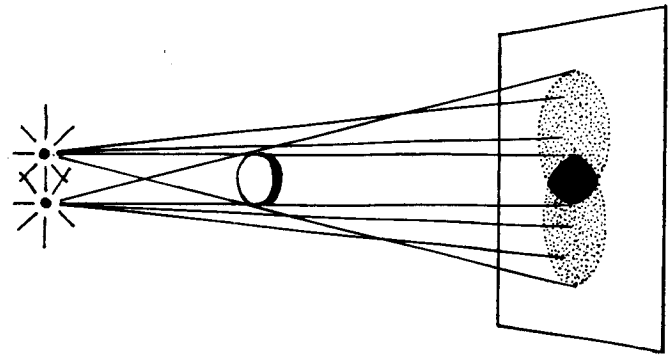


Illustration 6.

The dark central shadow is completely shielded from light from either source; the lighter outer

shadow is completely shaded from one source but illuminated by the other. The remainder of the screen receives illumination from both sources.

Rays, Pencils and Beams of Light

For the sake of clearer understanding, the light which we have suggested as traveling from the source to the object and past it in forming the shadows shown above is broken down into three classifications:

1. A **Ray** is the path of a single corpuscle of light from a single point on a light source. A ray would pass through an infinitesimally small hole in each of two screens.

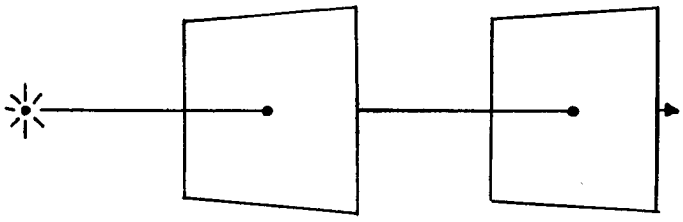


Illustration 7.

2. A **Pencil** of light is a group of rays diverging from a single point on a light source. A pencil would pass through one small hole and one large hole in the screens:

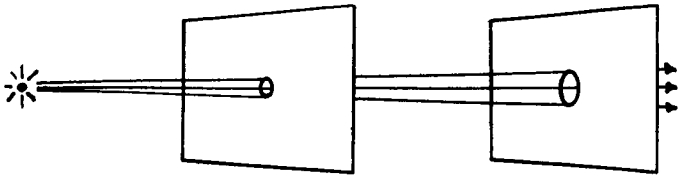


Illustration 8.

3. A **Beam** of light is composed of the group of pencils originating from all the points of a light source. A beam would pass through a large hole in each of the two screens and the further the source is from the screens the more nearly parallel the sides of the beam will be.

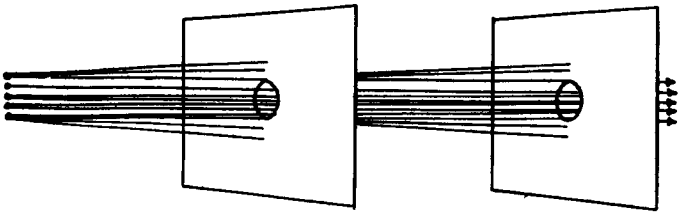


Illustration 9.

These factors are important in understanding why shadows formed by artificial light are generally not sharply formed, since the light source is usually of appreciable size and can be considered as being composed of a multitude of minute light sources, each giving off its own **rays** and **pencils** which combine into **Beams.**

For example, in the above illustration No. 6, the two sources might be considered as the top and bottom of the filament in an electric bulb. And actually, there are many other small sources on the filament, so the total shadow would be composed of a great number of overlapping shadows and would, therefore, not be sharply outlined.

As the distance from the light source to the object increases in comparison to the distance from the object to the screen, the shadow becomes more and more sharply defined. Thus, shadows formed by the bright sun are sharp because the sun is so far away that it has the effect of being a very small light source, and the beam intercepted by the object is composed of practically parallel rays.

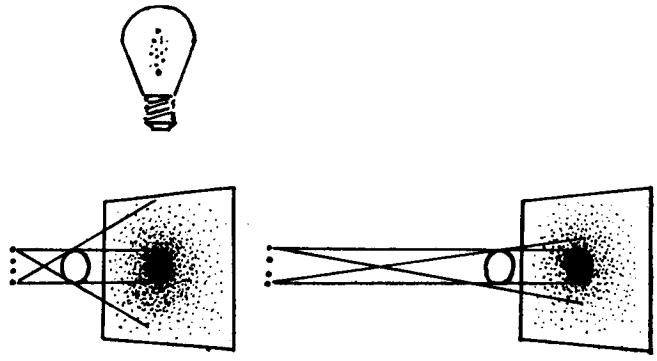


Illustration 10.

Wave Length And Color

So far, we have considered light as light. We have not attempted to analyze its qualities except with regard to wave length, frequency and direction. Now, another factor enters. You have often observed that sunlight (white light, so-called) in passing through a piece of cut glass, such as the stopper of an old fashioned vinegar bottle, creates a rainbow of many different colors. We observe from this that white light is really not white at all; rather, it is a combination of many colors which, when mixed together, appear to be white.

These different colors appear to us, however, only when the light is broken down into many lights of varying wave-lengths, as happened when the light passed through the cut glass stopper. For example, light with a long wave length appears red; light with a short wave length appears violet, and intermediate wave-lengths appear as different colors (orange, yellow, green and blue) between the two extremes.

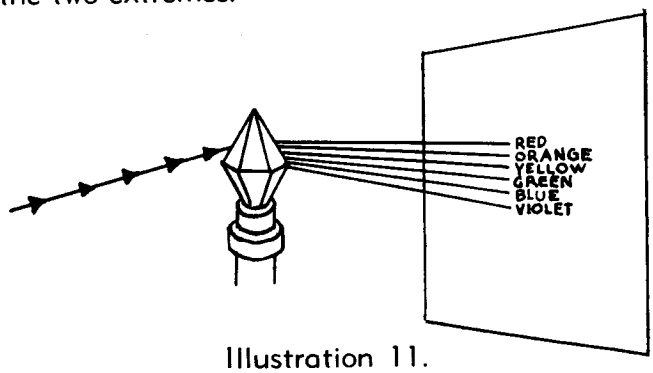


Illustration 11.

The Spectrum

The rainbow we observed is called a spectrum and is caused by the separation of light into its several wave lengths. The **visible spectrum** is composed of colors which can be seen by the eye (red through violet) but this visible spectrum is only a very small portion of the whole electromagnetic spectrum.

Beyond each end of the visible spectrum are many other wave-lengths not visible to the eye: X-rays, radio waves, ultra violet rays, infra red rays, etc. And even in the visible spectrum, the electromagnetic waves are so small that they are usually measured in a unit called a millimicron (abbreviated mu), which is equal to .000001 millimeters. And just for your own amusement, you can sit back and think that it would take 25,400.-000 millimicrons (mμ's) laid side by side to cover one inch.

The visible spectrum may be considered as including wave-lengths ranging from 400 millimicrons (deep violet) to 750 millimicrons (deep red).

VIOLET	light	results	from	wave lengths	from	400 mμ	to	466 mμ	(appro)
BLUE	"	"	"	"	"	446 "	"	500 "	"
GREEN	"	"	"	"	"	500 "	"	560 "	"
YELLOW	"	"	"	"	"	560 "	"	592 "	"
ORANGE	"	"	"	"	"	592 "	"	650 "	"
RED	"	"	"	"	"	650 "	"	750 "	"

Ultra violet light is still shorter in wave-lengths than violet, and of course, infra red is longer than red.

A question naturally arises at this point. If light is composed of all these different wave lengths, why do we not see the several colors in the air around us at all times?

The answer to this question is of utmost significance. We recommend that you learn it and understand it thoroughly because upon it is based a great proportion of the thinking in creating our instruments. It is this:

In air, all of the various wave-lengths travel forward, or outward from the source, at the same speed. However, their up and down motion, or vibrations differ in frequency (number of cycles per second). This may be illustrated as follows:

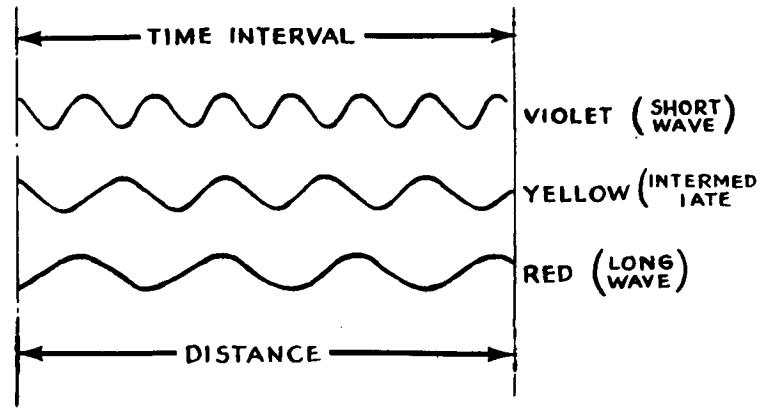


Illustration 12.

Each kind of light, as you can see, has gone forward exactly the same distance in the same time through air, but each also has maintained its own vibration rate while travelling this distance.

Now then, if we are to apply the formula previously given, we obtain the speed of these various wave-lengths—

(Velocity = frequency times wave-length)

For violet light in air
v=750,000,000,000,000 cycles/sec×400 mu=186,000 miles/second

For yellow light in air
v=509,000,000,000,000 cycles/sec×589 mu=186,000 miles/second

For red light in air
v=428,000,000,000,000 cycles/sec×700
mu=186,000 miles/second

(Frequencies and wave-lengths above are approximate)

You will note that the cycles per second are so many that despite the shortness of the wave-lengths the light is travelling at terrific speed. In white light there are so many vibrations of such short length and from so many rays entering the eye at one time and all at the same speed, that they all combine with each other and give the impression of white. The individual increments are so small and so numerous that the eye cannot discriminate between them.

186,000 Miles Per Second Through Air

In each of the above examples the answer works out to **186,000 miles per second,** and this figure, measured many times and by a number of different experiments is taken as the standard speed of light through air. Remember that figure: 186,000 miles per second.

Remember it because when light enters any other substance (water, glass, etc.) it slows down; its velocity is diminished. It will slow down in varying degrees according to the chemical composition of the substance it is passing through.

Index of Refraction

Since this is a most important basic phenomenon, there has been established a relationship between the speed of light in air and its speed in these various substances. This relationship is called **the index of refraction.** It is determined by a simple formula—

$$\text{Index of refraction of the substance} = \frac{\text{speed of light in air}}{\text{speed of light in the substance}}$$

We know the speed of light in air is 186,000 miles/second. It has also been determined that the speed of light in water is 140,000 miles/second, so substituting in the formula — Index of refraction of water $= \frac{186,000}{140,000} = 1.33$

Similarly, for one particular crown glass in which light travels at 122,000 miles/second—

$$\text{Index of refraction of the glass} = \frac{186,000}{122,000} = 1.52$$

and for one particular flint glass in which light travels at 113,000 miles/second—

$$\text{Index of refraction of the glass} = \frac{186,000}{113,000} = 1.65$$

The index of refraction, then, is a ratio between the velocity of light in air and in some particular substance. The index of air is 1.00 $\left(\frac{186,000}{186,000} = 1.00\right)$ and all indices are referred to the index of air, i.e., the index of water being 1.33 means that the speed of light in air is 1.33 times as great as the speed of light in water, or the speed in water is $\frac{1.00}{1.33}$ or 3/4 of the speed in air.

The effect of the index of refraction can best be shown if we consider a light beam striking a piece of glass with flat surfaces, **perpendicular** to its surface. For this illustration, imagine that the beam of light is composed of many rays of light (A, B, C, D, E) traveling at the same speed, and that the source is so far away that for practical purposes the beam is a parallel beam—

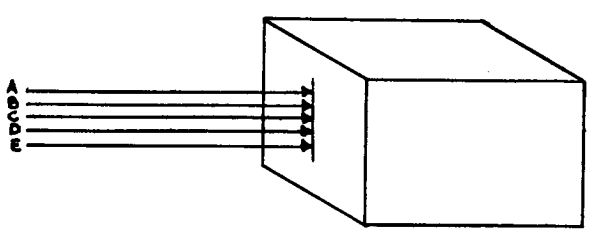


Illustration 13.

all the rays will then reach the surface of the glass at the same time.

If we draw a line (wavefront) connecting all the rays at the time they reach the surface, that line would be parallel to the surface. Since the rays are all traveling at the same speed before they hit the glass, and since the glass slows down all the rays equally, then a short time after the rays hit the glass they would have passed partially through the glass and the wavefront would still be parallel to the surface of the glass. The beam of light in this case then will travel straight through the glass, but it is traveling slower in the glass than it was in the air.

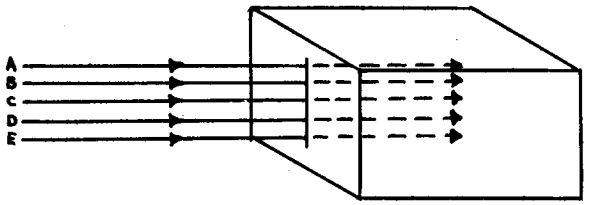


Illustration 14.

Suppose now that the same beam of light had approached the glass not perpendicularly, but at an angle to its surface.

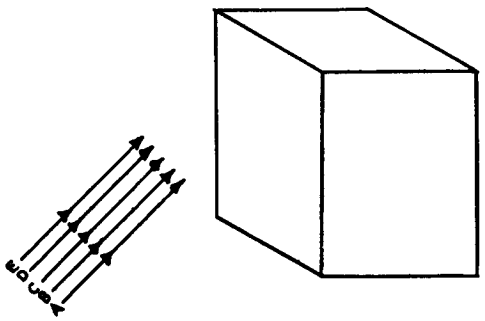


Illustration 15.

Then, since the rays all travel at the same speed, ray "A" would reach the surface before "B" got there, "B" before "C", "C" before "D", and "D" before "E". The line connecting the light rays at the instant "A" reached the surface would be at an angle to the surface.

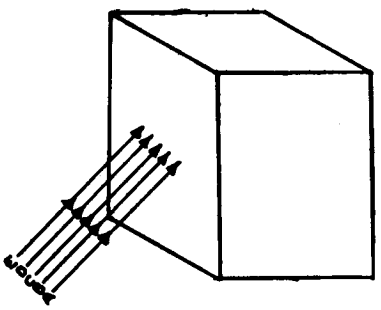


Illustration 16.

Ray "A" then enters the glass before "B" does, etc., so Ray "A" is slowed down before "B" is, etc.

Looking at this in cross section, it would appear as follows at the time when Ray "B" had reached the surface—

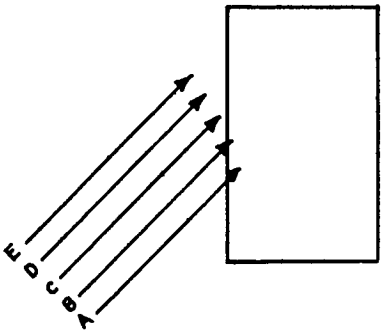


Illustration 17.

and when Ray "E" had reached the surface

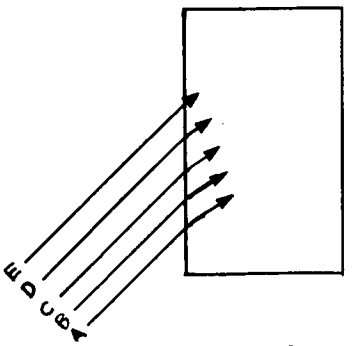


Illustration 18.

and shortly after "E" had entered the surface

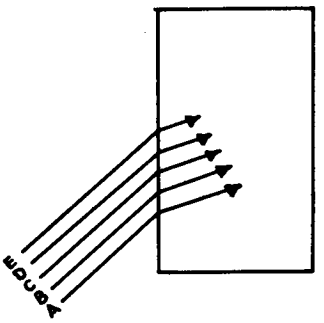


Illustration 19.

The effect, then, is that the beam of light striking the glass surface at an angle has been turned from its original path, or **refracted.** The amount it has been turned depends on the index of refraction of the glass because light travels slower in a high index glass than in a low index glass. Glass with a high index bends the light more than glass with a low index (flint more than crown). The bending takes place at the surface and the light is traveling rectilinearly both before and after the refraction (bending).

When passing from air into glass, the bend is always towards a line perpendicular to that surface of the glass.

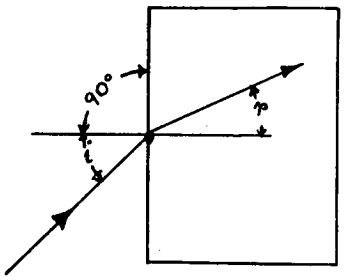


Illustration 20.

If the light was traveling in the opposite direction (from glass to air) then the reverse would be true—the bend would be away from a line perpendicular to that surface of the glass.

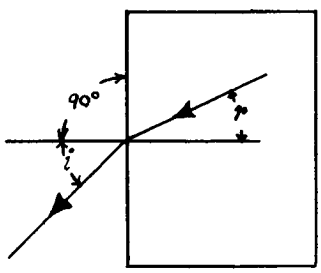


Illustration 21.

And inverting illustration No. 21—

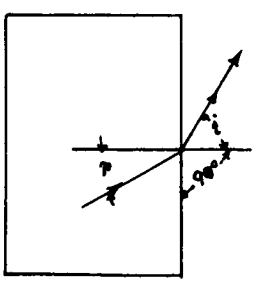


Illustration 22.

Combining these two so that the light goes from air through glass to air we have—

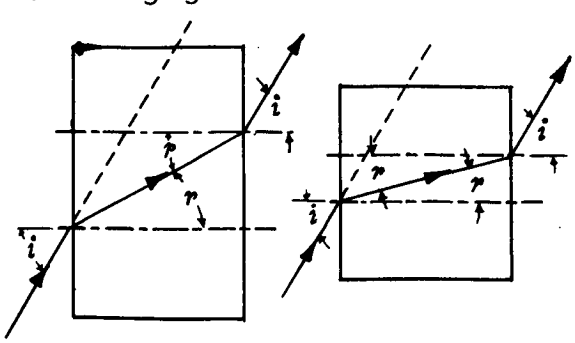


Illustration 23.

In this case (where the two sides of the glass are parallel) the ray would be traveling in the same direction after it went through the glass as it was before it entered the glass, but the ray would be slightly displaced sideways.

The angle "i" between the ray in air and the perpendicular to the surface is called the angle of incidence. The angle "r" between the ray in glass and the perpendicular to the surface is called the angle of refraction.

There is a definite trigonometric relationship between these angles, "i" and "r", and the index of refraction of the glass. Without going into the trigonometry, it will suffice to say that if we know the value of any two of the variables (index, angle "i", or angle "r"), we can determine the third variable. The relationship is called "Snell's Law".

If the two sides of the piece of glass through which a ray of light is passing are not parallel, the ray will follow a path which is different in direction after passing through the glass than it was following before entering the glass.

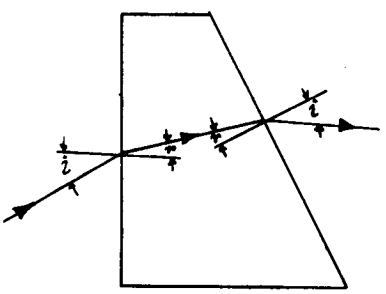


Illustration 24.

The relationship (Snell's Law) applies equally well whether the light is passing from air into glass, or from glass into air. So we can mathematically predict very accurately the direction in which the emerging ray will be traveling when we know the angle of incidence, the index of the glass, and the angle between the glass surfaces. By choosing the proper angle of incidence, glass of the proper index, and the appropriate angle between the glass surfaces, we can control the direction of the emerging light according to our desires.

Dispersion

In the discussion so far, we have indicated that rays of light are bent, or refracted, when they pass from the air into glass and from glass into air. We have also shown that **in air** all wavelengths of

light travel at the same speed. If we consider that the ray of light is "white light", we must recall that "white light" is composed of light of all the wavelengths in the visible spectrum. Although all wavelengths travel at the same speed in air, they all slow down in varying degrees upon entering glass.

Reviewing the diagram for refraction (Illustration 19), let us assume that instead of having a beam of light (made up of rays A, B, C, D, & E)

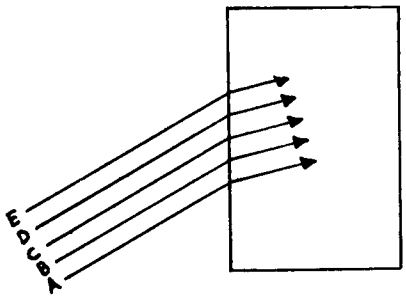


Illustration 25.

we take just the ray "A" and magnify it so that we have a ray composed of light of the different wave lengths incident on the glass.

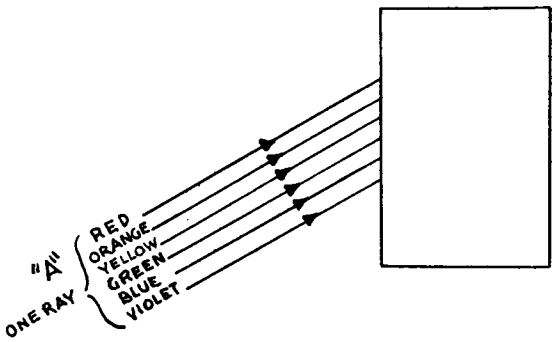


Illustration 26.

We have said that different wave lengths travel at different speed **in glass.** Actually, the red wavelengths travel the fastest in glass, orange slower than red, yellow slower than orange, and so on until we reach violet which travels slowest of all **in glass.** Extending the previous diagram, as the ray enters the glass, the red wavelengths bend the least and the violet rays bend the most, and the intermediate colors bend intermediate amounts and our diagram would look like this.

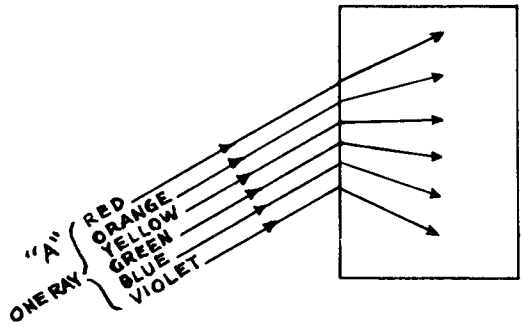


Illustration 27.

Now, if we no longer magnify the ray of light, but indicate it as just one ray (remembering that it is still actually composed of several wavelengths) we find that the ray is spread out into a spectrum as a result of the difference in the amount of bending of the different wavelengths.

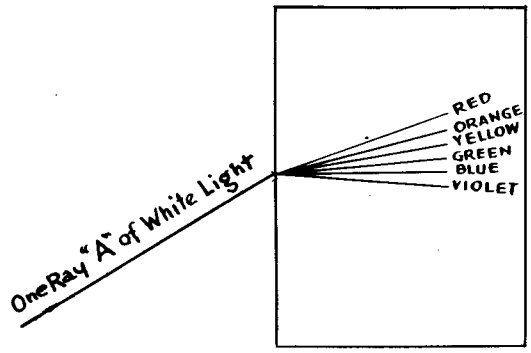


Illustration 28.

If the spectrum passes entirely through the glass with parallel sides, the individual wave lengths obey Snell's Law just as did the ray in our previous discussion and the result is as follows.

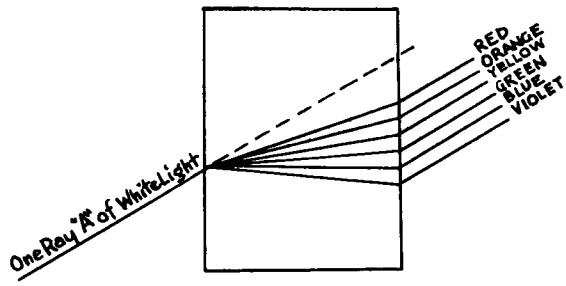


Illustration 29.

All the wavelengths emerge in paths which are parallel to the direction of the original incident ray, but all are displaced sideways and by various amounts.

If we could actually isolate **one** ray, a spec-

trum would be formed and, if we could magnify it sufficiently, we could see it as a spectrum. In practice, however, we cannot isolate one ray because it is so small. Since many rays are present, what happens is that the red wavelengths from one ray combines with the orange wavelength from another ray, the yellow from another, etc., so the final visible result is white light again. This is true because all the wavelengths from the rays emerge from the glass parallel to each other and, therefore, combine with each other.

You will recall that when our piece of glass had sides that were not parallel, the emerging ray was traveling in a different direction from that of the incident ray.

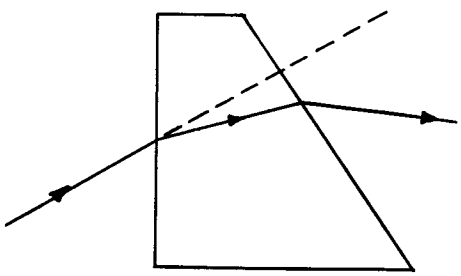


Illustration 30.

If we now consider the single ray as composed of the various wavelengths and passing through a glass whose sides are not parallel, we will have the following effect—

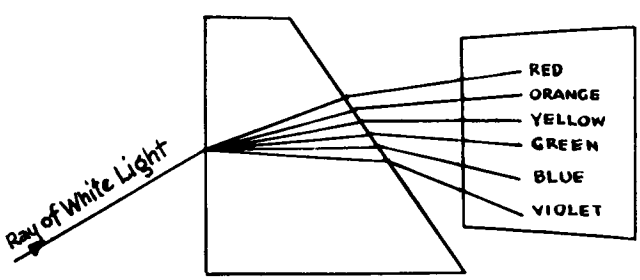


Illustration 31.

In this case the various wavelengths will emerge in different directions.

If many rays were incident, the red wavelengths from each ray would emerge in one direction, the orange wavelengths from each ray would emerge in another direction, etc. Since only wavelengths traveling in the same direction combine, we find all the red wavelengths combined, all the yellow wavelengths combined, etc. Here we have a situation in which the spectrum has not only been formed within the glass, but is actually present as a spectrum after emerging from the glass and can be seen as a rainbow.

This effect is called dispersion and results in the colored fringes seen around objects viewed through a prism, or through a lens held some distance from the eye. Dispersion is found to some degree in all glass. One glass may have greater dispersion than another glass, even though both glasses may have the same index. Other glasses of different index may have the same dispersion value.

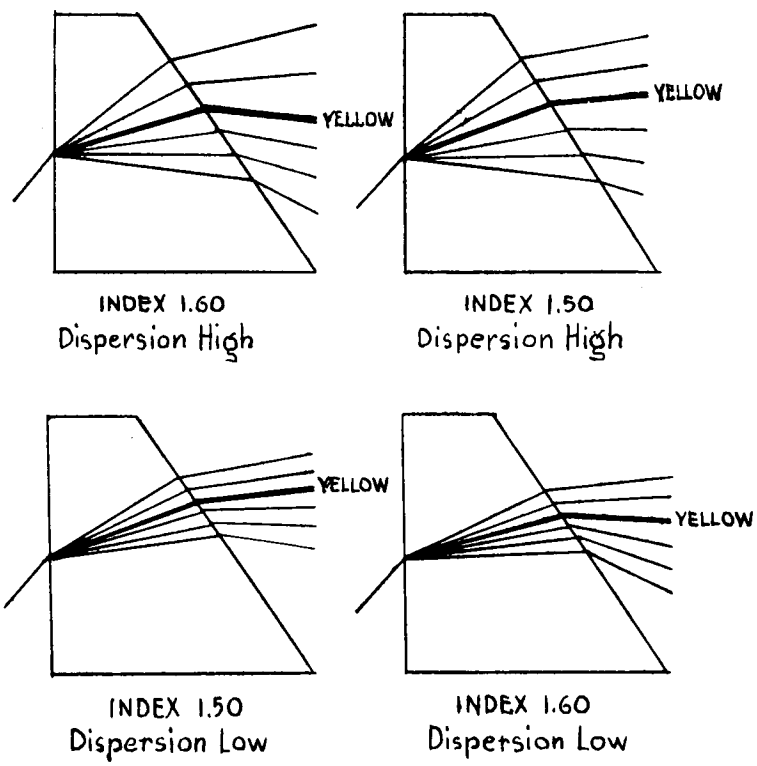


Illustration 32.

Index of refraction is measured by determining the angle of refraction as related to the angle of incidence (Snell's Law) but, as indicated above, one incident ray of white light when refracted results in several refracted wavelengths. In order to have an accurate measure of index, we always measure it from one particular wavelength (yellow light of 589 mu.). In the illustration above, note that the yellow wavelength passes through the glass at the same angle in both glasses of index 1.50 and at another angle in both glasses of

index 1.60 (the angle of incidence being the same in all four cases).

Reflection

If the top surface of the glass is a mirror, the ray incident on that surface will be reflected from the surface rather than entering the glass. A ray is reflected from a mirror at an angle equal to the angle of incidence. The angle of incidence and the angle of reflection are both measured from the imaginary line perpendicular to the mirror surface.

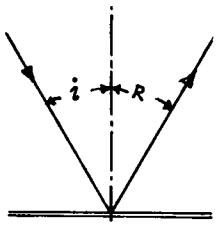


Illustration 33.

"i" is the angle of incidence
"R" is the angle of reflection
"i" is always equal to "R"

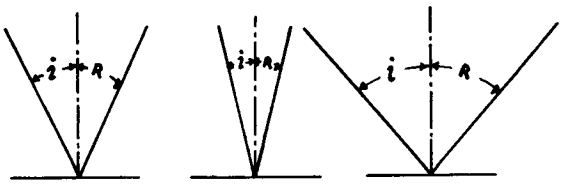


Illustration 34.

A pencil of rays acts just like a single ray when reflected.

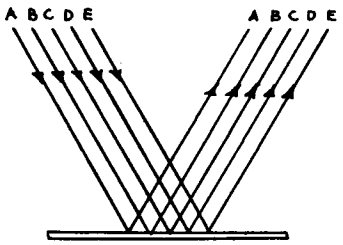


Illustration 35

REVIEW QUESTIONS CHAPTER ONE

BASIC OPTICAL CONCEPTS

1. A wavelength is the distance traveled during:

   ____1. 1 complete vibration

   ____2. 1/2 a complete vibration

   ____3. 2 complete vibrations

2. Frequency is the number of complete vibrations in:

   ____1. 3 seconds

   ____2. 1 second

   ____3. 1 light year

3. Frequency equals:

   ____1. Wavelength × velocity

   ____2. Velocity ÷ wavelength

   ____3. Wavelength × dispersion

4. Rectilinear propagation of light means that light travels in:

   ____1. a curved line

   ____2. a circle

   ____3. a straight line

5. The visible spectrum covers:

   ____1. Almost all of the electromagnetic spectrum

   ____2. None of the electromagnetic spectrum

   ____3. A small part of the electromagnetic spectrum

6. In air light of all wavelengths travels:

   ____1. At the same speed

   ____2. At different speeds

   ____3. At varying speeds

7. Speed of light in air is about:

   ____1. 186,000 miles per hour

   ____2. 186,000 miles per minute

   ____3. 186,000 miles per second

8. Light, passing from air into a more dense medium:

   ____1. Increases in velocity

   ____2. Continues at same velocity

   ____3. Decreases in velocity

9. In a medium of high refractive index as against a medium of low refractive index, light travels relatively:

   ____1. Slower

   ____2. Faster

   ____3. At the same speed

10. By choosing the angle of incident light, the index of the glass, and the angle between the two glass surfaces; the direction of emergent light is:

    ____1. Pre-determinable

    ____2. Not pre-determinable

    ____3. Partially pre-determinable

11. In passing through a prism a ray of white light is:

____1. Dispersed into its various wave-lengths

____2. Passed undeviated

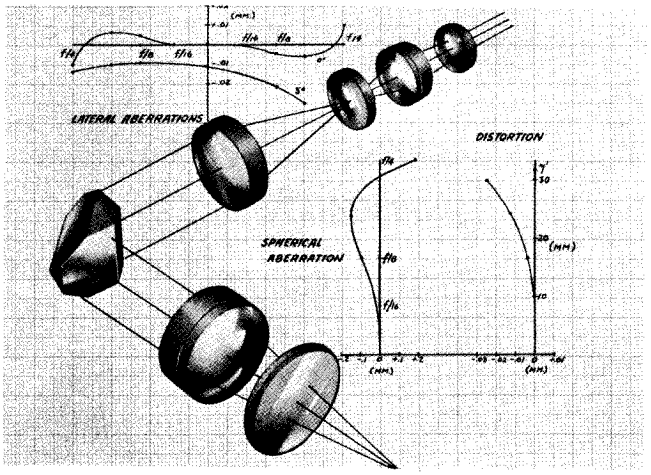
____3. Focused at a point

12. A ray of light reflects from a mirror at an angle:

____1. Greater than the angle of incidence

____2. The same as the angle of incidence

____3. Less than the angle of incidence



CHAPTER TWO

LENSES, PRISMS AND MIRRORS

It is our intention in this chapter to introduce some practical applications of the optical principles presented in Chapter 1. Here we will see how index of refraction, dispersion, and the other factors involved in lens design are applied to glass in such a manner that the resultant glass form becomes a lens, prism or mirror which will make light rays perform as desired.

First let us review several factors from Chapter 1. For the present we will consider a ray of light as composed of all the visible wavelengths but assume that no dispersion takes place during refraction. This will simplify our diagrams and explanations.

1. A ray of light which strikes a plate of glass perpendicularly (at 90°) to the surface of the glass will pass through that glass without deviation from its original path provided that the two sides of the glass plate are parallel to each other. Of course the ray slows up while it is in the glass but it is not refracted from its original direction of propagation.

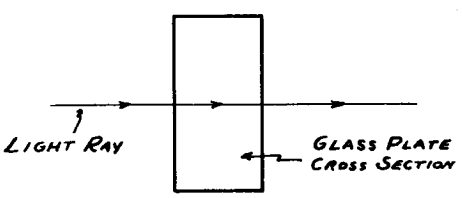


Fig. 1.

2. If a ray of light strikes that same plate of glass at some angle other than 90° then the ray is refracted or bent from its original path while passing through the glass. When it emerges from the second surface into the air it is refracted again and then travels in the same direction as its original direction of propagation but has been displaced sideways.

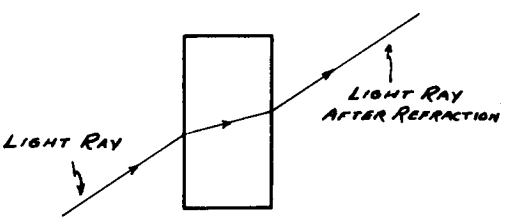


Fig. 2.

3. If a ray of light strikes a plate of glass whose sides are not parallel the ray will be refracted and emerge from the glass in a direction different from its original direction of propagation. This will be true whether the light ray approaches the glass perpendicularly or at some other angle to the surface.

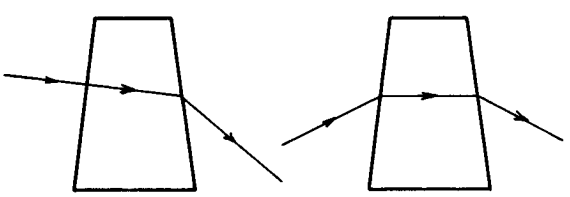
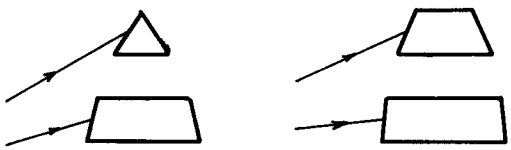


Fig. 3.

In all the above cases of refraction the direction of travel of the light ray after refraction is dependent on the index of refraction of the glass, the angle between the two surfaces of the glass, and the angle at which the light ray approaches the first surface. (Snell's Law, Ill. 24, Chapter 1.)

Now let us suppose that we have a series of glass plates and light rays under the following conditions.

1. The index of refraction of the glass is the same in all the plates.
2. The sides of the glass plates are not parallel and the various plates have different angles between their sides.
3. The light rays are approaching the first surface of the various glass plates at different angles.



LIGHT RAYS APPROACHING GLASS PLATES UNDER ABOVE MENTIONED CONDITIONS

Fig. 4.

If the light rays as in Fig. 4 continue on and pass through the glass plates they will be refracted and will emerge in different directions as follows:

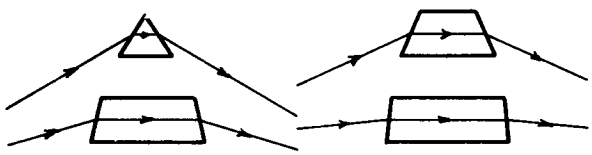
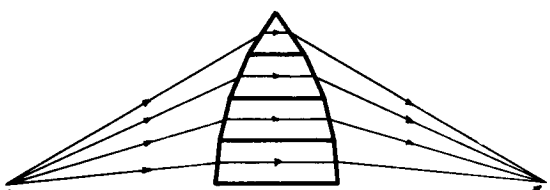


Fig. 5.

Assume now that we pile these plates of glass on top of each other and also that the rays of light which approach the different plates of glass all come from a single source of light.



ALL RAYS ORIGINATING FROM A SINGLE POINT-SOURCE OF LIGHT

ALL RAYS CONVERGING TO ONE POINT AFTER REFRACTION

Fig. 6.

If we have selected the correct angles between the sides of the various plates of glass then all the rays of light which started out from one single light source will be refracted by the pile of glass plates so that they all converge to one spot.

If we now take another pile of similar glass plates and place them upside down and on the bottom of the present pile we will have the following result.

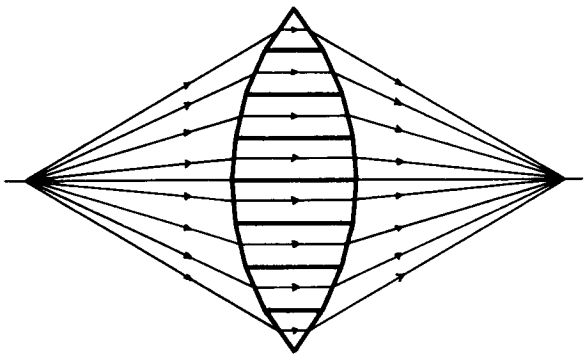
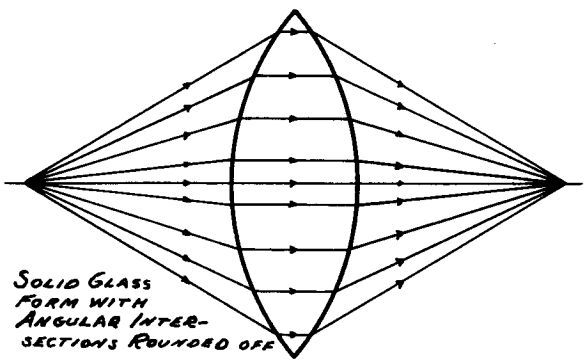


Fig. 7.

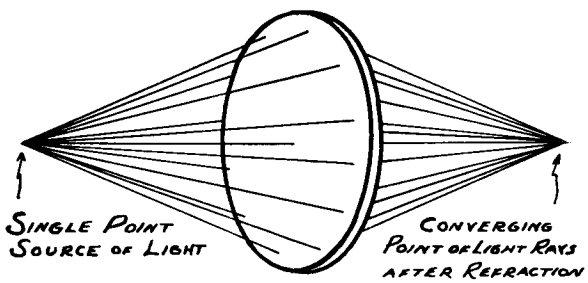
From Fig. 7, it is a simple step to visualize this as one solid piece of glass rather than a pile of separate pieces and if we smooth off the angular intersections where the blocks rested against each other we will have a smooth curved surface.



SOLID GLASS FORM WITH ANGULAR INTERSECTIONS ROUNDED OFF

Fig. 8.

Now we have to visualize this solid piece of glass in Fig. 8 as the cross section of a biconvex lens and that a multitude of light rays from the one source approach the first surface of that lens and are all refracted to one point.



SINGLE POINT SOURCE OF LIGHT

CONVERGING POINT OF LIGHT RAYS AFTER REFRACTION

Fig. 9.

The above illustration and explanations should indicate how and why a biconvex lens is capable of receiving light from a light source and refracting the various rays so that they are brought to a focus.

In the above illustrations the source of light is the so-called **object point** and the point where the rays converge and meet is called the **image point.**

When the object point is moved with relation to the lens the image point also moves. For every position of an object point there is a corresponding position for its image point. The two points are known as the **conjugate foci.**

The angles between the surfaces of our glass plates were so chosen that when we piled the plates and smoothed the edges down to a smooth curve that curve would result in a spherical surface.

A spherical surface is one which is formed as a part of a true sphere and has equal curvature all over the surface.

By altering the radius of curvature of one or both of the spherical surfaces which form the sides of a lens we can alter the angles between the two sides of the lens and thereby control the point at which the refracted rays will converge.

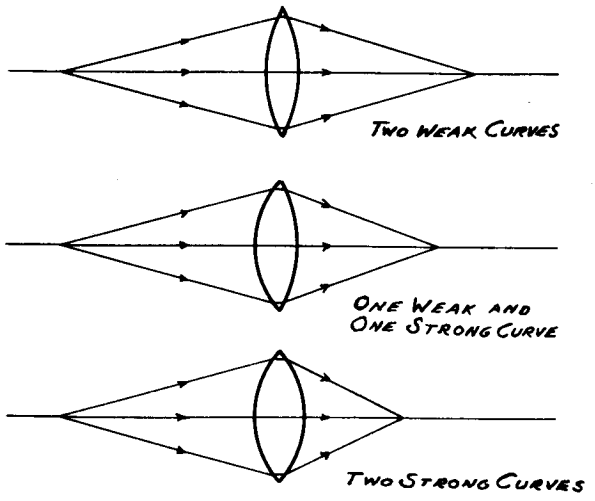


Fig. 10.

We can also control the point of convergence by using lenses of equal curvature but with different indices of refraction.

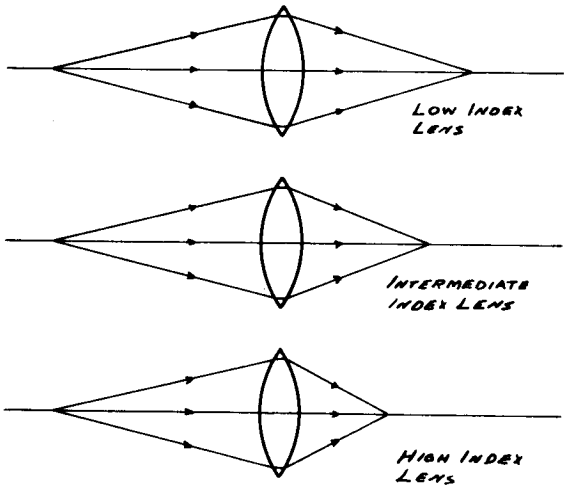


Fig. 11.

The focal length of a positive lens is determined by the distance from the lens at which the refracted rays converge to a point when the incident rays have come from a source of light which is so distant from the lens that the incident rays can be considered as parallel to each other.

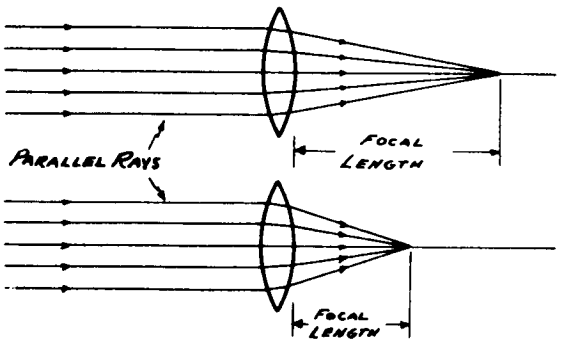


Fig. 12.

The function of any lens is to accept rays from a point at some given distance from the lens and bring them to a point of convergence or focus at a definite and desired distance from the lens. If the distance from the source or object point is known we can determine the radius of curvature for each surface of the lens and the index of the glass from which the lens should be made so as to bring the focus at the desired image point.

If for example we want a lens of a given focus and we have a blank with a certain index of refraction and with one side already polished we can alter the focal length or power of the finished lens as desired by selecting the proper radius of curvature to be ground and polished on the other surface.

The focal length of the lens determines the power of the lens. In the field of ophthalmic optics we measure the power of lenses in units called diopters. The power in diopters is found by determining the reciprocal of the focal length in meters. A reciprocal of a number is that number divided into 1 (one). The reciprocal of 1 would be 1/1=1.00; the reciprocal of 2 would be 1/2 or .50; the reciprocal of 3 would be 1/3 or .33.

A lens with a focal length of 1 meter would

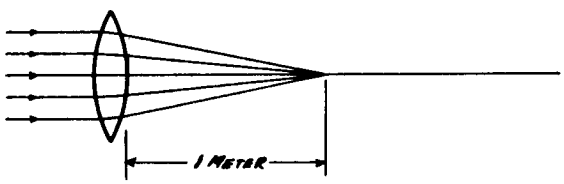


Fig. 13.

have a power of $\frac{1}{1 \text{ meter}} = 1.00$ diopter.

A lens with a focal length of 2 meters

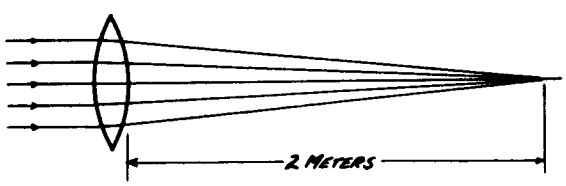


Fig. 14.

would have a power of $\frac{1}{2 \text{ meters}} = .50$ diopters.

A lens with a focal length of 1/2 meter (.5 meter)

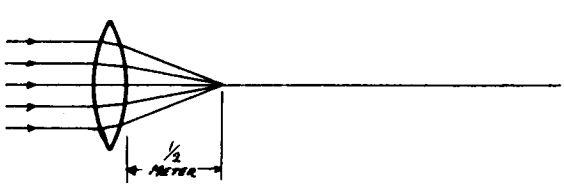


Fig. 15.

would have a power of $\frac{1}{1/2 \text{ meter}}$ or 1/.5 meters = 2.00 diopters.

A formula can be used for one unknown quantity of a lens if the other measurements are known. $1/f = (n - 1)\ (1/r_1 + 1/r_2)$ in which

f = focal length of lens
n = index of refraction of the glass
r_1 = radius of curvature of the first lens surface
r_2 = radius of curvature of the second lens surface

For example we could determine the focal length of a lens if we knew the index of the glass was 1.5, that the radius of curvature of the 1st surface was 2 meters, and the radius of curvature of the 2nd surface was 4 meters.

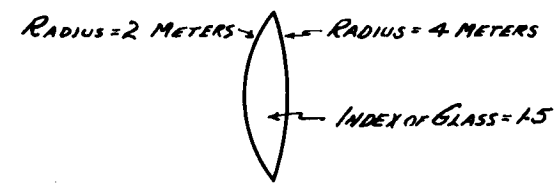


Fig. 16.

$1/f = (n - 1)\ (1/r_1 + 1/r_2)$
$1/f = (1.5 - 1)\ (1/2 + 1/4)$
$1/f = (.5)\ (3/4)$
$1/f = 3/8$ diopters or
$f = 8/3$ meters or
$f = 2.66$ meters

Such a formula will be applicable only to thin lenses. If the lens involved has considerable thickness then that thickness has to be taken into consideration also and the formula becomes too complicated to be discussed for the purpose of this course.

Note that the ray of light which passes through the center of the lenses in the several previous illustrations strikes the lens perpendicularly to the surface of the lens and passes through the lens without any change in its direction. This central ray is following the **optical axis** of the lens. The **optical center** of the lens is that point on the lens at which a ray striking the first surface at 90° passes through without deviation.

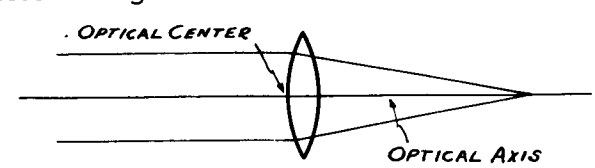


Fig. 17.

If a lens is edged so that the optical center is not at the mid point of the lens surface then there is a difference between the optical center and the mechanical center. The optical center stays at the same spot on the lens regardless of the final position of the mechanical center.

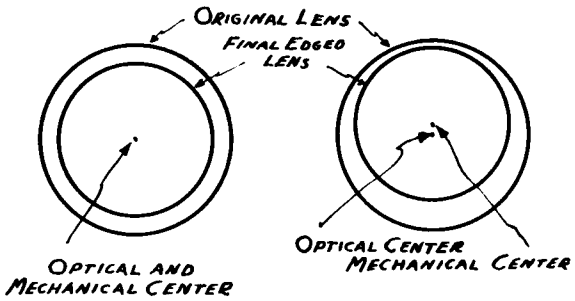


Fig. 18.

Up to this point we have discussed only lenses on which the two surfaces curve in opposite directions. And the lenses made in this way have been thicker at the center than at its edge. Any lens which is thicker at the center than at its edge will bring parallel rays of incident light to a focus at a point behind the lens. Any lens of this type is known as a positive or + lens.

Positive lenses may be biconvex, plano-convex, or meniscus.

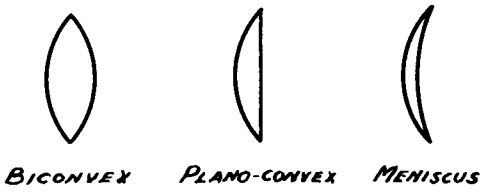


Fig. 19.

There are also negative or − lenses. All minus lenses are thinner at the center than at the edge. The three forms are biconcave, plano-concave, or meniscus.

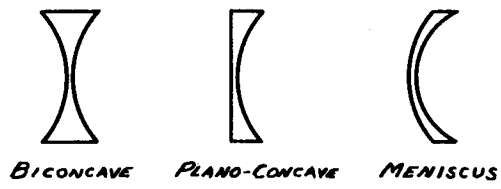


Fig. 20.

A minus lens diverges light rays rather than converging them but does so in a manner similar to that explained for positive lenses. We form a minus lens by placing the narrow ends of two piles of glass plates together.

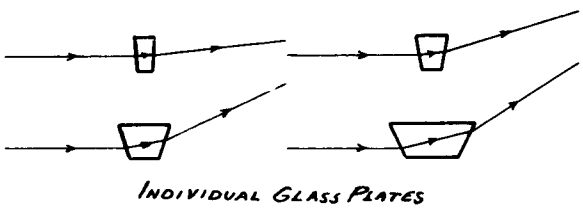


Fig. 21.

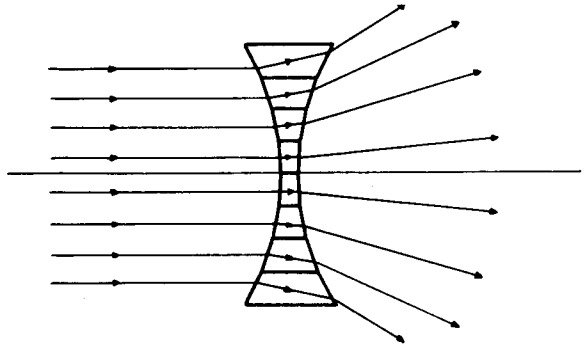


Fig. 22.

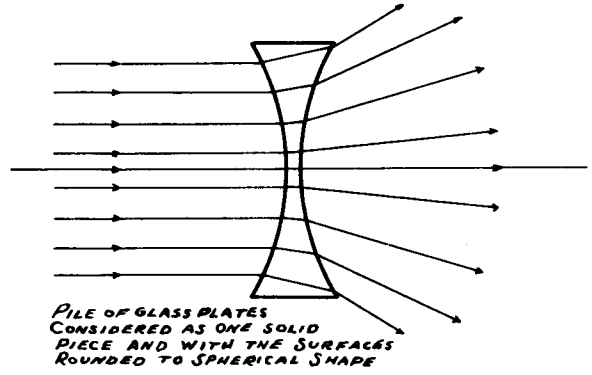


Fig. 23.

Since the rays diverge after refraction by a minus lens there is no point at which the rays will come together after the refraction. In order to determine the focus of a negative lens we must create an imaginary focal point. This is accomplished by extending the diverging rays backwards from the direction of propagation after refraction and by this means the rays would be found to appear, after refraction, as though they had all come from this imaginary point.

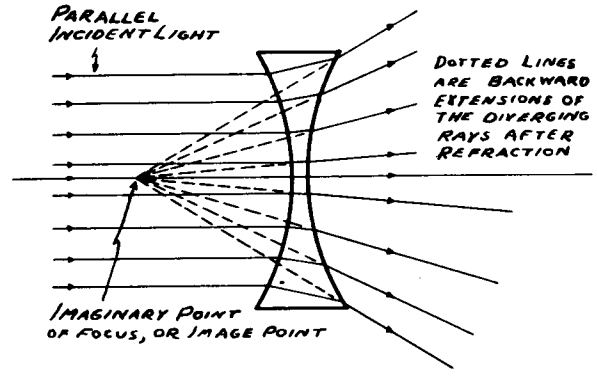


Fig. 24.

This imaginary point is the image point of a negative lens and its distance from the lens for any object point is determined by the focal length or

power of the lens.

Since the image point for parallel incident light is on the same side of the lens as the object point we call the focal length a negative quantity and in the equation for determining power this negative or −quantity results in a negative or −dioptric power.

If the lens has a focal length of −1 meter its power would be $\frac{1}{-1 \text{ meter}} = -1.00$ diopter.

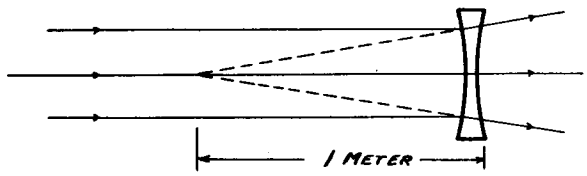


Fig. 25.

If the lens has a focal length of −1/2 meter its power would be

$$\frac{1}{-1/2 \text{ meter}} \text{ or } \frac{1}{-.5 \text{ meter}} = -2.00 \text{ diopters.}$$

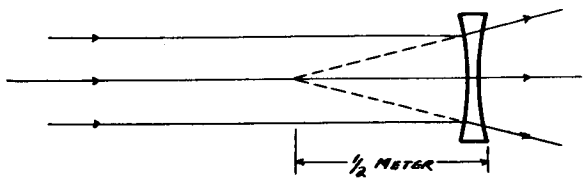


Fig. 26.

We have considered the rays of light in all cases previously to have come from one tiny source or object, and as a result the image of the source has also been one tiny point.

Complete images of large objects are formed by lenses because the rays from each point on a large object are all gathered by the lens and brought to a focus at an image point. In such a case only one of the object points will be on the optical axis of the lens and only its image will be formed on the optical axis. Object points which do not lie on the optic axis will result in image points off the optical axis.

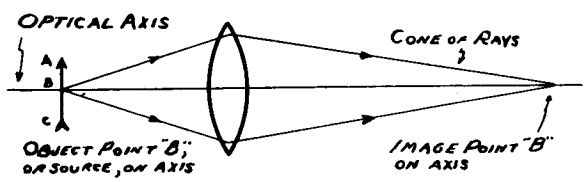


Fig. 27.

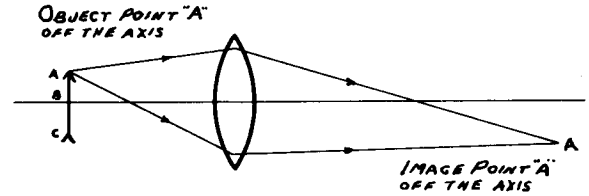


Fig. 28.

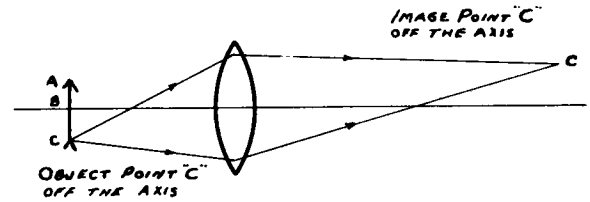


Fig. 29.

Combining Figs. 27, 28, and 29 and assuming that every point on the object (arrow) had similar cones of rays going from it to form image points the lens would form a complete image of the object.

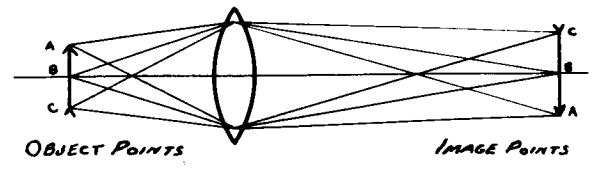


Fig. 30.

So far we have discussed lenses which have had true spherical surfaces or a spherical surface on one side and a flat or plano surface on the other side. Such lenses are all known as spherical lenses. They can be thought of as being of a shape which would result from slicing off a piece of a spherical glass ball; from the intersection of two spheres; or from filling the space between two spheres.

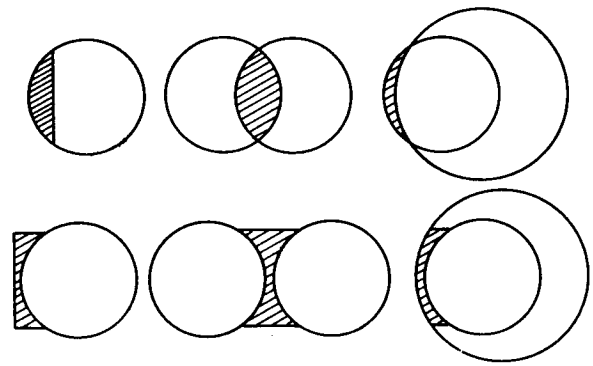


Fig. 31.

Now we should consider those lenses known as cylinders. The simplest cylinder lens would be one which on its curved side curved in one direction

but was flat in the other direction. This might be visualized as resulting from cutting a side from a cylinder of glass.

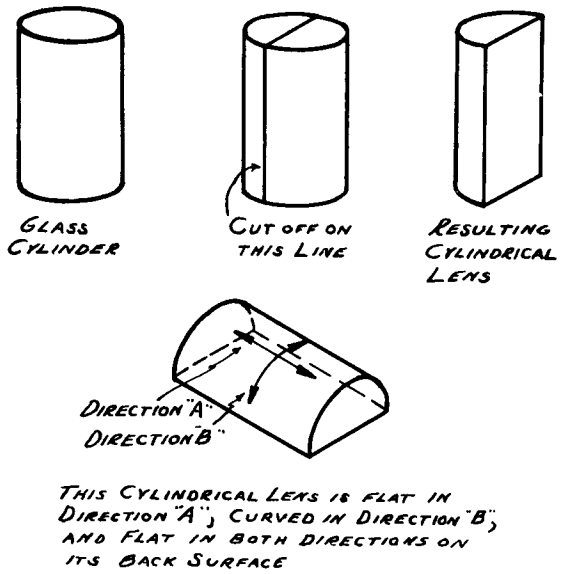


Fig. 32.

If we view a cross section of this cylindrical lens cut in direction "B", it has a curved and a flat surface. So, for rays striking the lens in direction "B", it will act as a spherical lens and bring rays to a focus. However, if we view a cross section of this same lens cut in direction "A", its front and back surfaces are parallel, and the rays striking the lens in this direction will be refracted as though the lens was a glass plate with parallel sides and will not be brought to a focus.

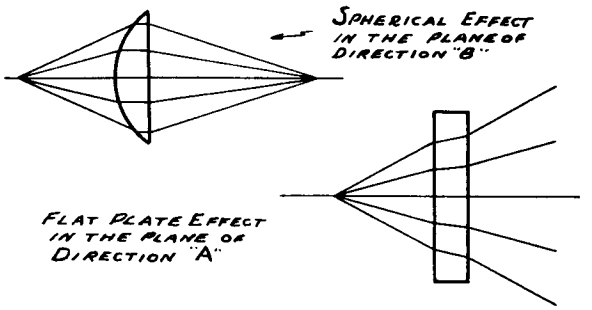


Fig. 33.

By combining the parts in Figure 33 in a three--dimensional view, we can visualize the effect of the cylinder on rays from one point source.

The point source, "ABC" sends out rays in all directions. We choose three pairs of rays. A and A' which diverge from the optical axis are

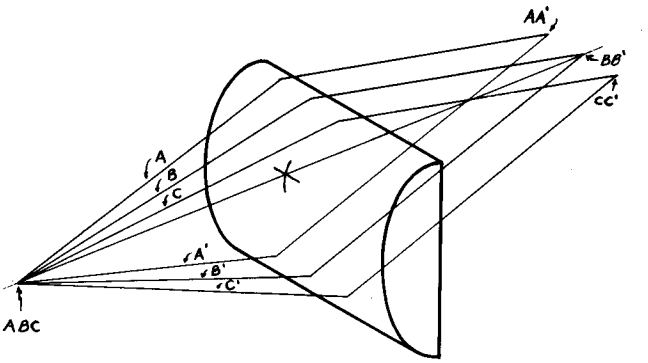


Fig. 34.

brought to a focus at AA' by the sphere refraction (direction "B", Fig. 32), but the image is not refracted back to the optical axis. B and B' are brought to a focus, BB', on the optical axis. C and C' are brought to a focus, CC', off the optical axis. Since all the rays which would be between those we have illustrated would come to focus at points between AA' and CC', the effect of the lens has been to form a line of image points from the original single object point. The object is a point but its image is a line.

The cylinder described above has no power in one direction and spherical power in the opposite direction. A more common type of lens is known as a sphero-cylinder. The sphero-cylinder has power in one direction and a different power in the opposite direction. We can visualize this type of lens if we think of it as similar in shape to the bowl of a teaspoon.

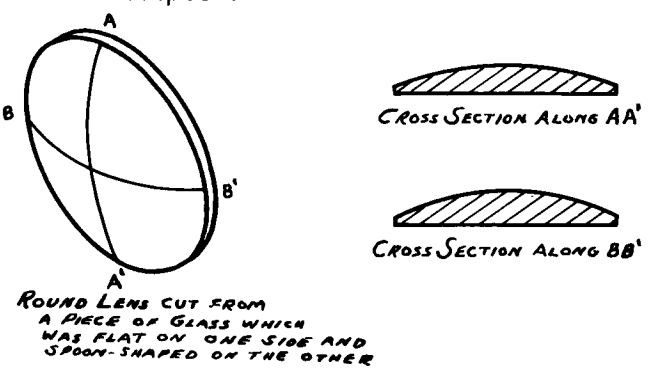


Fig. 35.

The line AA' drawn on the bowl of the spoon is drawn along the long direction of curvature and this line has the greatest radius of urvature of any line that could be drawn on that surface. The line BB' is drawn along the short direction of curvature and has the least radius of curvature. The lines AA' and BB' are at 90° to each other.

AA′ is called the **meridian** of least power and BB′ is the **meridian** of greatest power.

Since the power differs in the two meridians, light rays in the planes of the two meridians will be brought to a focus at different distances from the lens. There is a focal length for each meridian.

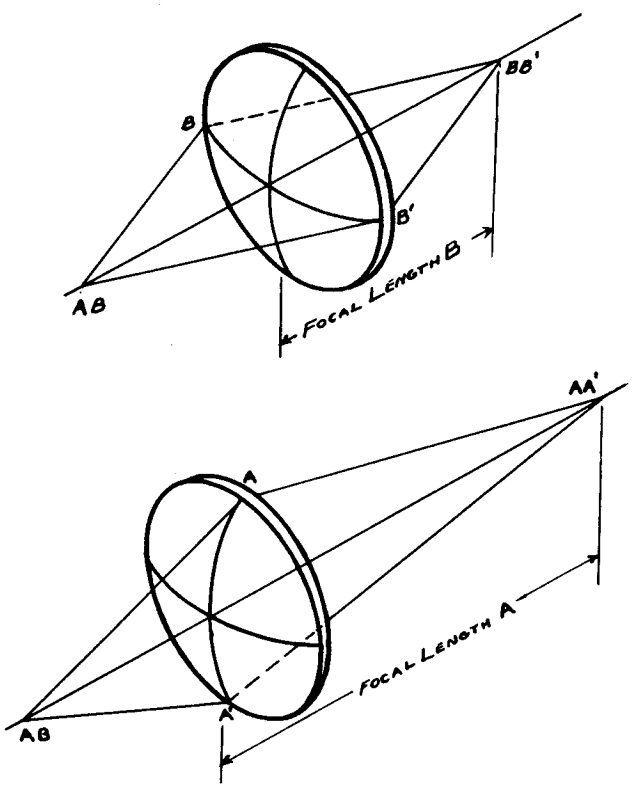
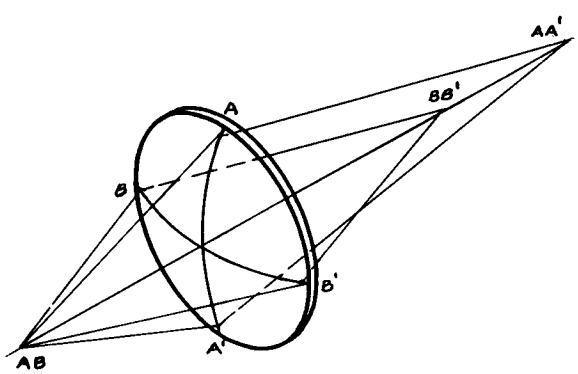


Fig. 36.

Combining the two parts of Figure 36, we have a figure illustrating the effect of the two focal lengths, and the ray paths after refraction can be visualized by means of graphic focal planes. At the image point BB′, rays AA′ would still be separated while at the image point AA′, the rays B and B′ would have passed through their focus and would have diverged.



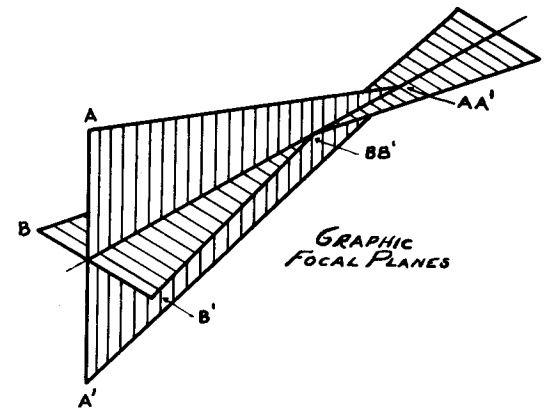


Fig. 37.

A prism is a glass form used to displace an image and may be considered as a glass plate with plane non-parallel sides.

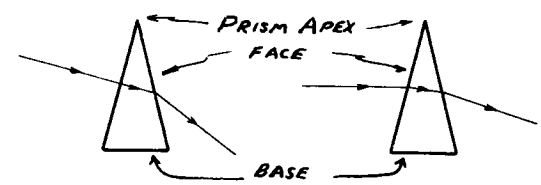


Fig. 38.

The power of a prism is determined by the amount the prism will displace a ray of light in a distance of one meter. If the prism displaces the ray by one centimeter at a distance of one meter, the prism is said to have a power of 1 prism diopter. A 2 cm displacement results from a power of 2 prism diopters (2$^{\Delta}$ Diopters) etc.

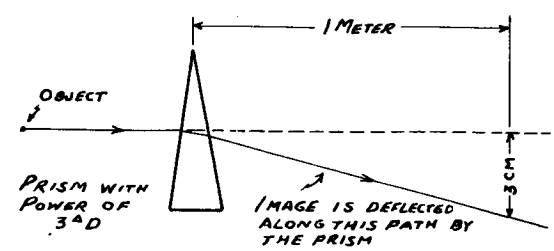


Fig. 39.

As explained at the beginning of this chapter, we have considered rays of light to be composed of all wavelengths and have assumed that no dispersion takes place during refraction. Actually, we know that dispersion accompanies refraction and so dispersion must be considered in lens design. For most applications of thin lenses and some applications of thick lenses, the dispersion is of a negligible quantity and is disregarded. It is always pres-

ent, however, and results in a defect in lenses, known as chromatic aberration.

Chromatic aberration is caused by the focusing of different wavelengths at different distances from the lens. The white light incident on the lens is dispersed and the various wavelengths are refracted by different amounts.

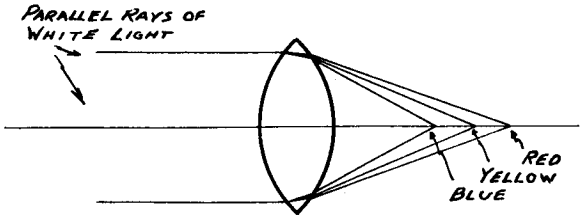


Fig. 40.

Particularly in instrument optics, it is often important that the chromatic aberration be reduced to a minimum, for, if it is present in excessive quantity, an image formed by the optical system may appear to have fuzzy and colored edges. Such an image is difficult to bring to a good sharp focus and might adversely affect measurements made with the instrument.

Three methods may be used to overcome chromatic aberration:

1. A light source may be used which emanates only light of one wave length, or at best only a narrow band of wavelengths (sodium vapor lamp). These rays, when traversing the optical system, will not be dispersed, or at least dispersed only within narrow limits.
2. A filter which allows the passage of one, or only a few, wavelengths can be placed somewhere in the system. Chromatic aberration will be present in the optical system up to the point where the rays of white light reach the filter. After the filter has taken out all but a few wavelengths, the chromatic aberration will be either eliminated or reduced, depending on the efficiency of the filter.

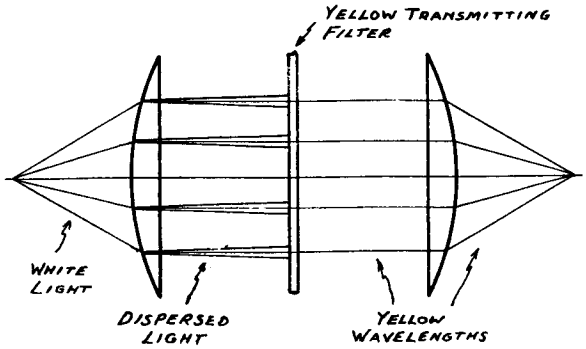


Fig. 41.

3. A doublet lens may be substituted for a single lens. By choosing glasses with the appropriate indices of refraction and dispersions (usually a crown glass of low index and a flint glass of high index, both having the same dispersion value) and designing the combination lens with appropriate surface curvatures, the chromatic aberration of the combination can be reduced below that from a single lens of the same focal length. Such a combination is called an achromatic lens.

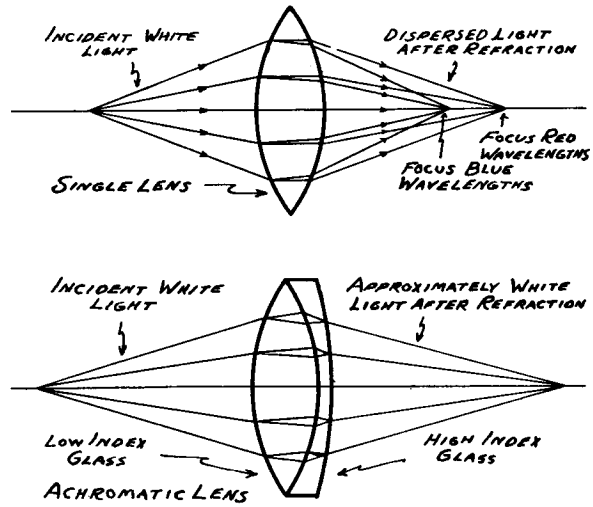


Fig. 42.

Various types of reticules are used in instrumentation. A reticule is usually a piece of glass with flat parallel sides. On one surface is etched the required reference lines. These lines usually take the form of cross lines, and/or single or concentric circles. They may take the form of a measuring scale.

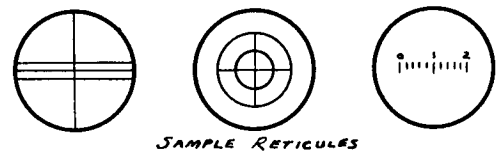


Fig. 43.

Reticules are placed in an optical system so that they are in the focal plane of the image being observed. Thus, they appear in the same plane as the image and are used to align images or to make measurements of the image.

An ordinary mirror is made of a glass plate which has parallel surfaces. A reflecting coating (silver, aluminum, etc.) is put on the back surface and a protective coating over the reflecting coating.

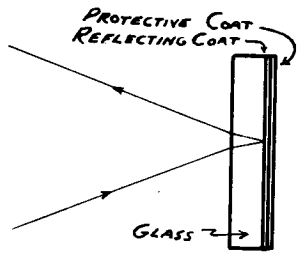


Fig. 44.

You will recall that the angle of reflection is equal to the angle of incidence.

The front surface of such a mirror actually reflects a small part (about 4%) of the light incident upon it, even though that surface is not silvered. As a result, the image from a ray traveling off the optical axis is doubled. One image has very low intensity as compared with the other, but for critical work it may be sufficient to fuzz the image.

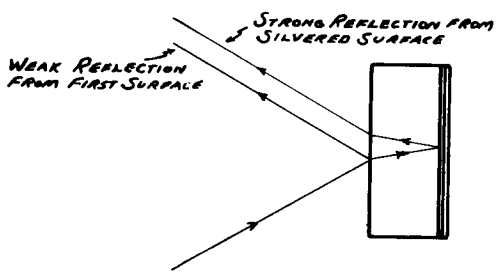


Fig. 45.

To get around this difficulty, we silver the front surface and all reflection takes place at that surface. Such mirrors are known as "first surface mirrors". The reflecting surface is quite fragile, easily scratched, etc., if no protective coating is put over it.

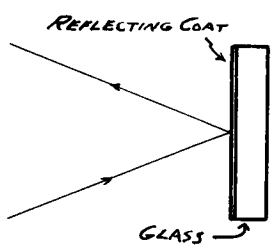


Fig. 46.

Prisms are also sometimes used as reflectors. This is possible because of a property of glass which allows refraction at any surface to occur only within very definite angles of incidence. For our purpose, we will discuss this only from the standpoint of a ray traveling through glass and reaching the second glass surface.

There is one angle of incidence for a ray of light striking the surface of a glass plate which is known as the **critical angle.** All rays striking the surface at an angle smaller than the critical angle will be refracted and emerge into the air. All rays striking the surface at an angle greater than the critical angle will be reflected back into the glass instead of refracted through that surface into the air. The ray following this critical angle will be refracted right along the surface of the glass plate. This reflection occurs without any silvering of the glass surface and is called total reflection.

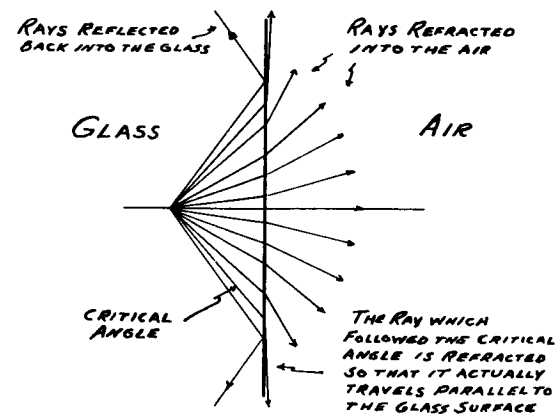


Fig. 47.

By a proper selection of angles between the surfaces of a prism, we can design very useful total reflecting prisms which are helpful in obtaining erect images from inverted ones and in changing direction without introducing chromatic aberration.

There are many types of total reflecting prisms for use in various types of instruments.

For some purposes, mirrors of spherical shape, either concave or convex, are used. A spherical concave mirror has a focal length and reflects parallel rays to a focus at a point in front of the mirror. A spherical convex mirror also has a definite focal length (negative in quantity) and diverges parallel rays. The focal point of a convex mirror is an imaginary focal point and lies behind the mirror.

REVIEW QUESTIONS CHAPTER TWO

LENSES AND PRISMS

1. Parallel rays of incident light are refracted by a biconvex lens and.

   ____1. Brought to a real focus

   ____2. Diverged

   ____3. Sent Back

2. Focal length of a lens may be altered by:

   ____1. Making the lens smaller

   ____2. Making the lens larger

   ____3. Altering the curvature of one or both surfaces

3. Focal length of a lens is the distance from the lens:

   ____1. To the circle of confusion

   ____2. To the point at which parallel incident rays are brought to a focus

   ____3. To the corner of the eye

4. A lens with a focal length of 1/2 meter has a power of:

   ____1. 2 Diopters

   ____2. 4 Diopters

   ____3. 1/2 Diopter

5. When the mechanical center of a lens is altered by edging, the optical center:

   ____1. Remains where it was

   ____2. Moves to a new place on the lens

   ____3. Disappears

6. Positive lenses are thicker at the:

   ____1. Center than at the edge

   ____2. Edge than at the center

   ____3. Nasal side than at the temporal side

7. Biconcave and plano convex lenses are:

   ____1. Both minus lenses

   ____2. Both plus lenses

   ____3. One minus and one plus lens

8. Plano-cylinder lenses have power in:

   ____1. All meridians

   ____2. All but one meridian

   ____3. No meridians at all

9. Sphero-cylinder lenses have:

   ____1. Equal power in all meridians

   ____2. Greatest power in one meridian

   ____3. No power in one meridian

10. Prism power is determined by:

    ____1. Size of the prism

    ____2. Color of the prism

    ____3. Amount prism turns light from its original course

11. Chromatic aberration is shown by:

    ____1. Focusing of different wavelengths at the same distance from the lens

    ____2. Focusing of same wavelengths at different distances from the lens

    ____3. Focusing of different wavelengths at different distances from the lens

12. An achromatic lens causes various wavelengths to be brought to a focus at:

    ____1. The same point

    ____2. Different points

    ____3. No point at all

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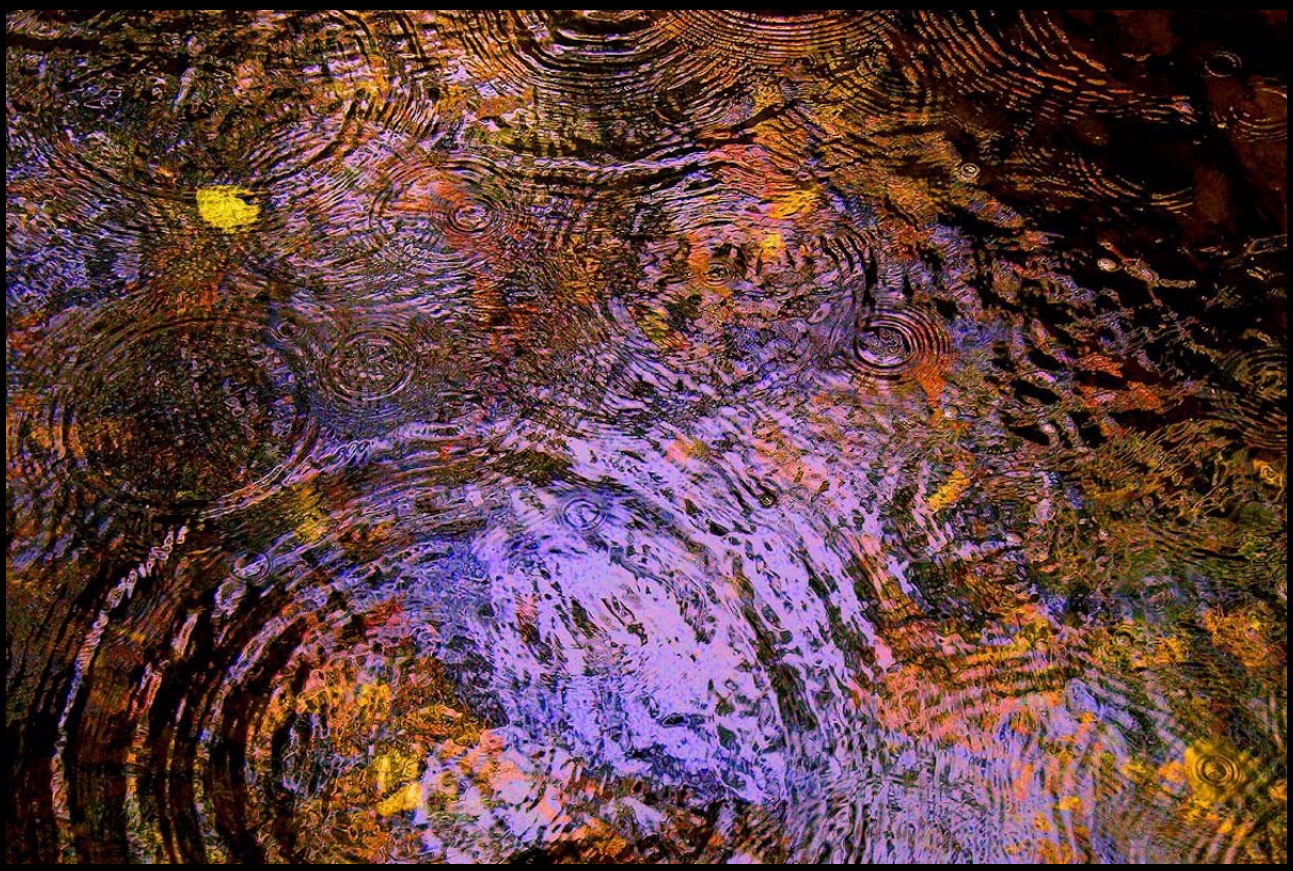
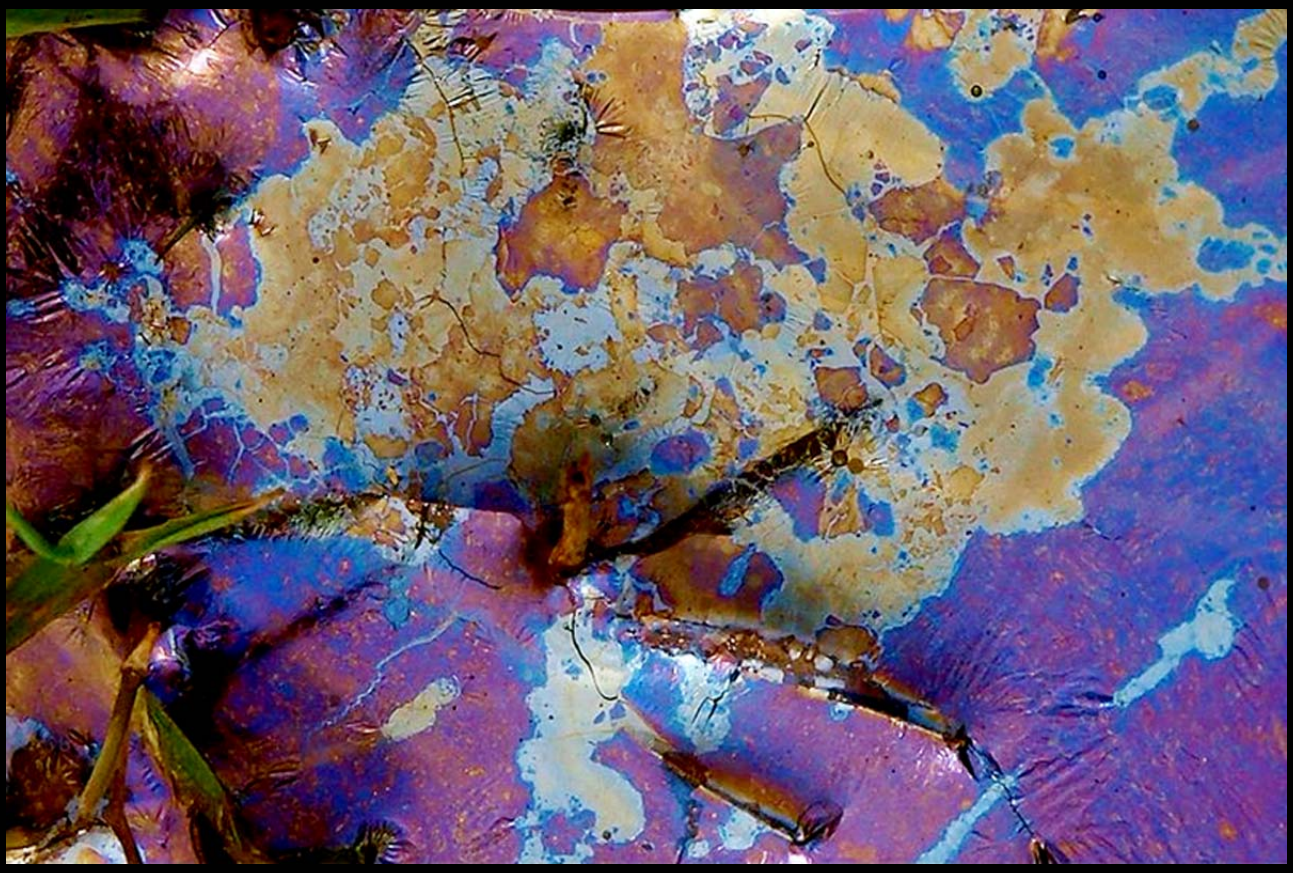


Interference of wavefronts caused by rain on pond – Image by Jeff Glover



Interference colors of oil slick on pond – Image by Jeff Glover