Geometric Optics

Paul Kryger

An investigation of the optical properties of light

I do set my bow in the cloud, and it shall be a token of a covenant between me and the earth

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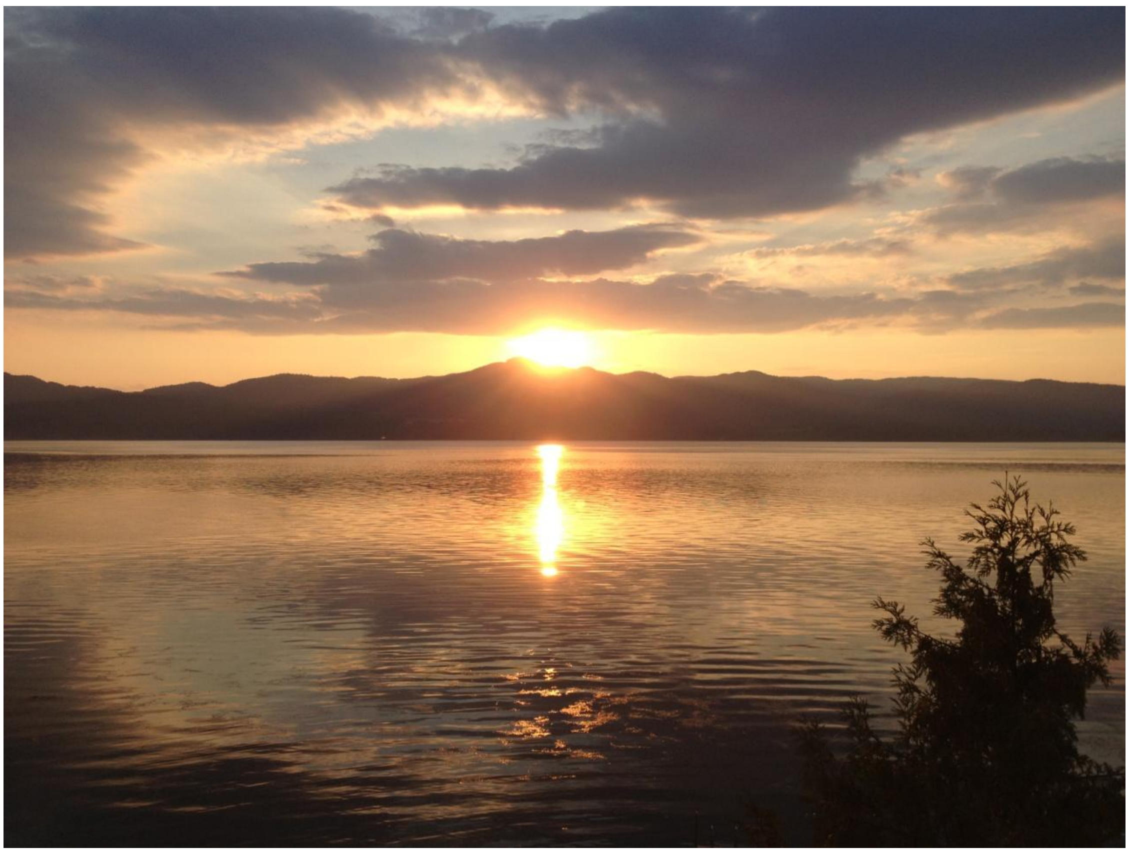


Sunset over Lake Champlain

To the Teacher

This unit contains four basic parts and should be used in its entirety. The first section, the Introduction introduces the properties of light and a history of the discoveries associated with light. The Introduction also includes many of the aspects of vision and the treatment of vision deficiencies such as Myopia and Hyperopia. The Introduction also includes the history of optical instruments, from early microscopes and telescopes to the development and construction of the Hubble Space Telescope (HST). It should be noted that the HST uses a reflecting mirror as its main light gathering component. This unit investigates devices that use the refractive properties of light.

Following the introduction is a section covering the six basic cases of images formed by converging lenses. This is an introduction to the hands-on investigation that follows in the next section.

Also included in this unit are three pages that the student will complete and submit at the end of the investigation process. It is suggested that the teacher determine his/her own grading criteria for evaluating the lesson.

Suggested time line for the unit:

Day 1: Assign the reading of the introduction. The teacher should distribute all pages except page 43, which contains the quiz. This will be distributed on Day 4.

Day 2: Assign each student the task of collecting the necessary material to perform the investigation. The lens, however, should be supplied by the teacher. All other supplies can be collected using the students resources. A “brainstorming” session may be included for students to share their ideas on the material to use for each of the items used in the

investigation. Also review the graphics pages, section two and also use the interactive software as an investigating tool to demonstrate the six cases described. This software can be displayed using a computer connected to a projector and can either be done while online, or the software can be downloaded and run independent of the Internet.

Day 3: Investigate the Internet links using a computer/projector and assign all links that were not completed during Day 3.

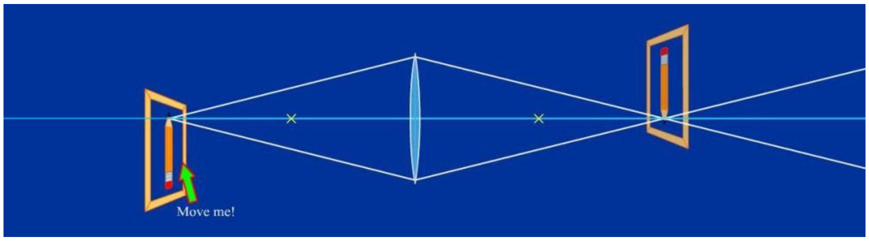
Day 4: Assign the quiz. This quiz may be given without the help of the Introduction, or it can be an "open book" quiz. Grade and discuss the quiz. Also take an inventory of the students' collected material. Have a discussion including suggestions on additional ideas of material to use for the necessary items.

Day 5: Assuming that all the students have obtained the necessary material, they should set up their apparatus in an appropriate location so as not to be disturbed by other students who may be using the classroom.

Day 6: Perform the investigation. Complete all six cases. Complete the calculations page, page 52, and enter the results in the Data Entry Form, page 53.

Geometric Optics

Introduction



Light can be studied in a variety of ways. Optics is only one of them. Many of the important concepts of optics can be understood using simple geometry. One of those concepts, which will be investigated here, is refraction and its use in lenses and reflection and its use in mirrors. Lenses have many uses, especially in binoculars, telescopes and microscopes. They also are beneficial for correcting, or rather compensating, for visual conditions called myopia, presbyopia, hyperopia, and **a**stigmatism.
We will also be discussing the wealth of optical instruments that utilize the properties of light, and the limitations of those instruments in terms of their effectiveness in producing useful results. At the conclusion of this lesson we will do a "hands on" investigation of the properties of simple lenses, and compare the results of the investigation with the expected mathematical outcome.

Light

In order to get a better understanding of optics, we first need to get an appreciation of God's first act of creation, the creation of light. He spoke, and it was so. ". . . And God said, 'Let there be light.'" This act, in itself, was nothing short of a miracle. Not only was this act of creation a miracle, but the wealth of beauty that resulted is mind boggling. Before we investigate the optical properties of light, it is, in my opinion, important to get a feel for the beauty of this phenomenon we call light.

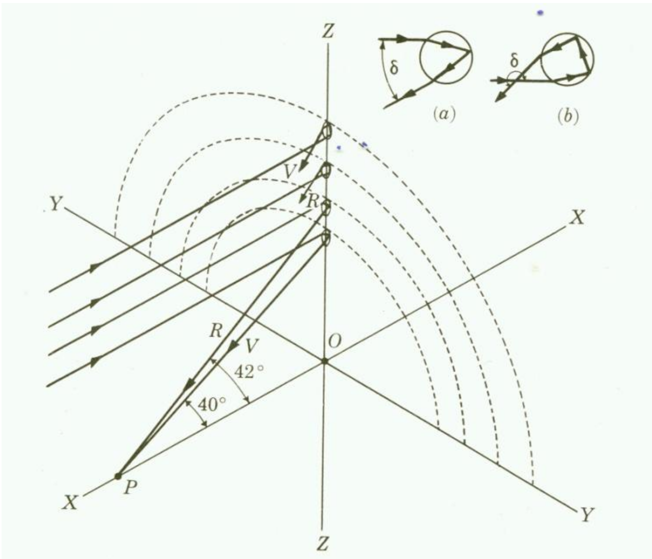
The nature of light

Until about the middle of the 17th century, it was generally believed that light consisted of a stream of corpuscles, emitted by light sources, such as the sun or a candle flame, and traveled outward from the source in straight lines. They could penetrate transparent materials and were reflected from the surfaces of opaque materials. When the corpuscles entered the eye, the sense of sight was stimulated. This was only a theory, and in order to support any theory, it must be shown to have the ability to account for known experimental facts with a minimum of hypotheses. This theory was an excellent candidate.

By the middle of the 17th century, while most scientists in the field of optics accepted the corpuscular theory, the idea had begun to develop that light might be a wave motion of some sort. Christian Huygens, in 1670, showed that the laws of reflection and refraction could be explained on the basis of a wave theory, as a result of a recently discovered phenomenon of double refraction. The argument against this theory was that if light were a wave, one should be able to see around corners. It was later discovered that light can, in fact, bend around corners, but was not easily observable due to the extremely short wave length. Without going into a lot of detail, one can appreciate the complexity of thee study of light, and also appreciate that the act of its creation "In the beginning . . ." was the first miracle that our loving God performed. And, He did it, I believe, just so that we can experience the beauty of the rest of His creation, visually.

An example of one of the most visually beautiful phenomena is the rainbow. Displayed below is a photograph of a rainbow as seen from the surface of the earth. Notice its apparent location, close to the ground.

No doubt, before the flood, people saw rainbows such as this. However, I am sure that the observers at that time had no idea of the mechanism behind the creation of this beautiful sight. Below is an illustration of the production of a rainbow, and the conditions necessary for observing it.



The mechanism causing the bending of light as it enters and exits the water droplets, (a) and (b), called refraction, will be discussed later.

Consider now an observer at the point P. The X-Y plane is horizontal and the sunlight is coming from the left parallel to the X-axis. All drops which lie on a circle subtending an angle of 42^o at point P and with center at O, will reflect red light strongly to P. All those on a circle subtending 40^o at P will reflect violet light strongly, while those occupying intermediate positions will reflect intermediate colors of the spectrum.

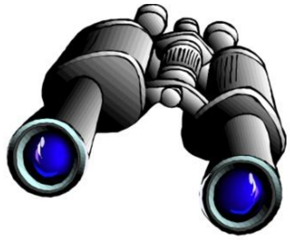
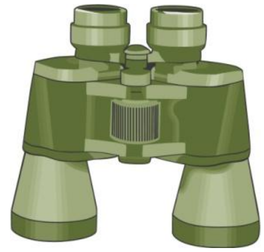
The point O, the center of the circular arc of the rainbow, may be considered the shadow of the point P on the Y-Z plane. As the sun rises above the horizon the point O moves down, and hence the increasing elevation of the sun a smaller and smaller part of the bow is visible. Evidently an observer at ground level cannot see the primary bow when the sun is more than 42^o above the horizon. If the observer is in an elevated position, however, the point O moves up and more and more of the bow may be seen. In fact, it is not uncommon for a complete circular rainbow to be seen from an airplane. This observation was obviously not possible during the time of the flood.

Now, let us consider the view of a rainbow in the sky, or "in the clouds." After the flood, God made a promise to all mankind that He would not destroy the earth by water. As a token of this covenant, we will look in the book of Genesis. *"And God spake unto Noah, and to his sons with him, saying, and I, behold, I establish my covenant with you, and with your seed after you; and with every living creature that is with you, of the fowl, of the cattle, and every beast of the earth with you; from all that go out of the ark, to every beast of the earth. And I will establish my covenant with you; neither shall all flesh be cut off any more by the waters of a flood; neither shall there any more be a flood to destroy the earth. And God said, This is the token of the covenant between me and you and every living creature that is*

with you, for perpetual generations; I do set my bow in the cloud, and it shall be a token of a covenant between me and the earth, And it shall come to pass, when I bring a cloud over the earth, that the bow shall be seen in the cloud; And I will remember my covenant, which is between me and you and every living creature of flesh; and the waters shall no more become a flood to destroy all flesh. And the bow shall be in the cloud; and I will look upon it, that I may remember the everlasting covenant between God and every living creature of all flesh that is upon the earth." Genesis 9:8 -16 KJV.

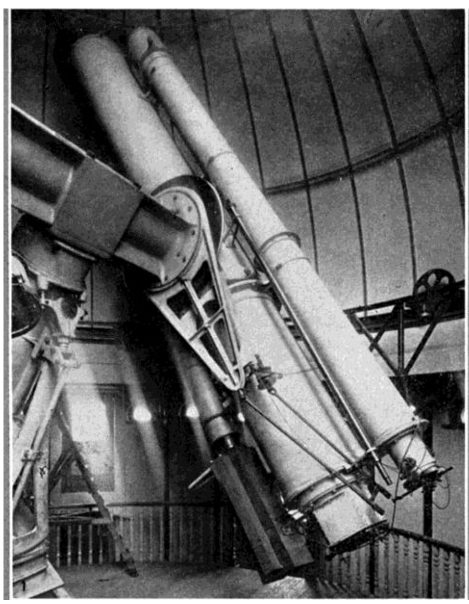
It is very likely that rainbows were observed before the flood, but it is believed by many biblical scholars that this was the first time a rainbow was seen "in the cloud", and that God used the post-flood environment to establish His covenant.

Optical Instruments

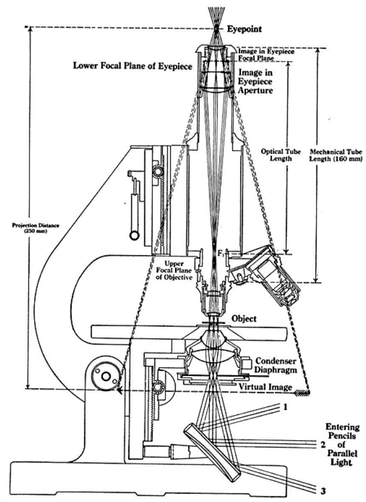



Binoculars

Binoculars are optical instruments used primarily for terrestrial observation. They provide the viewer with a magnified image of a distant object utilizing a compound system of lenses, in addition to incorporating a system of prisms.




Telescopes



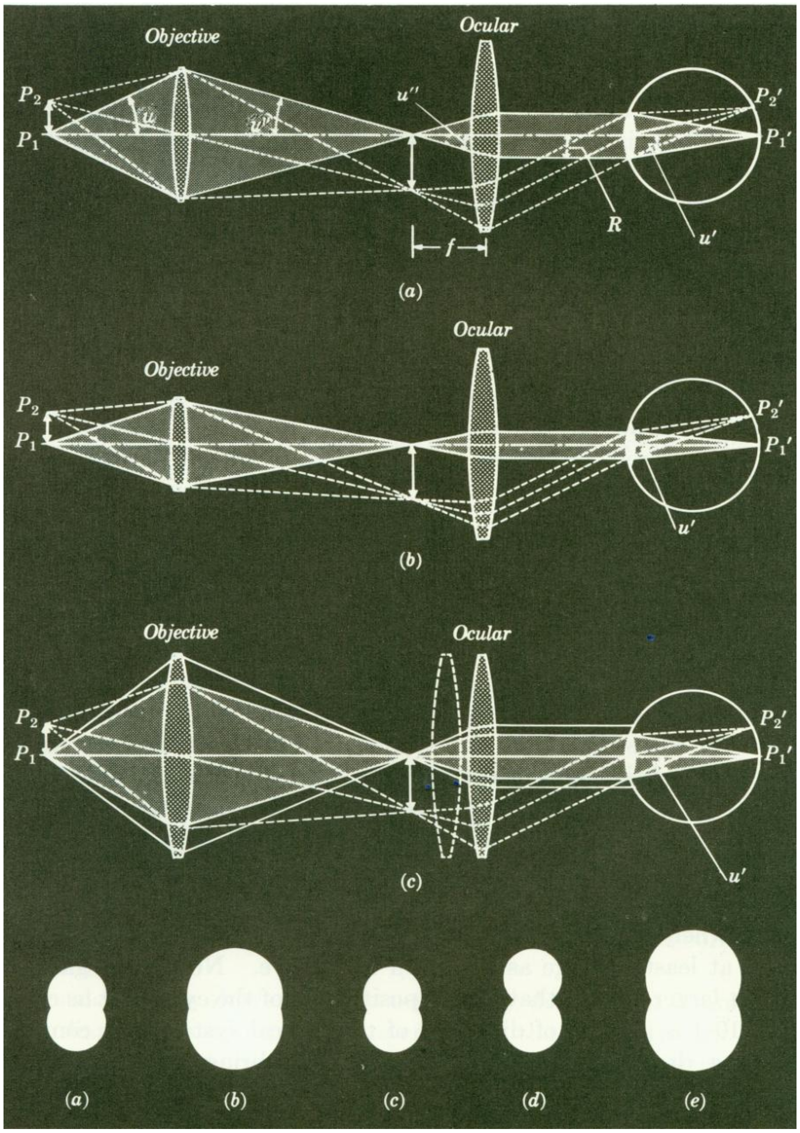
Microscopes

Telescopes and microscopes use only lenses to create a useful image of a distant or close object respectively. The primary function of a microscope (or telescope) is not to “magnify” an object, but to make it possible to observe finer detail in the object than with the unaided eye.

Limit of resolution of a microscope

Two points which are so close together that their diffraction disks overlap could be resolved if there were some way of making their diffraction disks smaller, and at the same time distinguishing these smaller disks. Below is a series of diagrams of the optical system of a compound microscope, drawn greatly out of proportion to bring out the features of interest. Without going into a lot of detail, one can see:

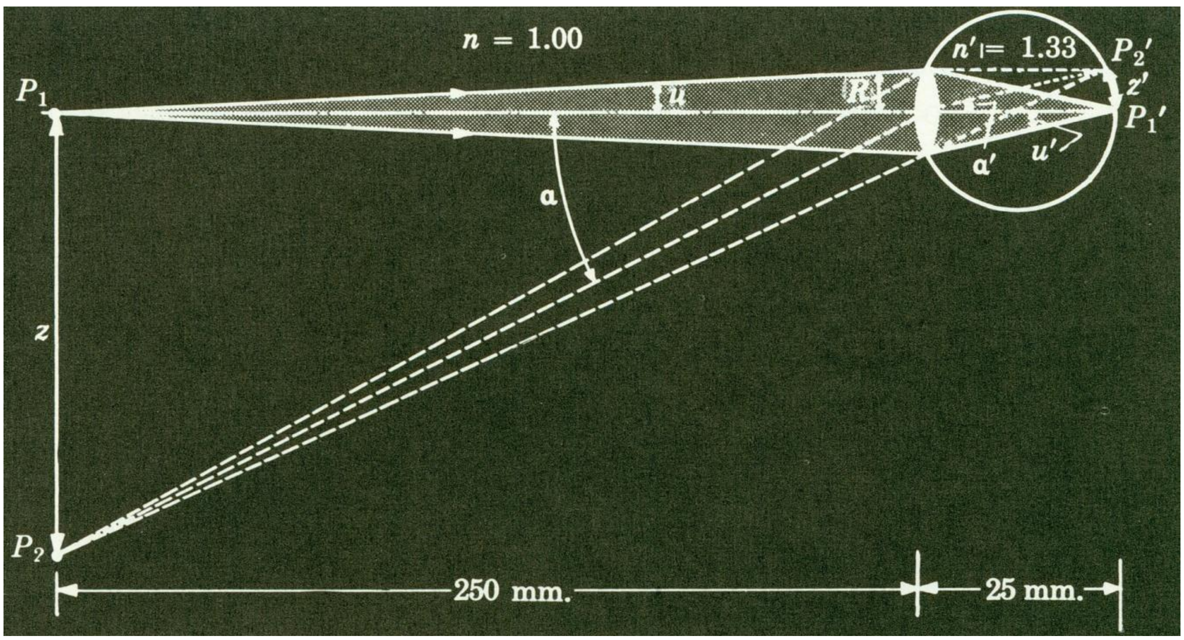
(a) Normal magnification; diameter of exit pupil same as pupil of eye.
(b) Diameter of exit pupil smaller than pupil of eye.
(c) Diameter of exit pupil greater than pupil of eye.



Limit of resolution of the human eye

Even though God's creation of man was His crowning glory, there are observable limits to the resolution of the human eye. This is not to say that God created an imperfect eye. To the contrary. If our human eye could detect the complete electromagnetic spectrum of which visible light is only a small part, we our visual sense would be bombarded with radiation that would detract from the pleasure of seeing things whose radiation fits within the visible spectrum. Other creatures, mostly insects have the capability of sensing radiation well into the ultra violet portion of the spectrum. God knew what He was doing when he limited us to what we refer to as the visible spectrum, red to violet. After all, that is where all of the visual beauty is.

The graphic below is a schematic diagram of the human eye, not drawn to a uniform scale, and with transverse dimensions and angles greatly exaggerated. Points P_1 and P_2 at the ends of an arrow of length *z*, represent two just resolvable object points at the minimum distance of distinct vision, 250 mm. The mathematics used to explain the determination of the limit of resolution is quite rigorous, and we will not deal with the details, but the results are consistent with the Rayleigh criterion (see web link), which is the linear separation of two point objects just resolvable at a distance of 250 mm. This separation, about three ten-thousandths of an inch, is in good agreement with the actual limit of resolution of the normal human eye.



I would like to emphasize at this point that this described limit does not, by any means, suggest the the human eye is not perfect. To the contrary. Beauty is in the eye of the beholder, and the properties of the human eye allow us to behold that beauty, without the confusion of unnecessary detail. The human body is fearfully and wonderfully made.

Presbyopia

Presbyopia is a condition where, with age, the eye exhibits a progressively diminished ability to focus on near objects. Presbyopia's exact mechanisms are not known with certainty. The research evidence most strongly supports a loss of elasticity of the crystalline lens, although changes in the lens' curvature from continual growth and loss of power of the ciliary muscles, the muscles that bend and straighten the lens, has also been postulated as its cause. There are many options for people with presbyopia, including contact lenses. Recent advances in technology allow people who show early signs of presbyopia to continue wearing contact lenses, instead of having to switch to bifocals, or reading glasses.

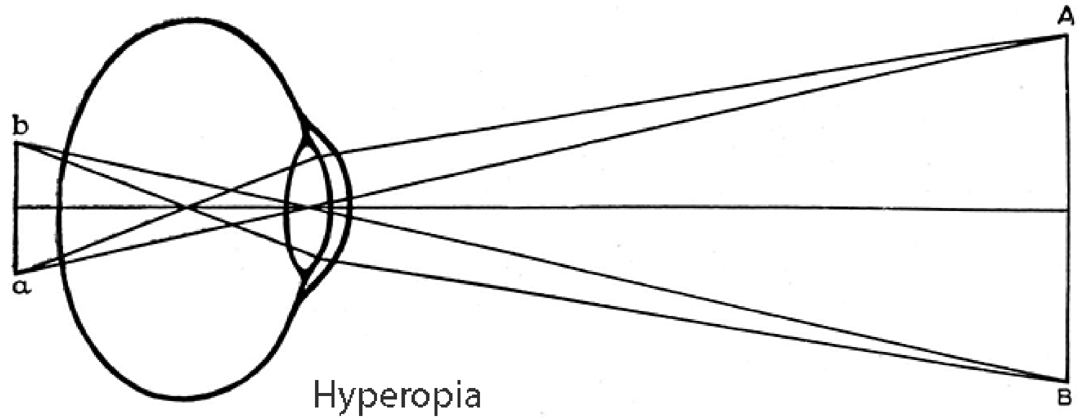
Myopia

Myopia (nearsightedness) is a visual defect in which distant objects appear blurred because their images are focused in front of the retina rather than on it. This condition is also called *short sight*.

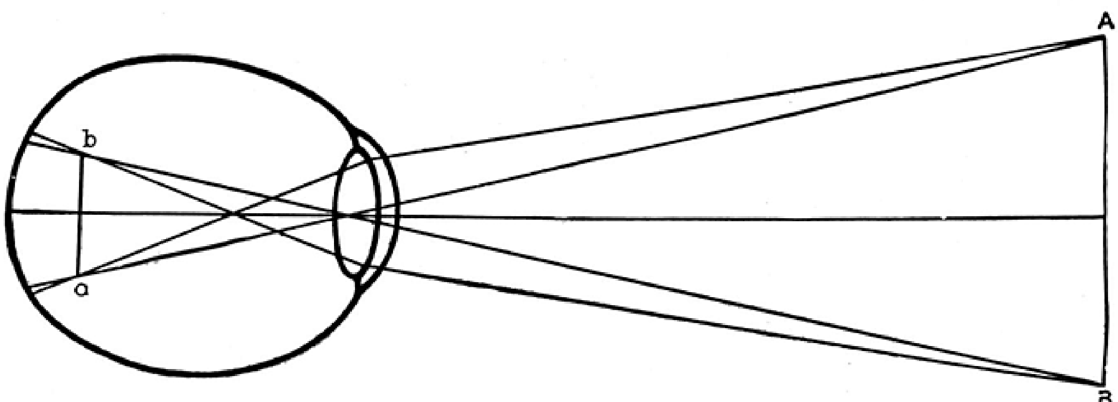
Hyperopia

Hyperopia (farsightedness) is an abnormal condition of the eye in which vision is better for distant objects than for near objects. It results from the eyeball being too short from front to back, causing images to be focused behind the retina. Also called *farsightedness* and *hypermetropia*. A convex lens, the type we will be investigating in this unit is the type of lens used to treat hyperopia.

A simple pair of over-the-counter reading glasses can be a useful remedy for early stage hyperopia.



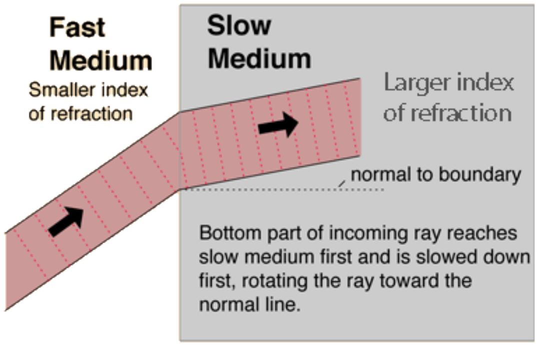
Hyperopia

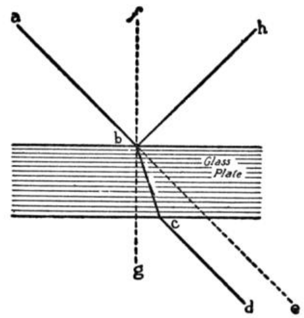


Myopia

In this unit we will be investigating uses of lenses and how those uses can be understood as lenses are used to form images, both real and virtual. We will also use the basic lens equation to verify the geometry of light convergence and divergence. After the investigation we will look at a number of web links that discuss some of the applications of the properties of lenses.

Lenses work the way they do because as light passes from air into the lens, usually made of glass, its speed changes. This process is called refraction. The figure below shows the mechanism of refraction.

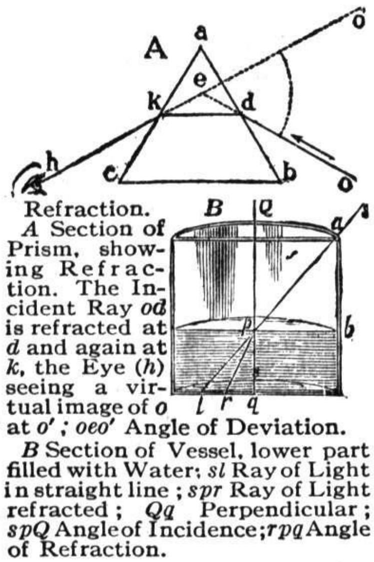




In optics the **refractive index** or **index of refraction** *n* of a substance (optical medium) is a dimensionless number that describes how light, or any other radiation propagates through that medium. It is defined as

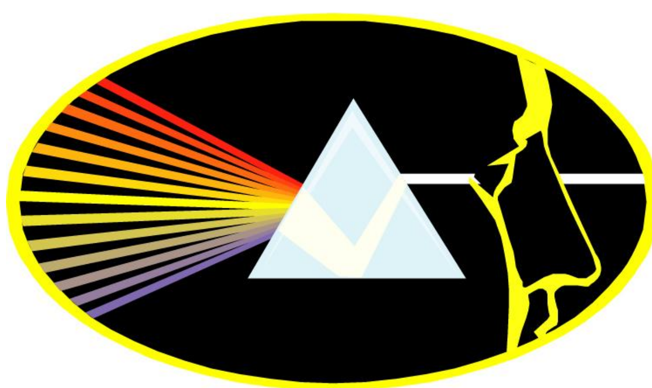
$$n = \frac{c}{v}$$

where *c* is the speed of light in vacuum and *v* is the speed of light in the substance. For example, the refractive index of water is 1.33, meaning that light travels 1.33 times slower in water than it does in a vacuum. Refraction is not noticeable when light passes through plane glass where the two surfaces are parallel. But as light passes through a prism, the emerging light rays are traveling in a different direction.



Optics by Francis W. Sears, MIT

You should also notice that different colors of light are refracted to different degrees as shown below.



The same is true for light passing through the edge of the lens. It is bent both on entering the glass and on exiting. This changes the direction of the emerging light ray, and causes the light rays to converge. A camera and the human eye use the refractive property of light to form an image, as illustrated in the diagram on the next page.

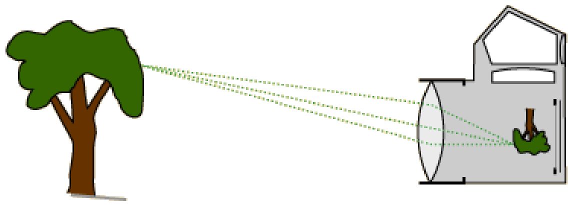


Image formed by a camera

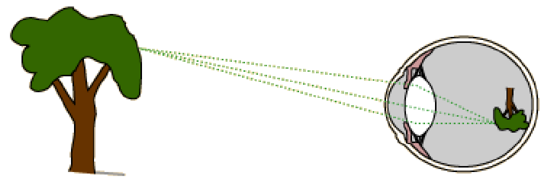
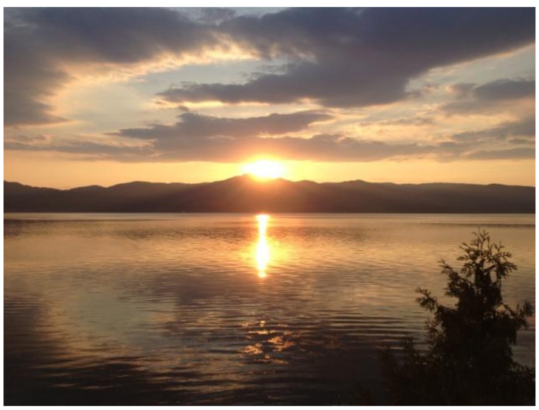


Image formed by the eye



As an example of the beauty all around us made visible by the properties of light, here is a photograph of one of the millions of sunsets displayed since the creation of the universe.

Total Internal Reflection and Critical Angle

In order to understand the many aspects of refraction in terms of the angles of the light rays, we need to convert the equation,

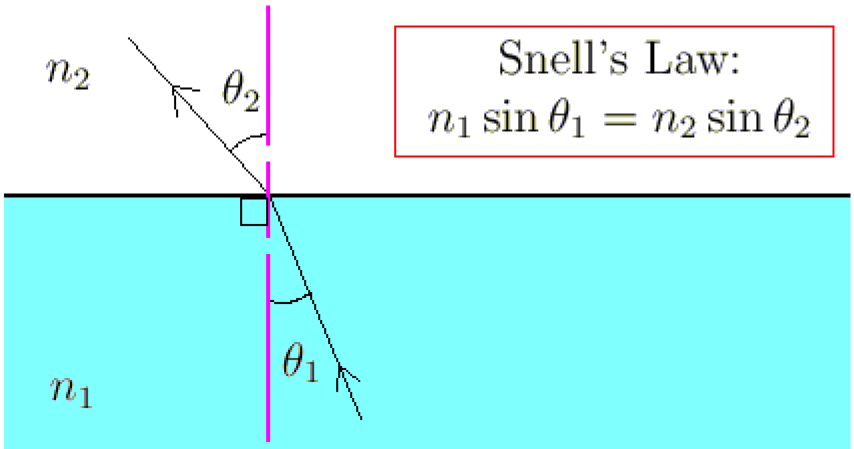
$$n = \frac{c}{v},$$

to an equivalent equation including the angular geometry. This will be done by using Snell's Law of Refraction. When light travels from one medium to another, it generally bends, or *refracts*. The law of refraction gives us a way of predicting the amount of bend. The law of refraction is also known as Snell's Law, named for Willobrord Snell, who discovered the law in 1621.

Refraction involves the angles that the incident ray and the refracted ray make with the normal to the surface at the point of refraction. Refraction depends on the media through which the light rays are

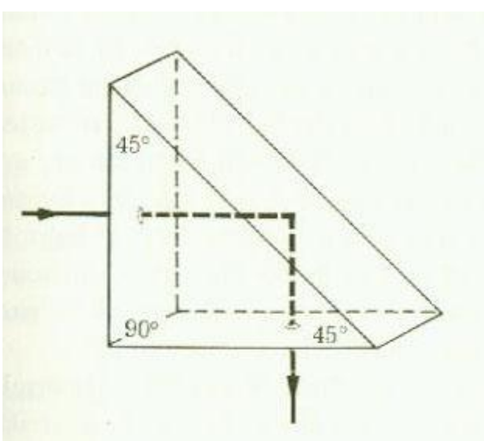
travelling. This dependence is made explicit in Snell's Law via *refractive indices*, numbers which are constant for any given medium.

Snell's Law is given in the following diagram.



Optics by Francis W. Sears, MIT

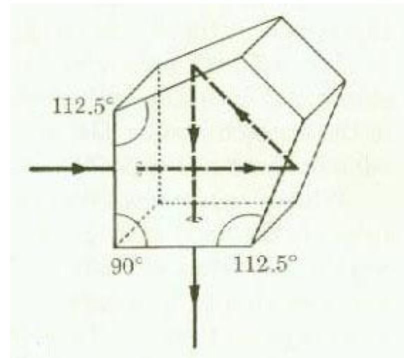
An interesting case of refraction can occur when light travels from a medium of larger to smaller index. The light ray can actually bend so much that it never goes beyond the boundary between the two media. This case of refraction is called *total internal reflection.*



At the left is an example of a practical use of total internal reflection. It is useful in periscopes and binoculars, where it is desirable to have the light rays bend at right angles.

Optics by Francis W. Sears, MIT

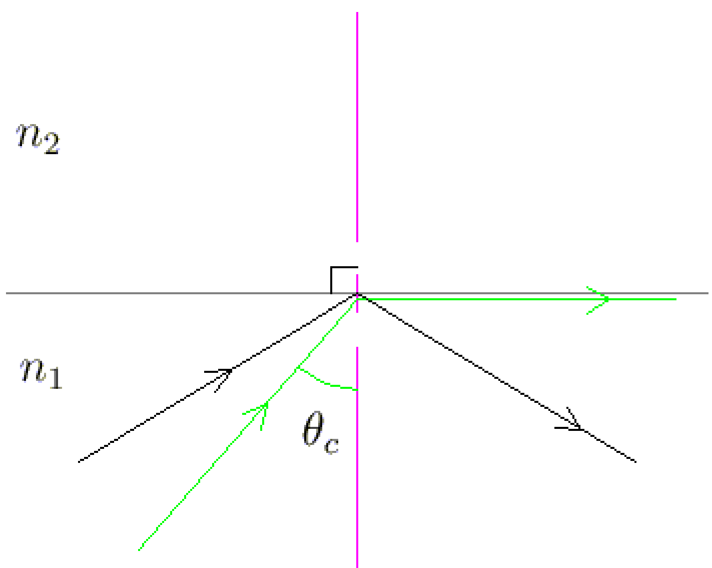
At the right is another use for total internal reflection. This application is used in the viewfinder of a single lens reflex camera, where the image is projected on the film or digital medium.



Optics by Francis W. Sears, MIT

It is important to note that, since the index of refraction of ordinary glass is around 1.4, and using Snell's law, the critical angle of glass is determined to be:

$1/1.4 = \sin(a_c)$. $1/1.4 = .7142$, which makes $a_c > 45^o$. So, as long as the incident angle inside the glass is greater than 45^o it will be totally reflected.



In the above diagram, imagine that we are trying to send a beam of light from a region with refractive index n_1 to a region with index n_2 and that $n_2 < n_1$. If x_1, x_2 are the angles made with the normal for the incident and refracted rays, then Snell's Law yields

$$x_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin x_1\right)$$

Since $n_2 < n_1$, we could potentially get an argument for the arcsin function that is greater than 1; an invalid value. The critical angle is the first angle for which the incident ray does not leave the first region, namely when the "refracted" angle is 90^o. Any incident angle greater than the critical angle will consequently be reflected from the boundary instead of being refracted. For concreteness, pretend that we are shining light from water to air. To find the critical angle, we set $x_2 = 90^o$. Using Snell's Law, and since the index of refraction for water is 1.33, we see that any incident angle greater than about 48^o will not leave the water. Now, since the paths of the light rays are reversible, light can be treated as going in either direction. So, imagine a fish below the surface of a lake or pond, looking up toward the surface. Unless the position of his or her eye makes an angle smaller than the critical angle he or she will not see above the surface, but simply a reflection of the bottom of the lake or pond.

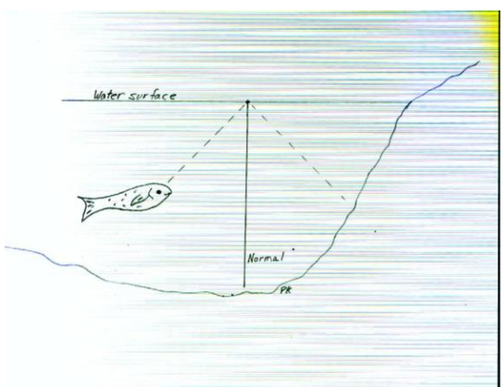


Photo from Wikipedia, the free encyclopedia

Total internal reflection can be observed while swimming, when one opens one's eyes just under the water's surface. If the water is calm, its surface appears mirror-like.

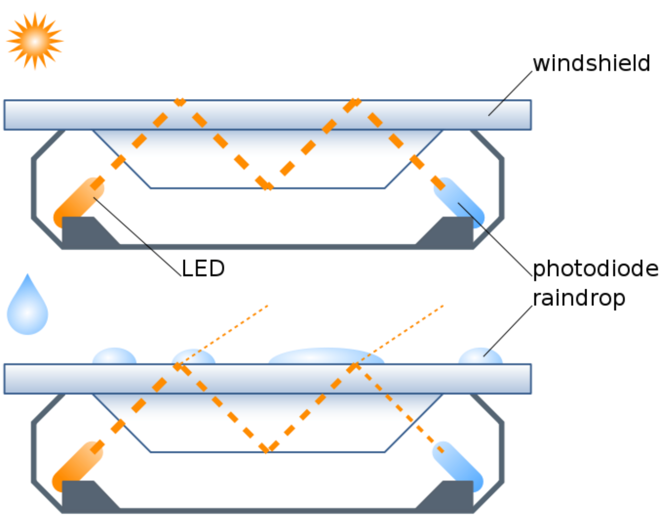
One can demonstrate total internal reflection by filling a sink or bath with water, taking a glass tumbler, and placing it upside-down over the plug hole (with the tumbler completely filled with water). While water remains both in the upturned tumbler and in the sink surrounding it, the plug hole and plug are

visible since the angle of refraction between glass and water is not greater than the critical angle. If the drain is opened and the tumbler is kept in position over the hole, the water in the tumbler will drain out, leaving the glass filled with air. This, then acts as if the drain plug has vanished. Viewing this from above, the tumbler now appears mirrored because light reflects off the air/glass interface.

Another common example of total internal reflection is a critically cut diamond. Since diamond has a ver high index of refraction, 2.42, this gives it a high brilliance and sparkle.

In 1958, the Cadillac Motor Car Division of General Motors experimented with a water-sensitive switch that triggered various electric motors to close the convertible top and raise the open windows of a specially-built Eldorado Biarritz model, in case of rain. The first such device appears to have been used for that same purpose in a concept vehicle designated LeSabre and built around 1950–51. For Model Year 1996, Cadillac once again equipped cars with an automatic rain sensor; this time to automatically trigger the windshield wipers and adjust their speed to conditions as necessary.

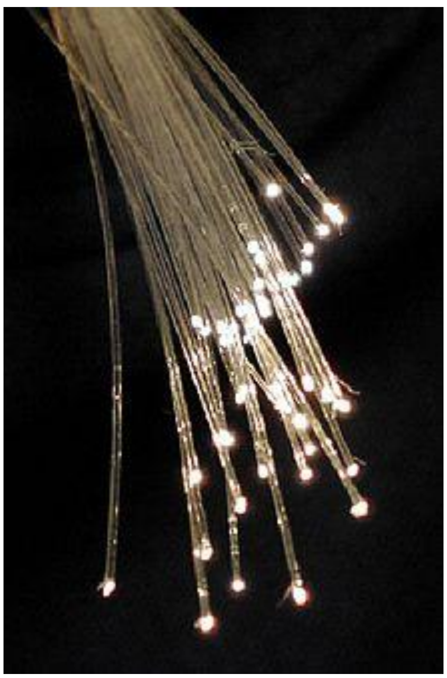
The most common modern rain sensors are based on the principle of total internal reflection: an infrared light is beamed at a 45^o angle (45^o being greater than the critical angle for glass) the windshield from the interior — if the glass is wet, less light makes it back to the sensor, and the wipers turn on. Most vehicles with this feature have an "AUTO" position on the stalk.



In this graphic of a rain sensor you can see that when raindrops are present on the windshield the photodiode will not receive light, thus keeping the circuit open.

Cadillac Motor Car Division of General Motors

Total internal reflection is the operating principle of optical fibers which are used in endoscopes and telecommunications. An **optical fiber**, pictured below, is a flexible, transparent fiber made of high quality extruded glass (silica)) or plastic, slightly thicker than a human hair. It can function as a waveguide or "light pipe" to transmit light between the two ends of the fiber. The field of applied science and engineering concerned with the design and application of optical fibers is known as **fiber optics**.



Stealth Fiber Crew installing a 432-count fiber cable underneath the streets of Midtown Manhattan, New York City

Photos from Wikipedia, the free encyclopedia Author: BigRiz

Guiding of light by refraction, the principle that makes fiber optics possible, was first demonstrated by Daniel Colladon and Jacques Babinet in Paris in the early 1840s. John Tyndall included a demonstration of it in his public lectures in London, 12 years later. Tyndall also wrote about the property of total internal reflection in an introductory book about the nature of light in 1870: "When the light passes from air into water, the refracted ray is bent *towards* the perpendicular... When the ray passes from water to air it is bent *from* the perpendicular... If the angle which the ray in water encloses with the perpendicular to the surface be greater than 48 degrees, the ray will not quit the water at all: it will be *totally reflected* at the surface.... The angle which marks the limit where total reflection begins is called the limiting

angle of the medium. For water this angle is 48°27', for flint glass it is 38°41', while for diamond it is 23°42'." Unpigmented human hairs have also been shown to act as an optical fiber.

Mirages

Another interesting phenomenon resulting from refraction of light is the Mirage. A **mirage** is a naturally occurring optical phenomenon in which light rays are bent to produce a displaced image of distant objects or the sky. The word comes to English via the French *mirage*, from the Latin *mirari*, meaning "to look at, to wonder at". This is the same root as for “mirror” and "to admire".

In contrast to a hallucination, a mirage is a real optical phenomenon that can be captured on camera, since light rays actually are refracted to form the false image at the observer's location. What the image appears to represent, however, is determined by the interpretive faculties of the human mind. For example, inferior images on land are very easily mistaken for the reflections from a small body of water.

Mirages can be categorized as "inferior" (meaning lower), "superior" (meaning higher) and “Fata Morgana”, one kind of superior mirage consisting of a series of unusually elaborate, vertically stacked images, which form one rapidly changing mirage.

Various kinds of mirages in one location taken over the course of six minutes, not shown in temporal order. In the photo at the left, the uppermost inset frame shows an inferior mirage of the Farallon Islands. The second inset frame is the Farallon Islands with a green flash on the left-hand side. The two lower frames and the main frame all show superior mirages of the Farallon Islands. In these three frames, the superior mirage evolves from a 3-image mirage (an inverted image between two erect ones) to a 5-image mirage, and then back to a 2-image mirage. Such a display is consistent with a Fata Morgana. All frames but the upper one were photographed from about 50–70 feet above sea level. The upper frame was photographed from sea level.

Since cold air is denser than warm air it has a greater refractive index. As light passes from colder air across a sharp boundary to significantly warmer air, the light rays bend away from the direction of the temperature gradient. When light rays pass from hotter to cooler, they bend toward the direction of the gradient. If the air near the ground is warmer than that higher up, the light ray bends in a concave, upward trajectory.

Once the rays reach the viewer's eye, the visual cortex interprets it as if it traces back along a perfectly straight "line of sight". However, this line is at a tangent to the path the ray takes at the point it reaches the eye. The result is that an "inferior image" of the sky above appears on the ground. The viewer may incorrectly interpret this sight as water that is reflecting the sky, which is, to the brain, a more reasonable and common occurrence.

In the case where the air near the ground is cooler than that higher up, the light rays curve downward, producing a "superior image".

The "resting" state of the Earth's atmosphere has a vertical gradient of about -1° Celsius per 100 meters of altitude. (The value is negative because it gets colder as altitude increases.) For a mirage to happen, the temperature gradient has to be much greater than that. According to Minnaert, the magnitude of the gradient needs to be at least 2°C per meter, and the mirage does not get strong until the magnitude reaches 4° or 5°C per meter. These conditions do occur with strong heating at ground level, for example when the sun has been shining on sand or asphalt, commonly generating an inferior image.

Inferior mirage

For exhausted travelers in the desert, an inferior mirage may appear to be a lake of water in the distance. An inferior mirage is called "inferior" because the mirage is located under the real object. The real object in an inferior mirage is the (blue) sky or any distant (therefore bluish) object in that same direction. The mirage causes the observer to see a bright and bluish patch on the ground in the distance.

An inferior mirage on the Mojave Desert in spring.

From Wikipedia, the free encyclopedia

Light rays coming from a particular distant object all travel through nearly the same air layers and all are bent over about the same amount. Therefore, rays coming from the top of the object will arrive lower than those from the bottom. The image usually is upside down, enhancing the illusion that the sky image seen in the distance is really a water or oil puddle acting as a mirror.

Inferior images are not stable. Hot air rises, and cooler air (being more dense) descends, so the layers will mix, giving rise to turbulence. The image will be distorted accordingly. It may be vibrating; it may be vertically extended (towering) or horizontally extended (stooping). If there are several temperature layers, several mirages may mix, perhaps causing double images. In any case, mirages are usually not larger than about half a degree high (same apparent size as the sun and moon) and from objects only a few kilometers away.

Superior mirage

A superior mirage occurs when the air below the line of sight is colder than the air above it. This unusual arrangement is called a temperature, since warm air above cold air is the opposite of the normal temperature gradient of the atmosphere. Passing through the temperature inversion, the light rays are bent down, and so the image appears above the true object, hence the name *superior*. Superior mirages are in general less common than inferior mirages, but, when they do occur, they tend to be more stable, as cold air has no tendency to move up and warm air has no tendency to move down.

Superior mirages are quite common in polar regions, especially over large sheets of ice that have a uniform low temperature. Superior mirages also occur at more moderate latitudes, although in those

cases they are weaker and tend to be less smooth and stable. For example, a distant shoreline may appear to *tower* and look higher (and, thus, perhaps closer) than it really is. Because of the turbulence, there appear to be dancing spikes and towers. This type of mirage is also called the Fata Morgana or *hafgerdingar* in the Icelandic Language.

A superior mirage can be right-side up or upside down, depending on the distance of the true object and the temperature gradient. Often the image appears as a distorted mixture of up and down parts.

A photo of a Superior mirage taken at San Francisco.

From Wikipedia, the free encyclopedia

Superior mirages can have a striking effect due to the Earth's curvature. Were the Earth flat, light rays that bend down would soon hit the ground and only nearby objects would be affected. Since Earth is round, if their downward bending curve is about the same as the curvature of the Earth, light rays can travel large distances, perhaps from beyond the horizon. This was observed and documented for the first time in 1596, when a ship under the command of Willem Barents in search of the Northeast passage became stuck in the ice at Nova Zemlya. The crew was forced to endure the polar winter there. They saw their midwinter night come to an end with the rise of a distorted Sun about two weeks earlier than expected. It was not until the 20th century that science could explain the reason: The real Sun had still been below the horizon, but its light rays followed the curvature of the Earth. This effect is often called a Novaya Zemlya mirage. For every 111.12 kilometers (69.05 mi) the light rays can travel parallel to the Earth's surface, the Sun will appear 1° higher on the horizon. The inversion layer must have just the right temperature gradient over the whole distance to make this possible.

In the same way, ships that are in reality so far away that they should not be visible above the geometric horizon may appear on the horizon or even above the horizon as superior mirages. This may explain some stories about flying ships or coastal cities in the sky, as described by some polar explorers. These are examples of so-called Arctic mirages, or *hillingar* in Icelandic.

If the vertical temperature gradient is +12.9°C per 100 meters (where the positive sign means temperature gets hotter as one goes higher) then horizontal light rays will just follow the curvature of the

Earth, and the horizon will appear flat. If the gradient is less (as it almost always is) the rays are not bent enough and get lost in space, which is the normal situation of a spherical, convex "horizon".

In some situations, distant objects can get elevated or lowered, stretched or shortened with no mirage involved.

Fata Morgana

A Fata Morgana, the name of which coming from the Italian translation of Morgan le Fay, the fairy shapeshifting half-sister of King Arthur, is a very complex superior mirage. It appears with alternations of compressed and stretched zones, erect images, and inverted images. A Fata Morgana is also a fast-changing mirage.

Fata Morgana mirages are most common in polar regions, especially over large sheets of ice with a uniform low temperature, but they can be observed almost anywhere. While in polar regions, a Fata Morgana may be observed on cold days and in desert areas; and, over oceans and lakes, a Fata Morgana may be observed on hot days. For a Fata Morgana, Temperature inversion has to be strong enough that light rays' curvatures within the inversion are stronger than the curvature of the Earth. This fact has yet to be verified experimentally.

Sequence of a Fata Morgana of the Farallon Islands as seen from San Francisco

From Wikipedia, the free encyclopedia

The rays will bend and create arcs. An observer needs to be within an atmospheric duct to be able to see a Fata Morgana. Fata Morgana mirages may be observed from any altitude within the Earth's atmosphere, including from mountaintops or airplanes.

A Fata Morgana can go from superior to inferior mirage and back within a few seconds, depending on the constantly changing conditions of the atmosphere. Sixteen frames of the mirage of the Farallon Islands, which cannot be seen from sea level at all under normal conditions because they are located below the horizon, were photographed on the same day. The first fourteen frames have elements of a Fata Morgana display—alternations of compressed and stretched zones. The last two frames were photographed a few hours later around sunset. The air was cooler while the ocean was probably a little bit warmer, which made temperature inversion lower. The mirage was still present, but it was not as complex as it had been a few hours before sunset, and it corresponded no longer to a Fata Morgana but rather to a superior mirage display.

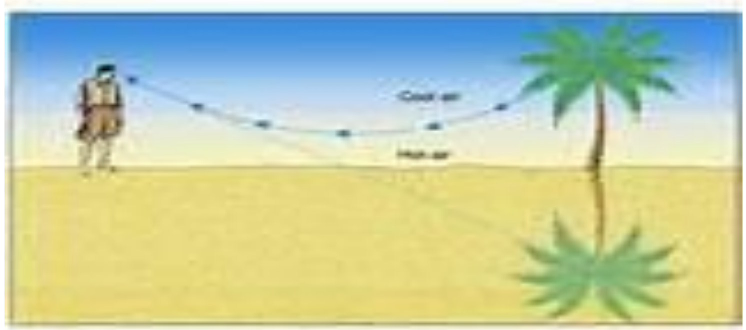
Distortions of image and bending of light can produce spectacular effects. In his book *Pursuit: The Chase and Sinking of the "Bismarck"*, the author Ludovic Kennedy describes an incident that allegedly took place below the Denmark Strait during 1941, following the sinking of the *Hood*. The *Bismarck*, while pursued by the British cruisers *Norfolk* and *Suffolk*, passed out of sight into a sea mist. Within a matter of seconds, the ship re-appeared steaming toward the British ships at high speed. In alarm the cruisers separated, anticipating an imminent attack, and observers from both ships watched in astonishment as the German battleship fluttered, grew indistinct and faded away. Radar watch during these events indicated that the *Bismarck* had in fact made no changes of course.

An artificial mirage, using sugar solutions to simulate the inversion layers. A cat is seen looking through a glass, which has three layers of solution, with decreasing index of refraction from bottom to top. The cat appears in multiple images. This simulates an atmosphere with two inversion layers.

From Wikipedia, the free encyclopedia

If this investigation is being done during an appropriate season, it would be beneficial to take the class to a location where a mirage can be observed and photographed. Mirages occur on sunny days. The role of

the sun is to heat the roadway to high temperatures. This heated roadway in turn heats the surrounding air, keeping the air just above the roadway at higher temperatures than that day's average air temperature. Hot air tends to be less optically dense than cooler air. As such, a non-uniform medium has been created by the heating of the roadway and the air just above it. While light will travel in a straight line through a uniform medium, it will refract when traveling through a non-uniform medium. If an observer looks down at the ground at a very low angle (that is, at a position nearly one hundred yards away), light from objects above the ground will follow a curved path to the observer's eye as shown in the diagram below.



Light that is traveling downward into this less optically dense air begins to speed up. Though there isn't a distinct boundary between two media, there is a change in speed of a light wave. As expected, a change in speed is accompanied by a change in direction, a result of Snell's Law (page 17). If there were a distinct boundary between two media, then there would be a bending of this light ray away from the normal. For this light ray to bend away from the *normal* (towards the *boundary*), the ray would begin to bend more parallel to the roadway and then bend upwards towards the cooler air. As such, a person in a car sighting downward at the roadway will see an object that appears to be located above the roadway.

This concludes a brief introduction to the refractive properties of light, optics, and optical instruments, in order to provide an appreciation for the workings of simple the simple lens. This unit includes an activity, in the form of an investigation, which shows the results of light forming an image of an object. The activity is best performed by no more than two students. Concave lenses will not be addressed in this unit since they can only form virtual images. Virtual images cannot be projected on a screen. (See CASE 6 on page 38) Even though the recently developed Hubble Telescope uses reflection rather than refraction as its primary element, it might be appropriate to discuss it at this point.

Hubble Space Telescope

In 1962, the National Academy of Sciences recommended the construction of a large optical telescope, more revolutionary than any of the earlier telescopes. However, this one would be the first telescope placed into orbit to capture visible light waves. Astronomers explained to all potential sponsors of the project that the telescope would be launched into orbit a few hundred miles above the earth's polluted and distorting atmosphere. It would have a primary mirror one-half that of Palomar's yet capable of producing photographs ten times sharper. The project was delayed many years by congressional debate and then by the 1986 explosion of the *Challenger* space shuttle. The Hubble Space Telescope (HST) blasted into orbit in 1990 and immediately became the world's most publicized and most talked about telescope. The HST is named to honor the preeminent astronomer Edwin Hubble

Escaping Earth's atmosphere gives an orbital telescope three distinct advantages over earth-based instruments. First, an orbital telescope does not suffer from the loss of light coming from outer space that is filtered out by the gases, moisture, and dust swirling in the earth's atmosphere. Ironically, these are the properties of our atmosphere that produce such beautiful sunsets, as described earlier. Second, it is not affected by distortions created by rising heat from the earth's surface. And third, it only collects light produced by celestial objects and not from the electric lights of metropolitan centers that mix with and degrade light from space. According to astronomers Daniel Fisher and Hilmar Duerbeck in their book *Hubble: A New Window to the Universe* , "Large telescopes on Earth can get nowhere close to the limit of theoretical resolution Only a telescope in space with comparable dimensions and optics of sufficient quality could deliver stellar images of a few hundredths of an arcsecond, and it should do so not only for visible light, but also for ultraviolet and near-infrared part of the spectrum. " (Page 26).

To get a feel for the magnitude of an arcsecond;

1 degree = 1° = 1/360 of a circle
1 arcminute = 1' = 1/60 of a degree
1 arcsecond = 1" = 1/60 of an arcminute = 1/3600 of a degree
This is roughly equal to the angle subtended by a dime at a distance of 4 km.

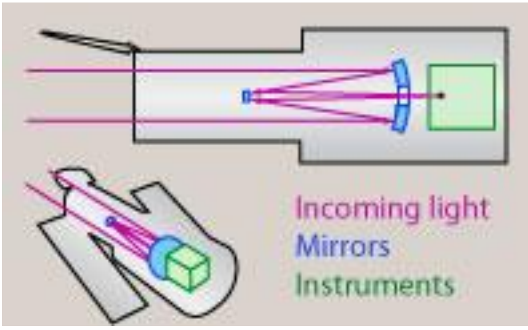
American astronomers outlined five principal objectives for the HST:

1. Explore the Solar System:
2. Measure the age and size of the universe:
3. Search for our cosmic roots:
4. Chart the evolution of the universe, and
5. Unlock the mysteries of galaxies, stars, planets, and life itself.

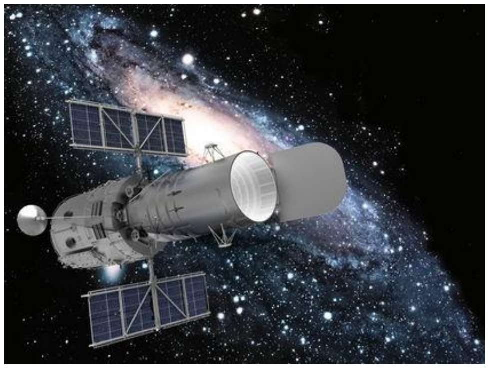
Of course, we, as Seventh-day Adventists know the answer to objective number three, and the mystery of life itself. To us, life itself is no mystery. However, accomplishing such diverse objectives required a telescope that was capable of making, on the one hand, minute geological observations of small objects such as asteroids and comets little more than a few hundred feet across, while on the other hand studying and photographing super galaxy clusters billions of times larger than asteroids and comets.

Construction of the HST

The HST is more than just a telescope, it is a satellite. A cylinder 43 feet long, 14 feet in diameter, and weighing 24,500 pounds, the HST is roughly the size of a school bus. Operating in the vacuum of space far from the aid of human hands, the satellite was constructed to accommodate some of the most technically complex astronomical instrumentation ever built.



To operate in space, the HST needs a power supply, communications equipment, computers, and a control system. Power is supplied by two 25-foot-long solar panels (384 square feet), each containing 48,760 individual photo cells. Together, the two panels are capable of generating 2,800 watts, roughly the equivalent of 28 standard incandescent light bulbs. The power generated by the panels is also used to charge six nickel-hydrogen batteries that provide power to the spacecraft for the approximate twenty-five minutes per orbit while Hubble flies through the earth's shadow every 97 minutes.



Designers of the Hubble Space Telescope had to take into account the conditions in which it was to operate. Hubble would be subject to the rigors of zero gravity and extremes in temperature, temperatures that fluctuated several hundred degrees Fahrenheit during each trip around the earth. To protect its delicate instruments, Hubble is cloaked in a cocoon of multilayered insulation that shields the interior from extreme temperature fluctuations.

What gives Hubble such remarkable eyesight? What makes its pictures of distant objects so sharp? Its position above Earth's atmosphere — although clearly advantageous — is only part of the answer. Without powerful eyesight, Hubble would not be able to take full advantage of its unique location.

Hubble's "eyes" are actually a system called the Optical Telescope Assembly. That system consists of two mirrors, support trusses, and the apertures (openings) of the instruments. Hubble's optical system is a straightforward design known as Ritchey-Chretien Cassegrain, in which two special mirrors form focused images over the largest possible field of view.

Hubble's optical system is held together by a truss system 17.5 feet in length and 9.5 feet in diameter. The whole optical unit weighs just 252 pounds because it is made of the space-age material graphite epoxy, the same material used in many of the latest golf clubs, tennis rackets, and bicycles. Graphite epoxy is a stiff, strong, and lightweight material that resists expanding and contracting in temperature extremes.

The most sensitive object in need of thermal protection is the mirror. Highly sensitive to temperature change, it must remain within a narrow temperature range to produce images that will answer astronomers' most profound questions about the universe.

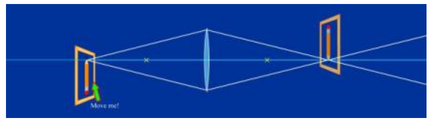
Edwin Hubble

One of the great pioneers of modern astronomy, the American astronomer Edwin Powell Hubble was born in 1889 in Missouri. He began his adult life by earning a law degree and serving in World War I. However, after practicing law for one year, he decided to turn to astronomy. He completed a PhD dissertation, "The Photographic Investigation of Faint Nebulae," at the University of Chicago and then continued his work at Mt. Wilson Observatory in Pasadena, California, studying the faint patches of luminous "fog," or nebulae, in the night sky.

Using the largest telescope of its day, a one-hundred-inch reflector, he studied Andromeda and a number of other nebulae and proved that they were other galaxies similar to our own Milky Way. He devised the classification scheme for galaxies that is still in use today, and he obtained extensive evidence that the laws of physics outside the galaxy are the same as on Earth—verifying the principle of the uniformity of nature. In 1929, using the one-hundred-inch telescope, he analyzed the speeds of recession of a number of galaxies and showed that the speed at which a galaxy moves away from the Milky Way is proportional to its distance. The explanation for this was apparent, yet revolutionary; he had shown evidence that the universe is expanding, a principle now called Hubble's law. The phenomenon was known as Red Shift.

Portions of the above information, including the images, were included by permission from Space Telescope Science Institute in Baltimore, MD.

This concludes much of the background information related to Geometric Optics, including some, but by no means all of the applications of optics. What follows is an investigation of one aspect of optics, the formation of images by converging lenses. We will not discuss diverging lenses, since they only produce virtual images. Virtual images cannot be projected on a screen.

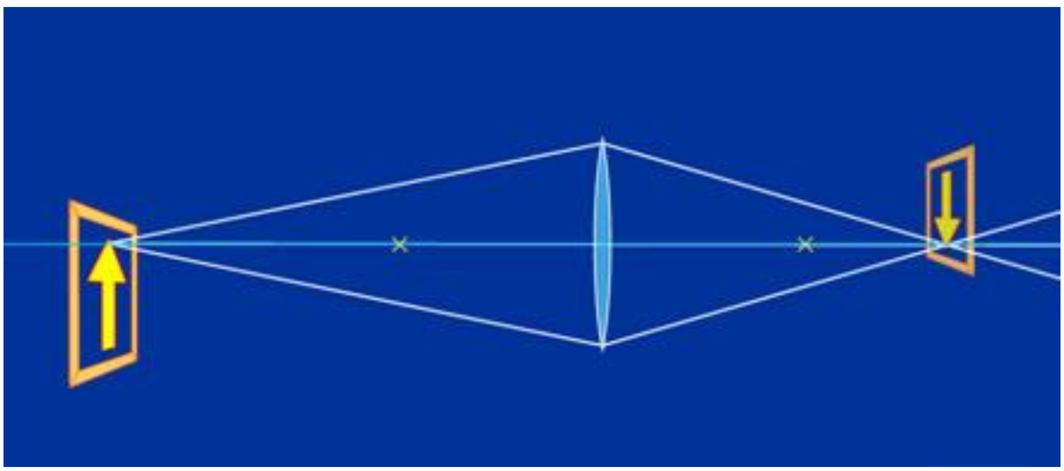


The Investigation

The purpose of this unit is to investigate the properties of converging lenses as applied by the Fresnel Lens Equation. The equation is written below.

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

where $D_i =$ image distance, $D_o =$ object distance, and $f =$ focal length of the lens.

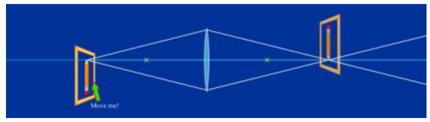


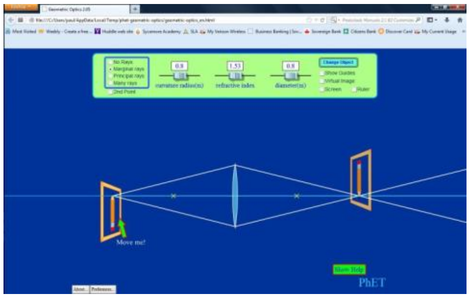
Before beginning the investigation, examine the interactive software provided as a demonstration of the convergence properties of the convex lens. Below is a link to the location of the software. This requires an Internet connection.

Geometric Optics

This software can also be downloaded and used freely, courtesy of The University of Colorado Boulder and can be run independent of the Internet by following this link:

Download the software





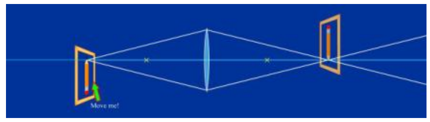
Here is a screen print of what the interactive display will look like.

Cartesian Sign Convention

1. All figures are drawn with light traveling from left to right.
2. All distances are measured from a reference surface, such as a wavefront or a refracting surface. Distances to the left of the surface are negative.
3. The refractive power of a surface that makes light rays more convergent is positive. The focal length of such a surface is positive.
4. The distance of a real object is negative.
5. The distance of a real image is positive.
6. Heights above the optic axis are positive.
7. Angles measured clockwise from the optic axis are negative.

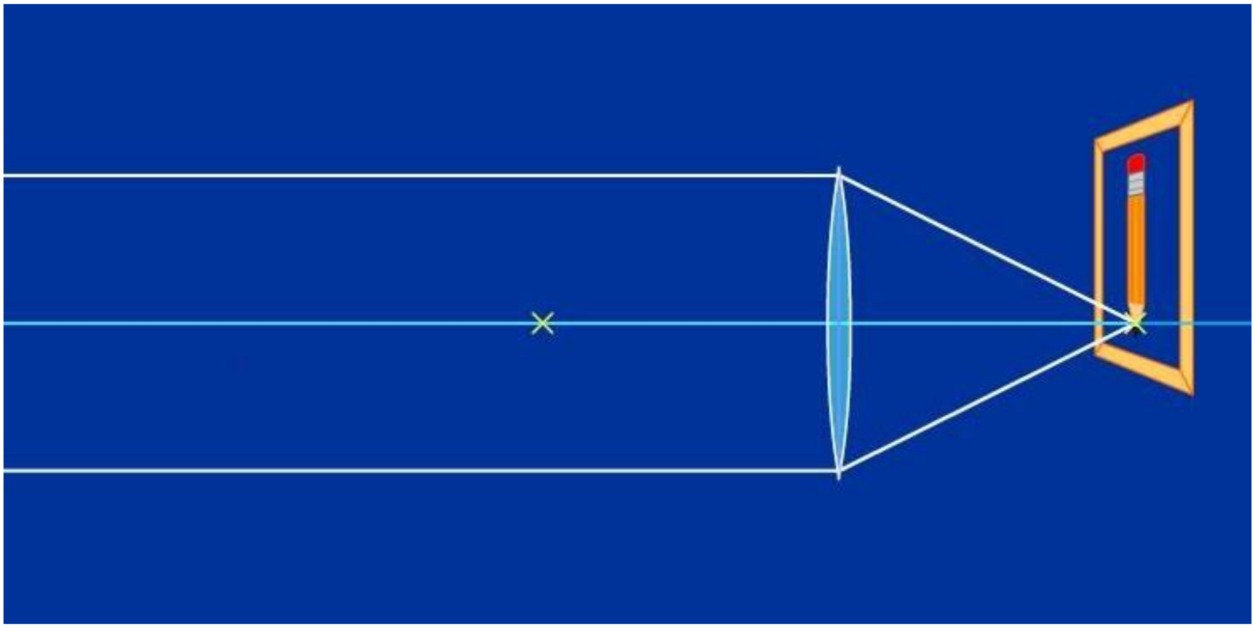
Because the direction of light travel is consistent and there is a consistent convention to determine the sign of all distances in a calculation, this sign convention is used in many texts. It has some advantages when dealing with multi lens systems and more complex optical instruments.

The application of the equation can be divided into six general cases as follows:



CASE 1

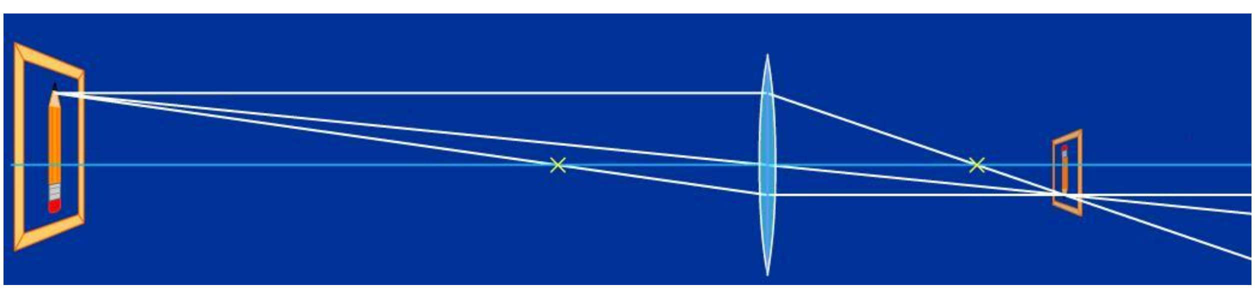
Object distance at or near infinity.

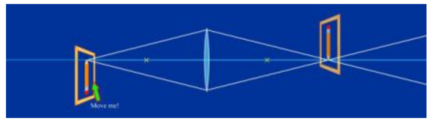


Any object placed near infinity will produce rays of light virtually parallel to the principle axis of the lens. Upon passing through the lens, they will converge at the focal point forming a virtual image. Since $\frac{1}{D_o}$ is essentially equal to 0, the equation reduces to $\frac{1}{D_i} = \frac{1}{f}$ making D_i = *f*. Hence the image distance equals the focal distance, forming an image at the focal point, as shown.

For the next five cases we will use a lens with a focal distance of 10 cm, which will make the center of curvature at 20 cm (twice the focal distance). We will also use an object size equal to 5 cm.

CASE 2



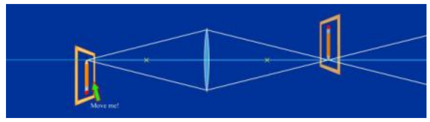


Any object placed beyond the center of curvature (beyond twice the focal distance) will form an image between the center of curvature and the focal point as illustrated in the diagram above.

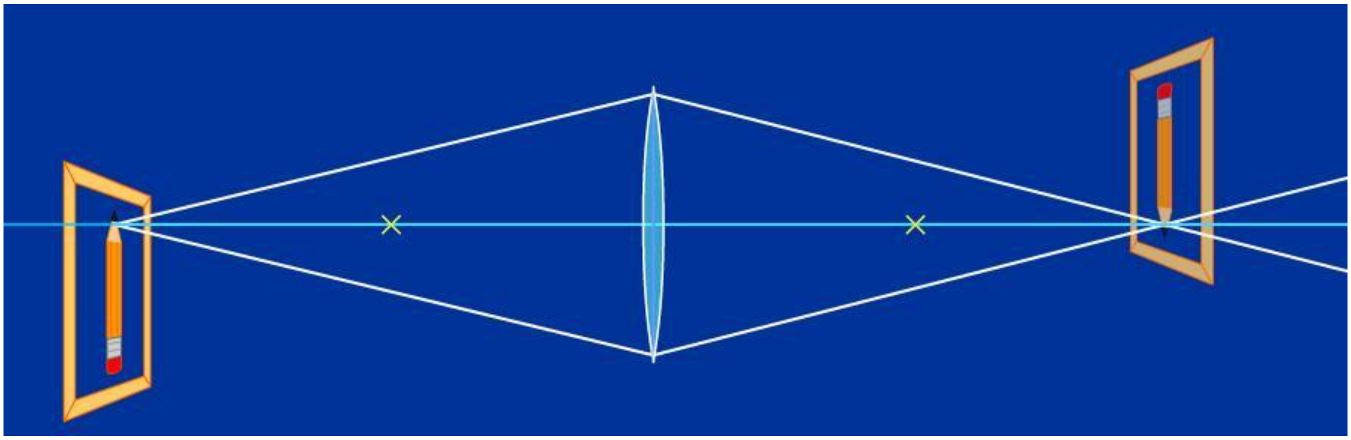
$$\frac{1}{D_i} + \frac{1}{D_o} = \frac{1}{f}$$

Solving the equation for D_i , where D_o = 30 and f = 10,

$\frac{1}{D_i} + \frac{1}{30} = \frac{1}{10}$, $\frac{1}{D_i} = \frac{1}{10} - \frac{1}{30} = \frac{3}{30} - \frac{1}{30} = \frac{2}{30}$. So, D_i = 15, between the focal distance and the center of curvature as shown below. Notice, also, that the image is inverted relative to the object and smaller in size.



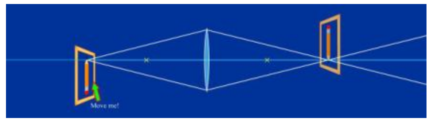
CASE 3



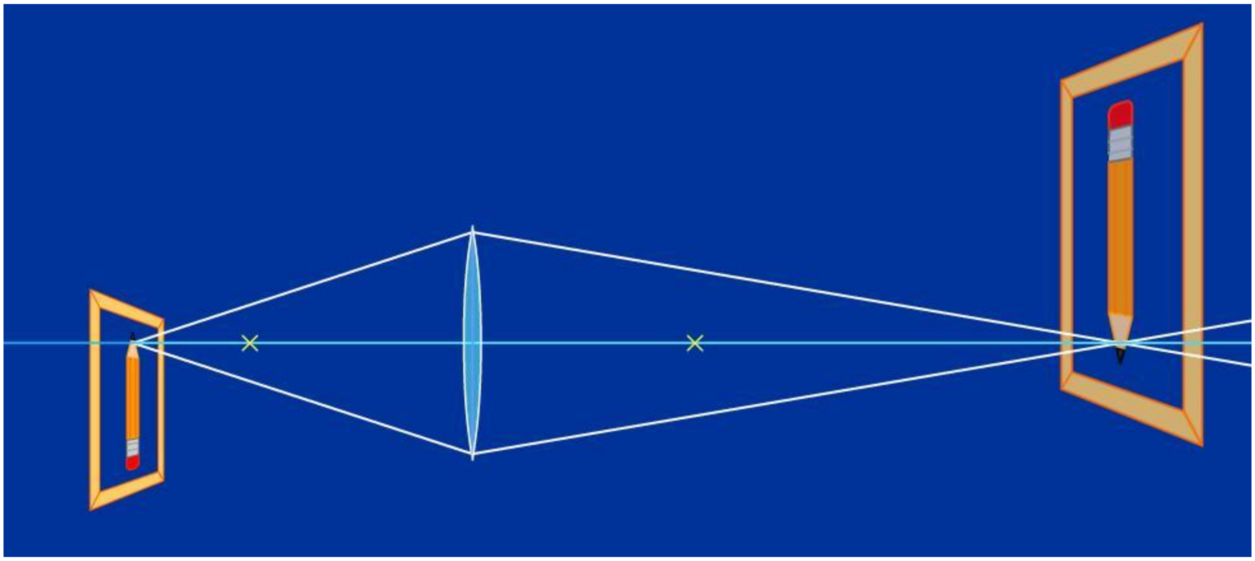
In this case the object is located at twice the focal length, the center of curvature of the lens. Since f = 10, $D_o = 2f$, or 20. Using the equation, $\frac{1}{D_i} + \frac{1}{20} = \frac{1}{10}$,

$\frac{1}{D_i} = \frac{1}{10} - \frac{1}{20} = \frac{1}{20} - \frac{1}{20} = \frac{1}{20}$, so D_i = 20

That puts the image at the center of curvature of the lens opposite the object. This image is also inverted and the same size as the object.



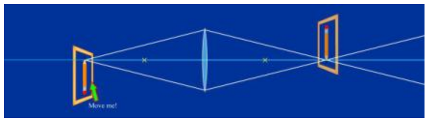
CASE 4



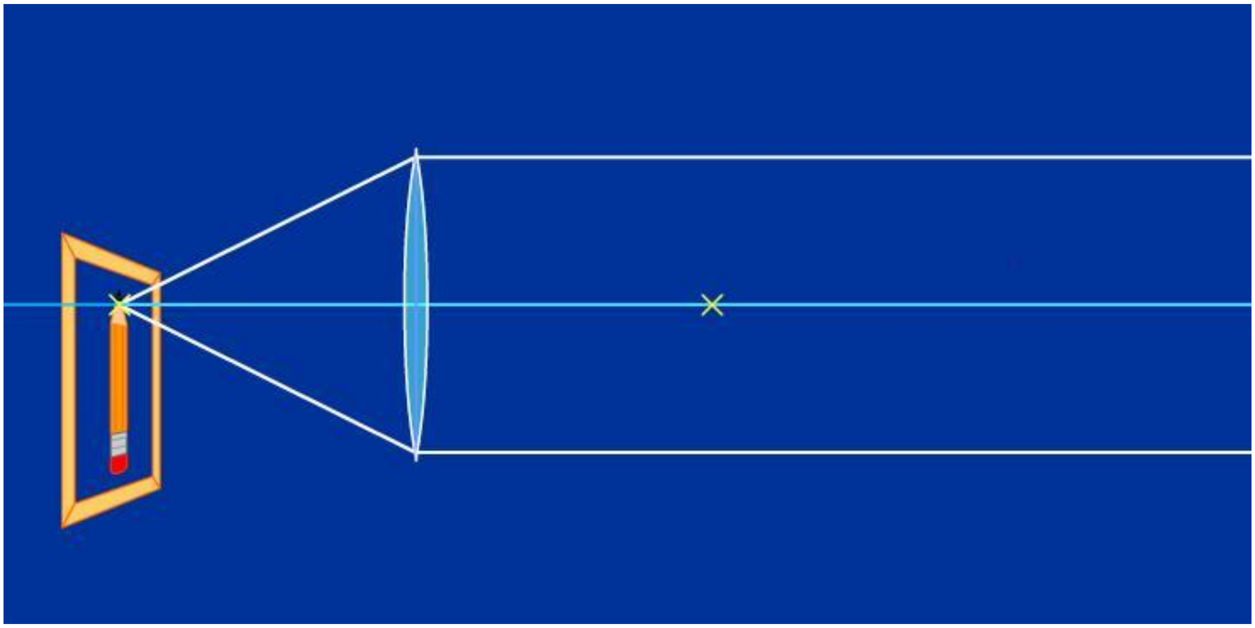
In this case, the object is located between the center of curvature and the focal point. For simplicity, let's locate it halfway between, at 15. Again we apply the equation,

where D_o = 15 and f = 10. $\frac{1}{D_i} + \frac{1}{15} = \frac{1}{10}$, $\frac{1}{D_i} = \frac{1}{10} - \frac{1}{15} = \frac{3}{30} - \frac{2}{30} = \frac{1}{30}$. So, in this case, the image is formed farther from the lens that the object, and is larger than the object. It is, however, still a real image.

For the first four cases, since the light rays converge at the image location, the images formed are real, that is to say, they can be projected on a screen.



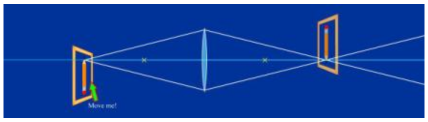
CASE 5



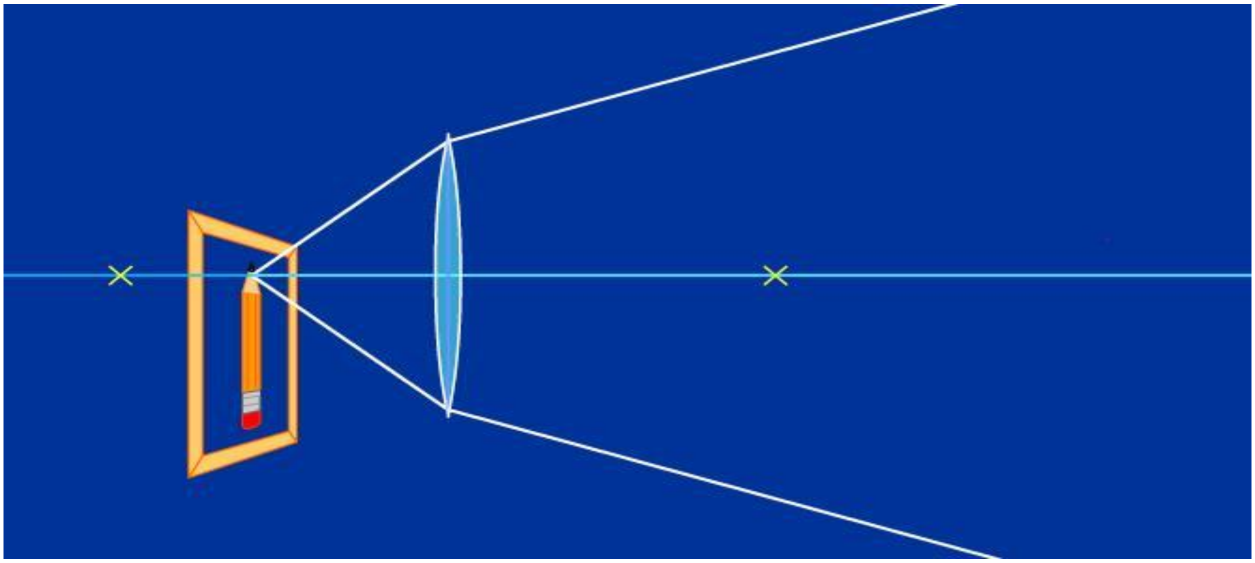
In this case the object is located at the focal distance, making $D_o = f$. Now the solution to the lens equation results in something strange.

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

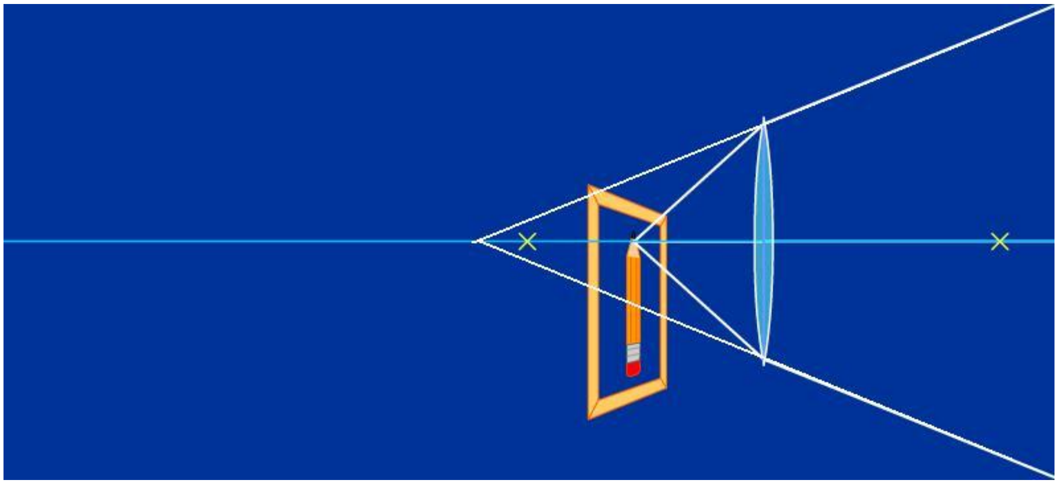
Since D_o and f are equal, either one can be substituted for the other, so, $\frac{1}{D_i} + \frac{1}{D_o} = \frac{1}{f}$ becomes $\frac{1}{D_i} + \frac{1}{f} = \frac{1}{f}$, and solving for D_i, $\frac{1}{D_i} = \frac{1}{f} - \frac{1}{f} = 0$. In order for $\frac{1}{D_i}$ to be 0, D_i would be infinite. Well, if you look at the diagram for CASE 5, the light rays emerging from the lens are parallel. Where do parallel lines meet?



CASE 6



In this case the object is located between the focal point and the lens. This means that $D_o < f$. For simplicity, let's agree that the object distance, D_o = 5, one half of f. Again, applying the lens equation, $\frac{1}{D_i} + \frac{1}{5} = \frac{1}{10}$ and solving this for D_i gives another strange result. $\frac{1}{D_i} = \frac{1}{10} - \frac{2}{10} = -\frac{1}{10}$. This means that D_i = -10. The significance of being negative is that the image is formed on the opposite side of the lens. Another aspect of this result is that the image is not real, since the rays only appear to be converging at the image location. However, the object still can be viewed looking through the lens from right to left.



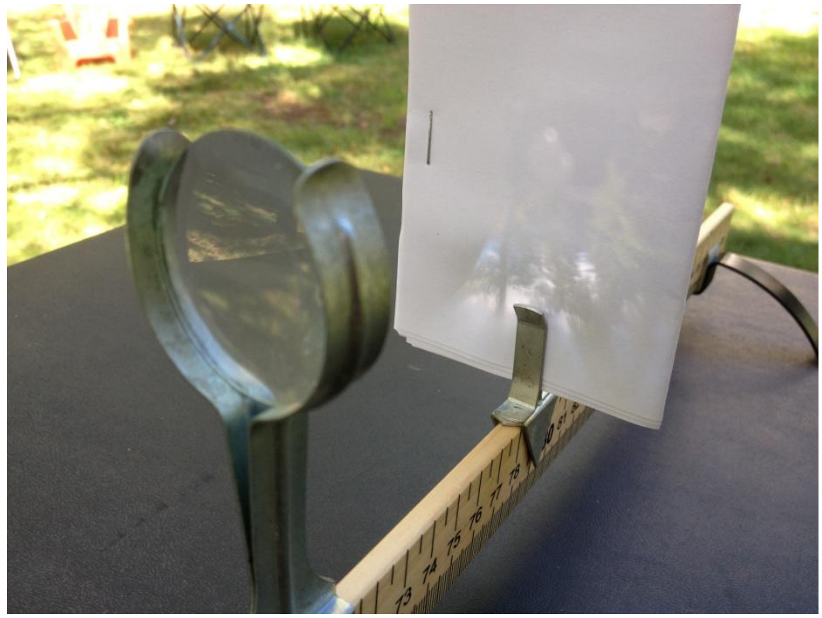
Setting up the Investigation

Below is a photograph of the apparatus for investigating all six cases of the lens properties. Any reasonably resourceful teacher or student can obtain all of these items or create alternative methods of supporting a meter stick, lens, and screen. The object I will use for this investigation is a small porcelain figurine about 3 cm tall.

Investigation for CASE 1

(Determining the focal length of the lens)

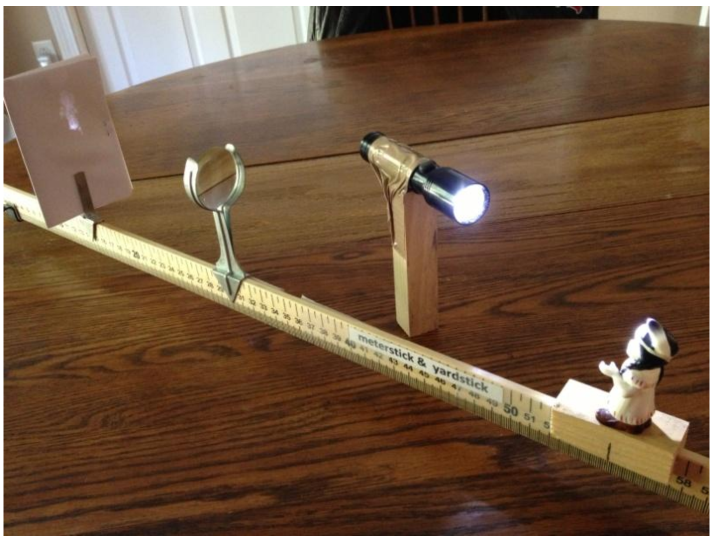
The first task is to determine the focal length of the lens. This is done by focusing a distant object on the screen. If the object is far away compared to the focal length of the lens, the rays of light from the object are parallel and will pass through the lens and be focused on the screen at the focal point. (Refer to CASE 1 above.) This procedure determined the focal length of the lens to be 10.0 cm.



The result should be entered in the data entry on page 53.

Investigation for CASE 2

For this case we will place the object at a distance beyond the center of curvature of the lens. Remember that the radius of curvature of a lens equals twice the focal length. The object will be placed 25.0 cm from the lens. This means that D_o = 25.0 cm.



Notice the use of a simple flashlight to brighten the object, thus forming a brighter image.

Using the lens equation, $\frac{1}{D_i} = \frac{1}{10} - \frac{1}{25} = \frac{5-2}{50} = \frac{3}{50} = .060$. That gives a value for D_i of 16.7 cm. This will be the calculated image distance, D_{ic} , and should be entered on page 53

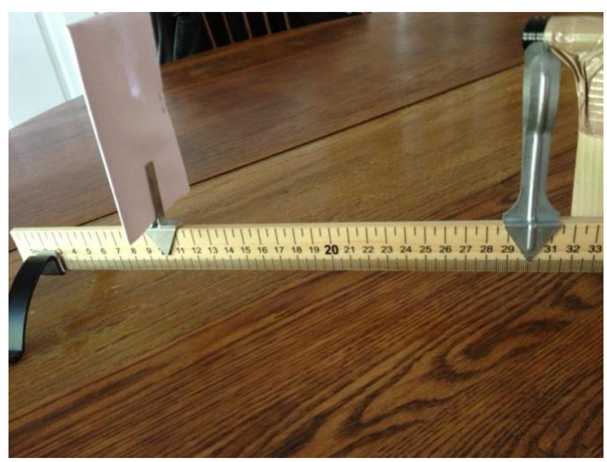
This can be verified by reading the relative positions of the object, lens, and the screen.

This will be the measured image distance, D_{im} , and should be entered on page 53

Investigation for CASE 3

For this case we will place the object at a distance at the center of curvature of the lens. Remember that the radius of curvature of a lens equals twice the focal length. The object will be placed 20.0 cm from the lens. This means that D_o = 20.0 cm.

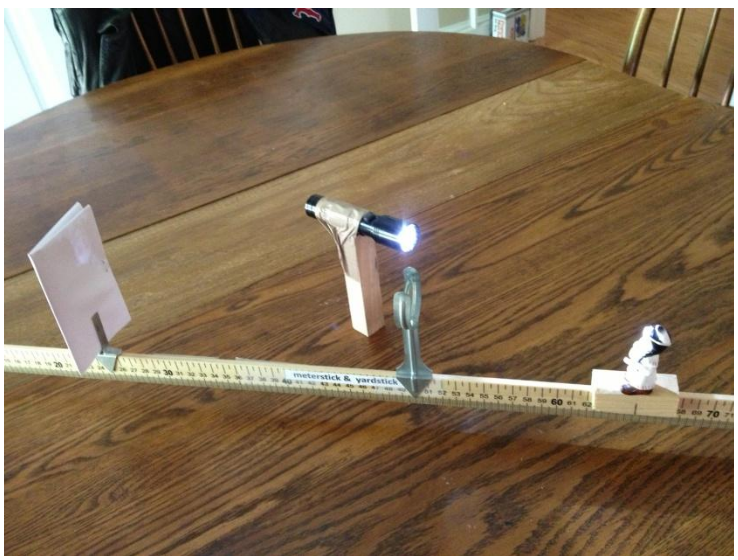
Using the lens equation, $\frac{1}{D_i} = \frac{1}{10} - \frac{1}{20} = \frac{2-1}{20} = \frac{1}{20} =$ .050. That gives a value of D_i of 20.0 cm. This means that the object and image distances are equal. This is consistent with the graphic for case three.



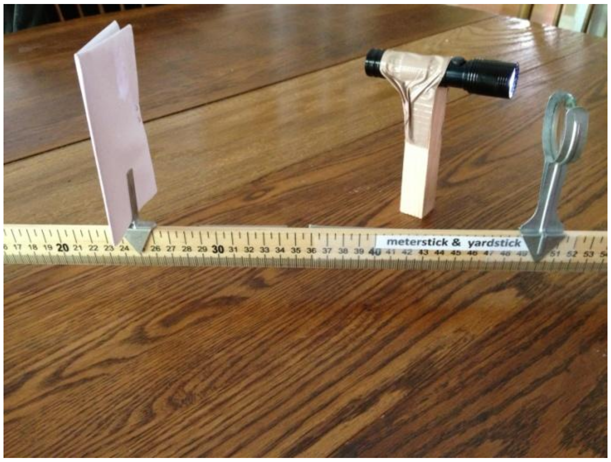
This will be the calculated image distance, D_{ic} , and should be entered on page 53
This can be verified by reading the relative positions of the object, lens, and the screen.
This will be the measured image distance, D_{im} , and should be entered on page 53

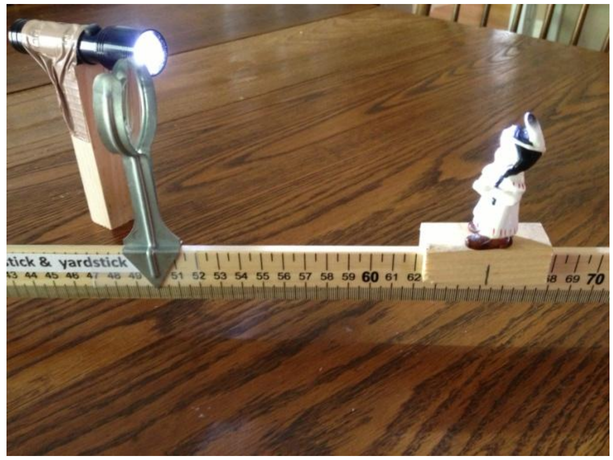
Investigation for CASE 4

For this case we will place the object at a distance between the focal distance and the center of curvature of the lens. Let’s select 15.0 cm, which is halfway between the focal distance and the center of curvature.



Using the lens equation, $\frac{1}{D_i} = \frac{1}{10} - \frac{1}{15} = \frac{3-2}{30} = \frac{1}{30} =$ .033. That gives a value of D_i of 33.0 cm.





This will be the calculated image distance, D_{ic} , and should be entered on page 53
This can be verified by reading the relative positions of the object, lens, and the screen.
This will be the measured image distance, D_{im} , and should be entered on page 53

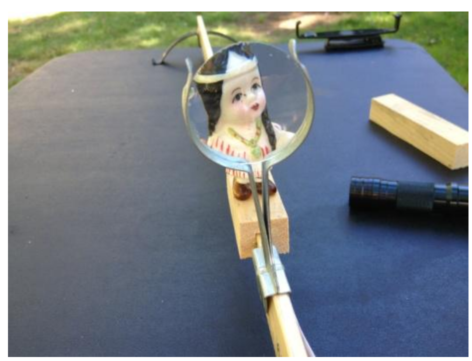
Investigation for CASE 5

For this case we will place the object at the focal point of the lens. That will make the object distance, D_o, equal to the focal distance, both being 10.0 cm.
Now, using the lens equation,
$\frac{1}{D_i} = \frac{1}{10} - \frac{1}{10}$ = 0. That results in an image distance of infinity. If we check back to our graphic of

CASE 5, we notice the rays emerging from the lens are parallel. This is consistent with an infinite image distance. Thus, there is no image formed.

Investigation for CASE 6

To investigate case six, where the object is placed between the lens and the focal point the image is formed by rays that diverge. That means the image is not real, that is, it cannot be projected on a screen. The only way the image can be seen is through the lens on the opposite side as the object. In this case the image is seen magnified and at a greater distance from the lens as the object.. This is the basic idea of a reading lens, or a pair of reading glasses. The image is larger and further away than the object, providing a beneficial condition for correcting, or compensating for hyperopia.



Using an object distance smaller than the focal length, such as 2, results in an image distance being negative.

$$\frac{1}{D_i} + \frac{1}{2} = \frac{1}{10} \qquad \frac{1}{D_i} = \frac{1}{10} - \frac{1}{2} = \frac{1}{10} - \frac{5}{10} = \frac{-4}{10}$$

That gives an image distance, D_i = -2.5

This will be the calculated image distance, D_{ic} , and should be entered on page 53
This can be verified by reading the relative positions of the object, lens, and the screen.
This will be the measured image distance, D_{im} , and should be entered on page 53

The significance of a negative image distance puts the image on the same side of the lens as the object. However, another aspect of a negative image distance is that the image is not real. In order to obtain a meaningful image distance you need to locate the image. This is not an easy task since the image is not real. To find out where the image is, take a pencil and position it where the image appears to be located. Then, move your eye from side to side and reposition the pencil to a location where it appears to move with the image. The location of the pencil will be the location of the image. This is refered to as finding the location by parallax.

Calculations Page

Calculations for Case 1 (Enter result in Data Entry Form as *f*)

Calculations for Case 2 (Enter result in Data Entry Form as D_{ic})

Calculations for Case 3 (Enter result in Data Entry Form as D_{ic})

Calculations for Case 4 (Enter result in Data Entry Form as D_{ic})

Calculations for Case 5 (Enter result in Data Entry Form as D_{ic})

Calculations for Case 6 (Enter result in Data Entry Form as D_{ic})

Data Entry Form

Name____________________________ Date_________________

For CASE 1, determine the focal length of the lens being used for this investigation. Enter below as *f*.

Focal length of lens used. f = ______cm

Object distance, D_o
Calculated image distance, D_{ic}
Measured image distance, D_{im}

	D_o	D_{ic}	D_{im}	% difference $\frac{\lvert D_{im} - D_{ic}\rvert}{\lvert D_{im}\rvert}$ x100%
CASE 1				
CASE 2				
CASE 3				
CASE 4				
CASE 5				
CASE 6				

For CASE 6, explain how you determined the image distance, D_{im}?

Internet links for further research

Comparing convex and concave lenses:

http://www.bing.com/images/search?q=Concave+and+Convex+Lenses+Images&qpvt=Concave+and+Convex+Lenses+Images&FORM=IGRE#a

Lenses and refraction of light:

http://interactagram.com/physics/optics/refraction/

http://micro.magnet.fsu.edu/optics/lightandcolor/refraction.html

http://www1.curriculum.edu.au/sciencepd/teacher/assessment/light/refr_lenses.htm

http://www.physicsclassroom.com/

Fiber Optics

http://computer.howstuffworks.com/fiber-optic.htm

http://www.webopedia.com/TERM/F/fiber_optics.html

http://cablesystems.corning.com/4-lighter?utm_source=google&utm_medium=cpc&utm_term=fiber%20optics&utm_campaign=Corning-%20Fiber%20Optic%20Cables

All about vision – Astigmatism and Presbyopia:

http://www.allaboutvision.com/conditions/astigmatism.htm

http://www.allaboutvision.com/conditions/presbyopia.htm http://www.nei.nih.gov/healthyeyestoolkit/factsheets/presbyopia.pdf

Rayleigh Criterion:

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/raylei.html

History of the microscope:

http://www.nei.nih.gov/healthyeyestoolkit/factsheets/presbyopia.pdf

http://www.microscope-microscope.org/basic/microscope-history.htm

http://www.history-of-the-microscope.org/robert-hooke-microscope-history-micrographia.php

http://www.indepthinfo.com/microscopes/history.htm

Electron Microscope:

http://www.jic.ac.uk/microscopy/intro_em.html

http://www.sciencedaily.com/articles/e/electron_microscope.htm

http://www.purdue.edu/rem/rs/sem.htm

History of the telescope:

http://www.nasa.gov/audience/forstudents/9-12/features/telescope_feature_912.html

http://telescopes.stardate.org/history/

http://www.huffingtonpost.com/2013/04/16/telescope-history-astronomers-photos_n_3076830.html

http://dictionary.reference.com/browse/Refracting+telescopes%27

http://www.coolscopes.com/advantagesanddisadvantagesofrefractors.html

http://telescopereviewsonline.com/articles/types-of-telescopes-advantages-and-disadvantages/

Largest refracting telescope:

http://astro.uchicago.edu/vtour/40inch/

The Hubble Telescope:

http://asd.gsfc.nasa.gov/archive/hubble/

http://history.nasa.gov/hubble/index.html

http://hubblesite.org/the_telescope/

http://hubblesite.org/about_us/copyright.php

The University of Colorado.PhET Interactive Simulations

http://phet.colorado.edu

Copyright Information

The interactive software accompanying this unit is provided by The University of Colorado.

Geometric Optics
Version: 2.04.00 (37306)
Build Date: Dec 11, 2009

Flash Version: WIN 11,7,700,224
OS: Windows Vista
PhET Development Team
Lead Design: Michael Dubson
Software Development: Michael Dubson
Design Team: Kathy Perkins
Interviews: Mindy Gratny, Danielle Harlow

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Quiz

It is now time to evaluate your understanding of what has been presented in the lesson. Please take this quiz and include this page with all the written material turned in at the conclusion of this unit.

Name________________________________ Date_________________

1. Name the property that causes light to change direction when passing from air into glass.
2. What is another term used for Hyperopia?
3. What is the major difference between a refracting telescope and a reflecting telescope?
4. Why is there no image formed when the object is placed at the focal point of a converging lens?
5. Why does a concave lens not form a real image?
6. What is the significance of a negative image distance?
7. What is the major advantage of a space telescope over an earth based telescope?
8. How does Myopia affect the location of the image formed in the eye relative to the retina?
9. What is the phenomenon called that showed that the universe is expanding?
10. When you see a rainbow in the sky, what color is seen on the outside edge of the rainbow?

Answer Key

1. Refraction

2. Farsightedness

3. A refracting telescope uses a lens to gather light, a reflecting telescope uses a mirror.

4. Because the rays of light go through the lens and emerge parallel.

5. Because the rays of light go through the lens and emerge diverging.

6. The image is formed on the same side of the lens as the object.

7. A minimum of atmospheric interference.

8. The image is formed in front of the retina.

9. The Doppler Effect.

10. Red