A Brief History of the Telescope and Ideas for Use in the High School Physics Classroom

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Introduction

Despite the inseparability of astronomy and physics since the Scientific Revolution, few topics in astronomy are taught in the high school physics setting. Although many demands are placed upon the high school physics teacher (particularly in light of the renewed emphasis on standardized testing) certain ideas and practical applications from astronomy fit readily within the context of the standard curriculum. Placing these within their historical context will present students with a deeper appreciation of physics, astronomy, and science in general. By researching the historical development and use of the telescope some examples become obvious and are discussed in this paper.

As a brief overview of this research paper, it consists of six distinct sections. The "Introduction" is followed by the text in "Part I. - Topics in Optics Related to the Physics Curriculum" and "Part II. - Other Brief Ideas Related to the Physics Curriculum" on pages two and nine respectively. Two appendices "Appendix A – The Physics of Basic Optics for Telescopes" and "Appendix B – Additional Details for Laboratories and Activities" are found starting on pages 12 and 21 respectively. Numerous ray diagrams are included in Appendix A and readers unfamiliar with the basic optical principles should refer to this appendix frequently while reading the text. A standard bibliography (including reference to several sources from the web) is found on the last page.

Part I. – Topics in Optics Related to the Physics Curriculum

Real images of the sun have been projected since at least 424 B. C. when Aristophanes used a glass globe filled with water to start fires. The directed use of lenses (Latin for lentils) to purposefully study the stars did not occur until almost 2000 years later. In similar fashion, many elementary school children (and unsuspecting ants) learn this practical use of converging lenses yet do not study optics in detail until a decade later. A natural starting point for the study of lenses is therefore to allow students to project real images of the sun with a single lens and discover the optimal distance for burning. [Caution - Students are often tempted to set each other on fire!]

By the 13th century magnifying glasses were often used and this led to the development of spectacles, in particular reading glasses, in the 14th century. Concave lenses were not made or used to correct for nearsightedness until the 15th century. The combination of lenses to create a telescope did not definitively occur until the early 17th century. An important point for students in this regard is to foster creativity and innovation based on current technology. Four hundred years for the above progression may seem excessive to students. [See appendix A for details on the basic physics of lenses and telescopes.]

Some students associate Galileo as the inventor of the telescope. This is incorrect although he was the first person to make the telescope famous through both his astronomical observations and renowned ability to construct quality telescopes. Hans Lippershey applied for a patent for his telescope in the Netherlands in 1608. The Hague did not grant patent rights to Lippershey due in part to similar claims by Jacob Metius and Sacharias Janssen but also because the idea seemed apparently simple to copy. Galileo certainly agreed with this assertion and constructed his first telescope in 1609 after merely hearing that such a device existed. The actual term "telescope" was coined on April 14, 1611 by Prince Frederick Cesi at a reception where Galileo was demonstrating one of his instruments. After mentioning these historical points to high school students, an in-class challenge activity would be to give students a variety of lenses and ask them to try to make a basic telescope. [See appendix B.] The physics and optical principles for systems of lenses could be discussed after this exploratory activity.

A discussion with students regarding Galileo's initial observations seems appropriate at this point. In my experience only a small percentage of students have ever explored the night sky with a telescope or binoculars. However the remarkable discoveries of Galileo regarding the moons of Jupiter, the phases of Venus, and mountains on the moon can readily be observed with 7x50 (or even 6x30) quality binoculars. These binoculars may show greater detail than Galileo's 33x50 telescope due to major improvements in optical components (lenses in particular). In his book "Exploring the Moon Through Binoculars and Small Telescopes", Cherrington claims to have found 605 out of 670 lunar features from "The Photographic Lunar Atlas" simply by using 7x50 binoculars mounted on a tripod. Hosting a Star Party for students (or finding one sponsored by an amateur astronomy club) may be appropriate at this time and more of the astrophysics could be discussed outside of class. [See appendix B.] The formation of shadows is often included in the physics curriculum and to actually watch the shadows cast by the moons of Jupiter onto the planet's surface through a telescope is something that students will not forget. Coupling this with appropriate ray diagrams is a useful tool.

In 1611, Johannes Kepler suggested an alteration to the telescope. Although still using a convex objective lens, Kepler switched from a concave eyepiece to a convex eyepiece. [See appendix A, figures 9 and 10.] This allows for a larger field of view and projection of images (such as the sun and its accompanying sunspots) onto a screen. One potential drawback of this system is the inversion of images but Kepler did show how a third convex lens could correct for this. Kepler did not actually construct such a telescope but his idea was embraced by astronomers around 1630. Astronomers did not use the third lens since inverted images were inconsequential and an additional lens would further degrade the image quality. For terrestrial observations, the telescope popularized by Galileo continued to dominate the field and it became known as a Galilean telescope or Galilean refractor.

Most all physics students learn how to construct ray diagrams for converging and diverging lenses [see appendix A, figures 5 through 7] but few high school students apply them to systems of two or more lenses. After students fully understand diagrams for single lenses, ray diagrams demonstrating the operation of Galilean and Keplerian telescopes should be readily grasped by students. This is due to the inherent simplicity of parallel rays entering the first lens (objective) and parallel rays exiting the second lens (ocular). Students should therefore recognize that the focal points for these two lenses must coincide. Ray diagrams will also show that the rays of light leaving the second lens are more closely spaced (hence brighter) than those entering the first lens. Many students will protest that these telescopes do not form images if the exiting rays are parallel so reference to the lens of the human eye (and perhaps another ray diagram) may be necessary. In addition, it can be reasoned that if you can see a star without a telescope (with parallel rays incident upon your eyes) that you should be able to see a star with a telescope (with more concentrated parallel rays incident upon your eyes). Another geometrical problem that many physics students should be able prove is that the angular magnification for either of these systems is approximately the ratio of the objective focal length to the ocular focal length.

Most high school physics students have been introduced (via ray diagrams) to the concepts of spherical and chromatic aberrations. [See appendix A, figure 11.] This would lead one to naturally point out the many potential solutions that were suggested and/or attempted to remedy these problems. Kepler suggested the use of hyperboloidal (rather than spherical) lenses after studying the hyperboloidal shape of the human eye's lens. Using Willebrord Snell's Law from 1621 [known by all physics students], Rene Descartes showed in 1637 that spherical lenses cannot produce point images of point objects. Descartes went on to study elliptical and hyperboloidal lenses and showed that plano-hyperboloidal or spherico-ellipsoidal lenses would eliminate spherical aberrations. He actually paid a Paris optician to make these types of lenses but they were unsuccessful. Perhaps a factor in his lack of success was that the nature of chromatic aberrations were not adequately understood at the time. Although his lenses may have actually corrected for the spherical aberrations, the chromatic aberrations may have become worse.

Tiny focal lengths result in extreme aberrations therefore a natural solution for more powerful telescopes with limited aberrations was the introduction of longer and longer objective focal lengths. Johannes Hevelius had constructed a 140 foot long telescope by 1673 but due its enormous length it was difficult to keep the lenses aligned. The slightest wind buffeting the tube produced extreme motion of the images. Around 1675 Christian Huygens therefore chose to remove the tube and simply mount the objective on top of a sturdy pole. These telescopes were known as aerial telescopes and Sir Isaac Newton had commented favorably on their relative ease of use. Huygens also developed a compound negative eyepiece using two thin separated convex lenses that corrected some of the chromatic aberrations. Another solution to mechanical problems with longer tubes was suggested by Robert Hooke in 1668. He showed how the use of three or four plane mirrors strategically placed within a tube could drastically shorten the tube. In one of his designs, a 60 foot focal length was accommodated by a 12 foot tube. Hooke's design was simple enough that high school physics students should be able to develop similar designs without actually seeing his original plans. This could perhaps be a useful homework assignment or in-class activity while studying the Law of Reflection.

As a novel approach to the problems with aberrations, Marin Mersenne (in 1636) suggested using a system of two paraboloidal mirrors but was dissuaded from its construction by Descartes. In 1663 James Gregory designed a telescope using a concave paraboloidal primary mirror (with a hole in the center), a concave ellipsoidal secondary mirror, and a biconvex ocular lens. Although the design was ingenious, the opticians of the time were not able to make quality mirrors for this type of telescope. A similar design was proposed by Cassegrain [scholars disagree regarding his first name due to his relative obscurity] in 1672. Cassegrain's design used a convex secondary mirror that only allowed the tube to be further shortened but more importantly tended to cancel aberrations from the primary mirror. [Owing to Newton's disapproval of this design it did not become popular until many years after Cassegrain's death.]

The first successful reflecting telescope was constructed by Newton in 1668 using a two inch diameter concave spherical mirror (made from a mixture of copper and tin), a flat angled secondary mirror, and a convex eyepiece lens. [See appendix A, figure 13.] Unfortunately the mirror tarnished rapidly and had to be repolished several times a year. Also, due to a lack of experience in the construction of curved mirrors, the Newtonian reflector did not become popular until the middle of the 18th century. By the late 18th century Newtonian reflector telescopes had also become enormous in order to gather more light. In 1789, Sir William Herschel had constructed a 40 foot long reflector telescope with a four foot aperture. Although reflector telescopes are easier to mount than refractor telescopes [by virtue of its lower center of mass], a 40 foot reflector was still difficult to manage. Herschel generally preferred to use his 20 foot telescope unless if the object was otherwise too dim.

Newton's study of light, especially regarding the nature of white light and colors [another point known by many physics students – see appendix A, figure 4], led him to the construction of reflector telescopes to solve the problem of chromatic aberration. He did not believe that it was possible for a system of lenses to eliminate chromatic aberrations and his insistence deterred others from this undertaking. Students of physics recall from tables of indices of refraction that different types of glass have different indices. Most tables include both crown and flint glass and a practical application of this is the achromatic compound lens developed in 1729 by Chester Moor Hall. It combined concave flint glass with convex crown glass. This type of lens, although vastly superior to a single convex lens, was not widely publicized. John Dolland, in 1757, further refined this idea by placing a concave flint glass lens between two convex crown glass lenses. Despite Hall's earlier work, Dolland successfully petitioned for patent rights and his achromatic lenses led to a resurgence in the popularity of refractor telescopes.

At the end of the 18th century Robert Blair achieved success using a variety of fluid lenses to eliminate chromatic and spherical aberrations. He found that solutions of metal salts were especially dispersive. This led him to place a biconcave lens with a solution of hydrochloric acid and a metal next to plano-convex crown glass lens. Skeptics were hesitant to use his lenses due to the corrosivity of the acid but Peter Barlow used a small corrective fluid lens filled with carbon bisulfide that was still in excellent condition after 15 years. However, in 1832 the Royal Society purchased a telescope using an eight inch fluid lens from Barlow and considered it to be poor quality. Demonstrations of liquid prisms and spherical fish-bowl lenses are popular in the high school physics class but few students are aware that fluid lenses were actually used for astronomical observations. [See appendix A, figure 8 for sketches of a variety of different lenses.]

Part II. – Other Brief Ideas Related to the Physics Curriculum

At the end of the 18th century Herschel noticed, while observing the sun, that some of his color filters reduced the intensity of light considerably but not heat and vice-versa. In some cases the heat was intense enough to hurt his eyes. To investigate this phenomenon, Hershel set up a single slit to allow sunlight through a prism to produce a spectrum of colors. [See appendix A, figure 4.] He then proceeded with a set of three thermometers to measure the temperature for a given color. (Two of the thermometers were actually controls that monitored the temperature of the room.) As Herschel expected, the highest temperature was noticed for the red light but when he went beyond the red the temperature rose even higher. He named this invisible light calorific rays which currently are referred to as infrared rays. Most students are aware that infrared light is used to keep some food items warm in a buffet line but few students realize that their discovery was due to an astronomer's intention to solve a problem. The dispersion of light by a prism is demonstrated by nearly all introductory physics teachers. A natural extension of this is a demonstration (or laboratory activity) of Herschel's experiment. [See appendix B.]

The development of the photographic process was first used as a tool in astronomy in 1840 by J. W. Draper using the daguerreotype method to image the moon. The wet plate process was first used in 1852 by Warren De la Rue. Most introductory physics texts include one or more problems dealing with cameras. For a camera, the basic idea is that the film should be located at the position of the real image to be properly focused. Hence a brief mention of the use cameras in astronomy may fit into a classroom lecture or discussion. Also of interest are De la Rue's stereoscopic pictures of the moon that led to his Gold Medal of the Royal Astronomical Society [although I have not personally seen them].

Many physics students are familiar with the Doppler Effect (from 1841) that states that the perceived frequency of a wave depends upon the motion between the source and receiver. An erroneous thought encountered in students is that the red shift actually causes some stars to appear red. However they are in good company for Doppler himself first suggested this. He proposed that the reddish hue of certain binary stars was possibly due to a receding radial velocity and that the bluish hue was due to an approaching radial velocity. He was immediately criticized for this interpretation and in 1848 Fizeu pointed out that the Doppler Effect would only produce a slight shift in spectral lines. This shift was first measured by Huggins in 1868 for the F line of hydrogen. [Again, for more details on spectral lines please consult most any standard college physics or chemistry textbook.]

Circular motion and centripetal force are topics covered in most physics classes. [Again, consult any standard physics text for details.] The observation of the orbiting moons of Jupiter allow for immediate analogies between simple harmonic motion and circular motion as well as a discussion of Newton's Law of Universal Gravitation. Another interesting point that relates to the history of telescope construction is the use of a rotating pan of mercury by R. H. Wood (in 1908) to automatically make a concave paraboloidal mirror of variable focal length. In this case his fluid mirror had a diameter of 20 inches and a focal length ranging from 3 to 20 feet. Although it was successful, the drawback was that it could only be pointed straight up. Nonetheless this idea can readily be demonstrated to students using a pan of water mounted on record player, a moveable light source above the pan, and a projection screen above the light.

As a closing thought, many of the recent radio, infrared, and X-ray images of astronomical objects would make excellent bulletin board displays for the physics room or hallway. These images could be directly related to an introduction of the electromagnetic spectrum. Alongside these images, photographs of the related telescopes would serve to reinforce the relationship between visible light and the rest of the electromagnetic spectrum. Most students associate telescopes with visible light but seeing the telescope alongside its related image may cause students to alter this perception.

Appendix A – The Physics of Basic Optics for Telescopes

Refraction and Snell's Law

We often think of light as traveling in straight lines. For example if you use a laser pointer for a lecture, a beam of light from the laser will travel straight across the lecture hall. However, light does not have to travel in straight lines. As a general rule, when light travels from one substance (such as air) into another substance (such as water) it will pivot or refract. [See Figure 1.] In optically denser media (such as the water), the light will pivot towards the normal line. A normal line is a line sketched perpendicular to the surface of the second substance. For the below scenario, angle θ_2 is therefore smaller than angle θ_1. Angles are measured from the rays to the normal line.

Willebrord Snell is credited with determining the mathematical relationship between these angles in 1621. As a result this relationship is known as Snell's Law. Snell's Law is stated as

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

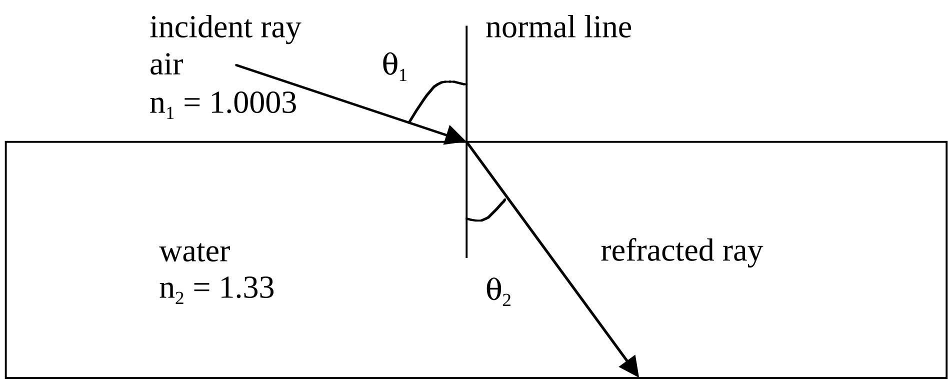
where "n" is merely a constant that depends upon the medium be it air, water, glass, diamond, or other transparent materials. The product of "n" and the sine of the angle in one medium (such as air) is equal to the product of "n" and the sine of the angle in another medium (such as water).

In particular, "n" is referred to as the index of refraction and is actually the ratio of the speed of light in a vacuum ("c", equal to 300,000,000 m/s) to the average speed of light in the medium ("v"). In equation form,

$$n = c/v.$$

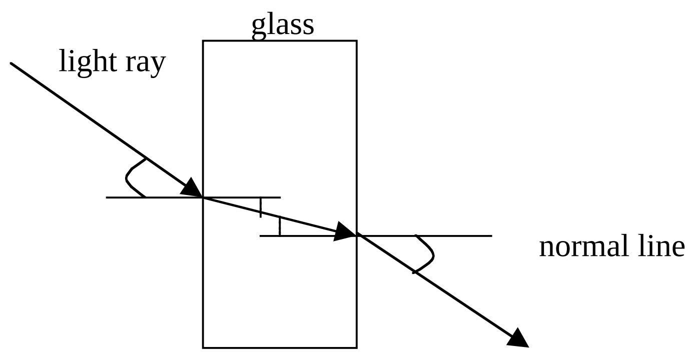
If light is traveling through a vacuum, the "n" value is therefore equal to one since "v" is equal to "c". In optically denser mediums such as water or glass "n" is greater than one since the average speed of light is less than "c".

Figure 1 - Light ray refracting into a tank of water.



As an extension of Snell's Law note see Figure 2. Note how light will pivot towards the normal line when entering glass (n=1.5) from air and then pivot back away from the normal line when exiting the glass block and returning to the air. Since the two glasses surfaces are parallel to each other, the incident ray and exiting ray are also parallel to each other with a slight lateral shift present.

Figure 2 - Refraction of light through a block of glass.



If the faces of the glass are not parallel to each other, there will be a deviation of the original direction of the light ray. Figure 3 illustrates one possible path of a light ray through a prism. The exact path depends on the index of refraction for the prism. Since the index slightly depends upon the frequency of light (i.e. – color), white light (which is a combination of all the colors of light) passing through a prism will disperse into a spectrum of colors as illustrated in Figure 4. Violet light, which has the highest frequency of visible light, refracts the most since it travels a little bit slower through glass than the other colors. Red light, which has the lowest frequency of visible light, refracts the least since it travels a little bit faster through glass than the other colors.

Figure 3 – Refraction of monochromatic (one color) light through a glass prism.

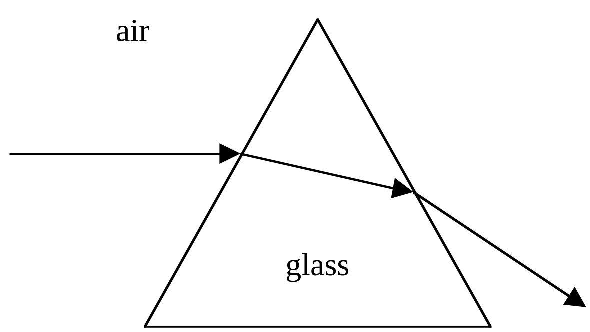
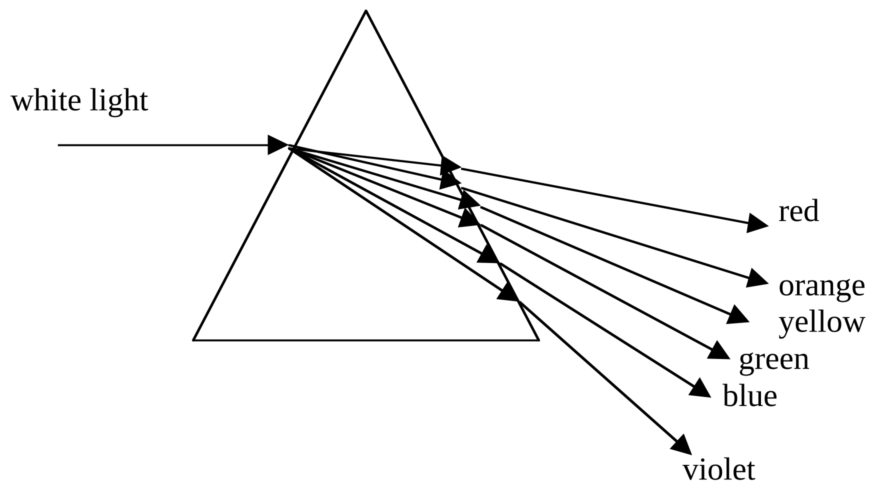


Figure 4 – Refraction of white light (or sunlight) through a glass prism. The range of dispersion is exaggerated for sake of clarity.

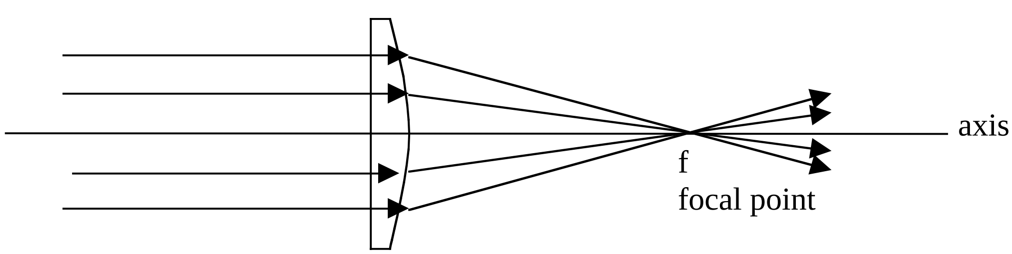


Application of Snell's Law to Form Lenses

If a piece of glass is shaped into a curve, different parts of the glass will refract parallel light rays to differing degrees. If the shape is just right, the refracted rays of light may pass through a common point. This point is known as a focal point. Figure 5 shows an example of glass shaped into a plano-convex lens (flat on one side, bulging out on the other). Parallel rays that pass through the lens are refracted and intersect at the focal point of the lens. The axis of the lens is a line of symmetry that passes through the center of the lens.

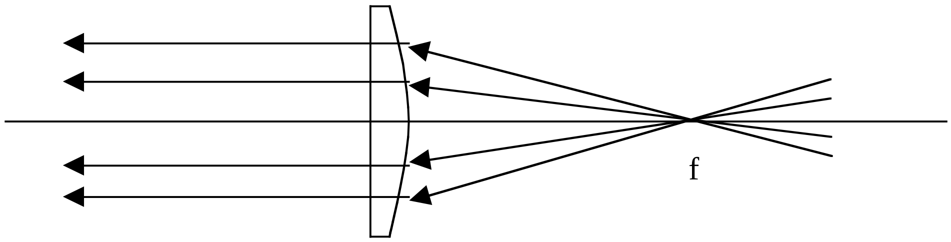
This type of lens is also known as a converging lens and is used for reading glasses, magnifying lens, binoculars, objective lenses for refractor telescopes, and Keplerian eyepieces for telescope.

Figure 5 – Refraction through a plano-convex lens.



The path of light is reversible. Therefore light rays that pass through the focal point of and then strike the lens will exit in parallel paths. This is illustrated in Figure 6.

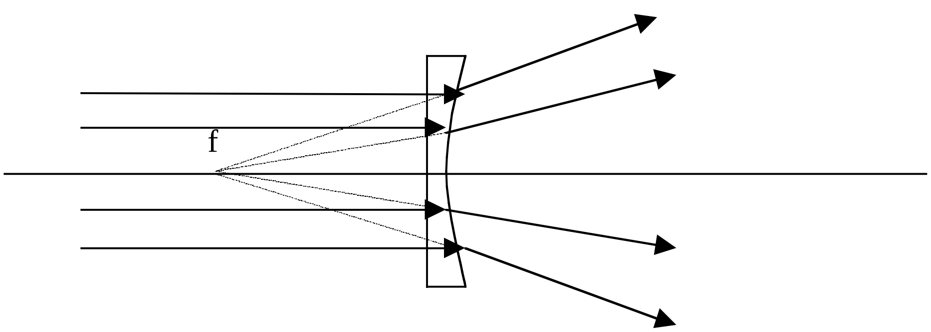
Figure 6 – The reversible path of light.



If a lens is shaped to have the opposite curvature, it will spread light out rather than bringing light together. Figure 7 shows an example of glass shaped into a plano-concave lens (flat on one side, caving in on the other). Parallel rays that pass through the lens are refracted and spread out as if the came from a common point on the other side of the lens. The refracted rays have been extended backwards to illustrate this concept. This point is also known as a focal point but the focal length (the distance from the center of the lens to the focal point) is mathematically considered negative since the rays do not converge.

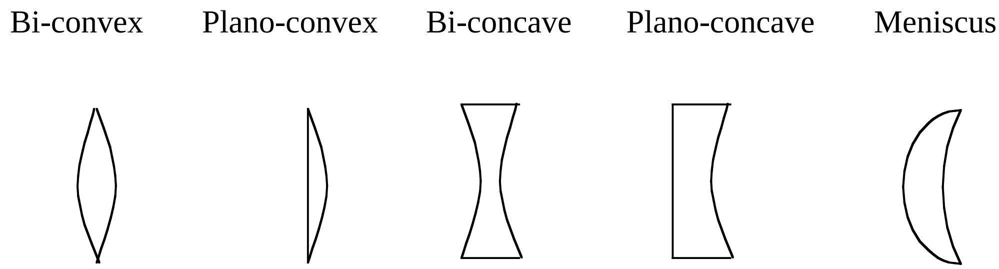
This type of lens is also known as a diverging lens and they are the basis for corrective glasses for myopia (nearsightedness) and were the first eyepieces used for telescopes by Lippershey and Galileo.

Figure 7 – Refraction through a plano-concave lens.



Lenses occur in many different shapes, sizes, and configurations depending on their purpose. Figure 8 illustrates several common types of lenses. As a general rule of thumb, if the lens is thicker in the center than on the edges it is a converging lens and if it is thinner in the center it is a diverging lens.

Figure 8 – Assortment of lens shapes.



<u>Application of Lenses to Create Simple Telescopes</u>

The primary function of an astronomical telescope is to gather light. Good astronomical telescopes are large in order to collect large amounts of light. The objective (or first) lens of a good refractor telescope should therefore have a lens that has a greater diameter than the human eye. By having a greater diameter, it can collect more light than the human eye and allow one to see objects that would otherwise be too dim. A common misconception is that the purpose is magnification. It is true that telescopes will magnify images but that is only a secondary purpose after it has collected sufficient light to allow for visibility. Although magnification is nice for the moon, planets, and sun, it useless for distant stars. Regardless of the telescope’s magnification, a star will always appear as a point when properly focused. Unlike images for terrestrial objects, the images of astronomical objects will be located at the focal point (or plane) of the telescope. This is due to the immense distance separating us from other planets and stars.

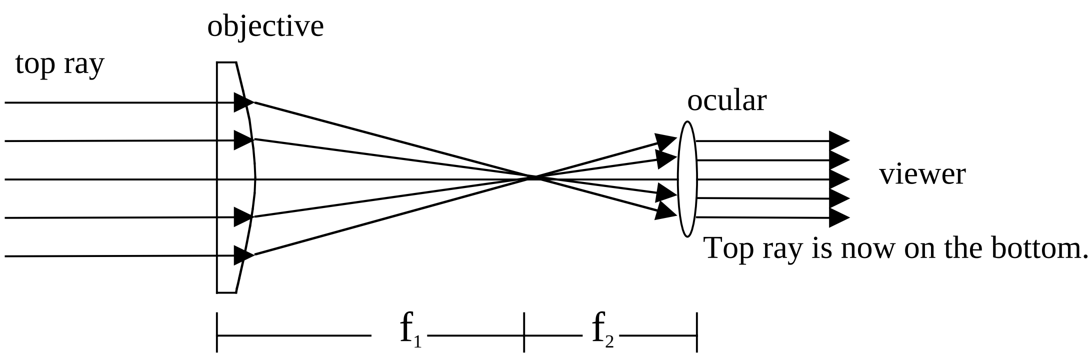
A ray diagram for a simple refractor (Keplerian) telescope is shown in figure 9. Note the focal points of the two lenses coincide. Since objects of interest (such as stars and planets) are extremely far away (distances much greater than the focal length), the incident rays are approximately parallel and refract to the first focal point. If the focal point of the ocular (or second) lens is at the same location, the rays will refract through the second lens in a parallel fashion. Note that the light rays are closer together and more light will now enter the eye. Also note that the top ray is now the bottom ray and vice-versa. This indicates that the image is inverted or upside-down. For astronomical viewing this is inconsequential. For a terrestrial viewing, a third lens can be used to re-invert the image.

Note that the magnification is simply the ratio of the objective focal length divided by the ocular focal length. Hence the focal length of the ocular is always smaller than that of the objective. In equation form,

$$m = f_1/f_2$$

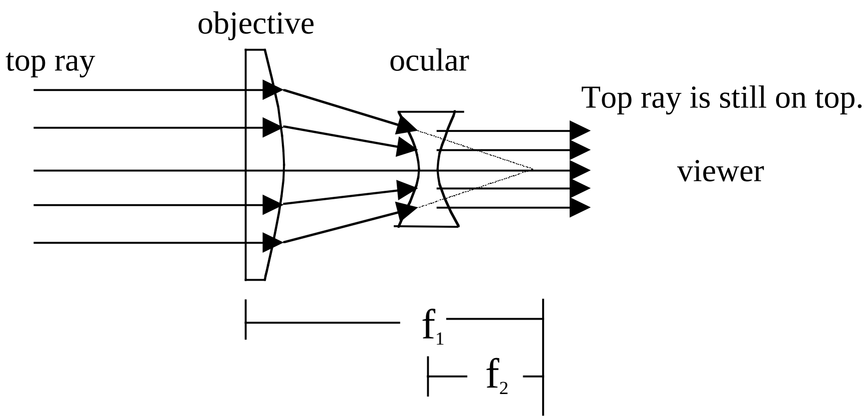
Since the light rays are closer together at the ocular, its diameter can naturally be smaller than the objective. This is generally the case since this is more cost efficient.

Figure 9 – Diagram of a refractor (Keplerian) telescope.



The first telescope (invented by Lippershey and popularized by Galileo) was intended to be used for terrestrial purposes and therefore used a diverging lens for the eyepiece. Figure 10 illustrates this type. Note that if the rays refracted by first lens are directed along a path towards the focal point of the second lens (extensions shown as dashed lines for two of the rays) that they will pivot and come out parallel through the second lens. Recall that the path of light is reversible. For a diverging lens, parallel rays refract from a focal point. Hence rays headed for a focal point will refract and come out parallel.

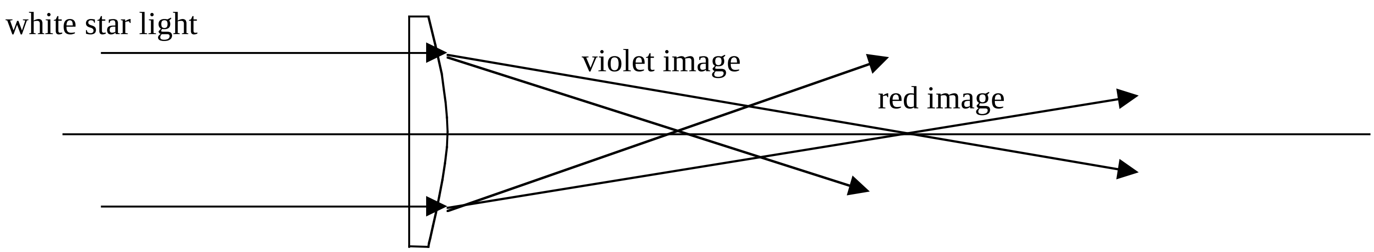
Figure 10 – Diagram of a refractor (Galilean) telescope.



Aberrations of Lenses

Two of the fundamental optical problems associated with lenses are chromatic aberrations and spherical aberrations. As discussed previously, the different colors of light travel at slightly different speeds. Violet light will have the shortest focal length of the colors and red light will have the longest focal length of the colors. These images will be along the axis ranging from the violet image that is slightly closer to the lens and the red image that is slightly farther from the lens. Figure 11 illustrates this (in exaggeration) for red and violet light. When considering the parallel rays that exit from the eyepiece of a telescope, it therefore follows that red rays will not be as close together as the violet rays. A spectral ring of colors will therefore surround images. Compound lenses made from more than one type of glass can partially compensate for this problem. Mirrors do not have this problem and that is one of the reasons for their use (instead of lenses) in telescope construction. [Mirrors will be discussed in the next section.]

Figure 11 – Chromatic aberrations for a lens.

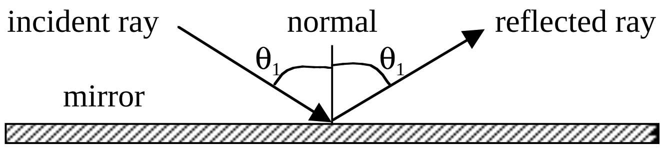


Spherical aberrations are caused by slightly different foci for rays passing near the edge of a spherically shaped lens compared to rays passing near the center of a lens. This again will produce a spread of images along the axis. Descartes proved that using either plano-hyperboloidal or spherico-ellipsoidal lenses would eliminate these problems. A more practical solution is to simply mask the edges of a lens and restrict the use to the central portion. Another partial solution is to use lenses with relatively small curvatures (i.e. – long focal lengths).

The Law of Reflection

When a light ray bounces from a surface, the incident angle is equal to the reflected angle. This relationship is known as the Law of Reflection. These angles (similar to the angles for Snell's Law) are also measured from a normal line drawn to the surface at the point of incidence. Figure 12 illustrates the Law of Reflection which is true for all types of waves and is independent of frequency.

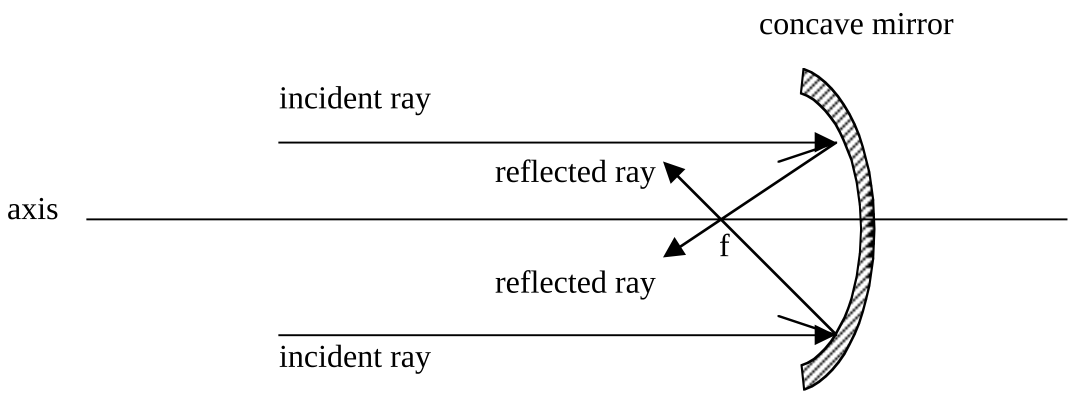
Figure 12 – Reflection from a plane mirror.



Application of the Law of Reflection to form Converging Mirrors

Curved mirrors can be constructed for astronomical use based upon the Law of Reflection. If a mirror is parabolic, rays parallel to the axis of the mirror will reflect and pass through a common point known as the focal point. At this point real images of distant stars or planets would be properly focused. The parabolic shape eliminates spherical aberrations and, as mentioned previously, there no chromatic aberrations for a mirror. Figure 13 illustrates the focal point for a concave mirror. Approximate normal lines are also drawn out from the mirror. (The shape of this mirror is not truly parabolic.) A concave mirror is considered a converging mirror and is analogous to a converging lens (e.g. – plano-convex lens). Since convex mirrors are generally not applicable to the study of telescopes and astronomy this topic will not be discussed in detail. In brief, however, convex mirrors are analogous to diverging lenses (e.g. – plano-concave lenses).

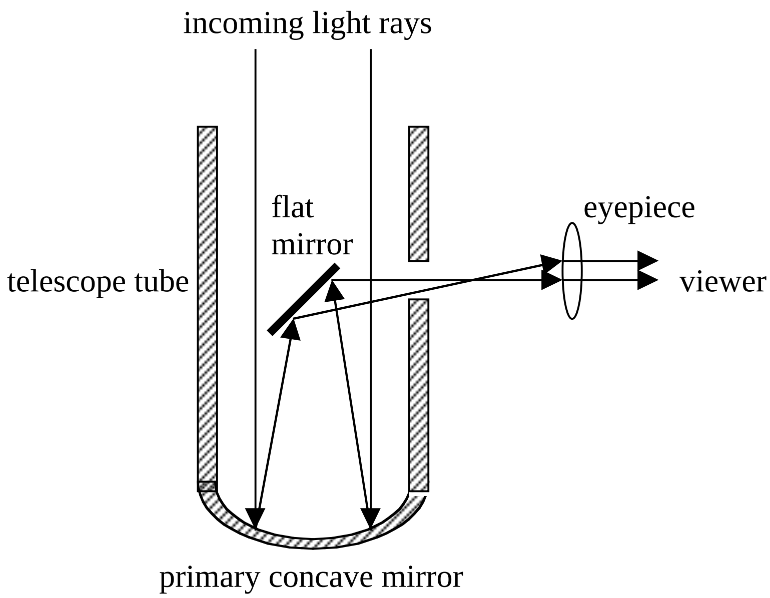
Figure 12 - Reflection from a concave mirror.



Application of Mirrors and Lenses to Create Newtonian Telescopes

Sir Isaac Newton constructed the first successful telescope using a primary concave mirror instead of an objective convex lens. Since Newton discovered the optical principals governing color, this was a natural way for him to eliminate chromatic aberrations from images. His telescope used a primary concave mirror, a secondary plane (or flat) mirror, and a converging lens for the eyepiece. A common arrangement is illustrated in figure 13. (Dimensions are exaggerated.) Note that the purpose of the secondary mirror is simply to change the direction of the rays reflected from the primary mirror. The secondary mirror is placed at a 45º angle to incoming rays in order to produce a net deviation of 90º and send the image out the side of the tube to the eyepiece. Similar to Kepler’s design, Newton’s design also yields inverted images. Most modern observatories use primary mirrors instead of objective lenses. Even serious amateur astronomers typically use primary mirrors for Newtonian or Cassegrain telescopes. Cassegrain telescopes use convex (instead of plane) secondary mirrors to shorten the tube length. It is generally easier and cheaper to use large primary mirrors instead of large objective lenses.

Figure 13 – Diagram of a reflector (Newtonian) telescope.



Appendix B – Additional Details for Laboratories and Activities

Student Construction of Telescopes

One possible approach for student construction of telescopes would be through use of a "learning cycle". The "learning cycle" is a method of instruction popularized for science instruction in the 1980s. In a typical cycle, students begin a hands-on exploration, followed by a class lecture/discussion based on the exploration, and concluding with a more formal laboratory application of the topics of interest. I would use this lesson after students have learned basic optics including reflection, refraction, ray diagrams, simple lenses, and possibly curved mirrors.

As an exploratory activity, I would simply provide students with a wide variety of lenses (and possibly mirrors and prisms but lenses would suffice). Both converging and diverging lenses of a variety of diameters and focal lengths should be included. [A list of possible materials and prices from Edmund Scientific is found at the end of this section.] Small groups often wok best for this type of activity. For exploratory activities I normally do not provide much instruction but instead save it for after the initial activity as part of a "learning cycle". Perhaps I would merely ask the students to try to use a combination of two or more lenses to see and magnify a distant object (perhaps 20 meters away). Also I may ask one student in each group to be a recorder and sketch diagrams of both their best telescopes and what they were able to see. While students are working, I often mingle with them and perhaps ask questions or make suggestions depending on what they have attempted. I prefer to use a variety of questioning techniques to steer students in a given direction if necessary. I deliberately avoid direct instruction if at all possible for this type of activity. This initial activity would probably last from 10 to 20 minutes depending on the students and their experience with optical instruments. Darkening the room and having students look out a window (most of the shades or blinds should be closed) at brightly illuminated objects typically works well.

After completing this activity, I would provide students with a 10 to 20 minute lecture on basic telescopes including rays diagrams for Galilean and Keplerian refractors (as well as a Newtonian reflector if students have already studied curved mirrors). Details and diagrams similar to those in appendix A (such as figures 9, 10, and 13) would be included. The need for a fairly large diameter convex objective lens with a long focal length (the lens should not bulge out too much) would now be stressed due to its ability to gather more light. Coupling this lens with an eyepiece having a small diameter and short focal length should provide decent results if the lenses are properly separated. Possibly hold them together at arms length and gradually separate them by moving the eyepiece closer to your eye. For the lenses listed by Edmund Scientific this should work.

For the remainder of class time I would ask students to specifically try to make Galilean and Keplerian refractor telescopes and compare the results with their earlier creations. Students should measure the optimal distance between the two lenses used and verify that it is the sum of focal lengths for the individual lenses. [Focal lengths for each lens are stated on their individual boxes/packages.] Students should also use a ruler to measure the apparent size of a distant object when viewed through the telescope and when viewed at the same location with the naked eye. The ratio of these sizes is the magnification and this should be the same as the ratio of the focal lengths. [See appendix A.]

Another extension of this learning cycle would be to now assign this as an out-of-class project. Each group of students could be assigned a particular telescope type and asked to construct it at home. This would require students to find or make an appropriate tube to house their optical components. These telescopes could be brought in later and other students can try to use them. Perhaps bringing them to a star party [discussed next in this appendix] to attempt to reproduce some of Galileo's initial observations of our moon, Jupiter, and Jupiter's moon would be an appropriate test of their quality. The best of these homemade telescopes can perhaps be placed in a display case in the school.

Equipment for Telescope Construction

http://es.rice.edu:80/ES/humsoc/Galileo/Student_Work/
Recently students in a history class at Rice University attempted to build and use a telescope similar to Galileo's to try and reproduce his findings. An excellent description of instructions on building a homemade Galilean telescope and their relevant observations is found on this site.

Edmund Scientific
http://www.edmundscientific.com/
Commercial supplier of general science supplies.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=1240
Assorted double convex lenses: 31.75 mm, 38 mm, 50 mm, and 75 mm diameters,
focal lengths of 50 mm, 75 mm, 100 mm, 150 mm, 200 mm, 250 mm, and 300 mm
$2.95 each.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=1212
Assorted plano-convex lenses: 50 mm and 75 mm diameters,
focal lengths of 100 mm, 150 mm, 200 mm, 250 mm, and 400 mm
$3.95 each.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=1194
Assorted double concave lenses: 31.75 mm, 38 mm, 50 mm, and 75 mm diameters,
focal lengths of -75 mm, -100 mm, -150 mm, and -200 mm
$3.95 each.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=1217
Assorted plano-concave lenses: 50 mm diameter,
focal lengths of -100 mm and -125 mm
$6.95 each.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=2389
12" diameter parabolic mirror
$29.95.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=1249
Assorted flat mirrors: 31.75 mm, 38 mm, and 50 mm
$2.95 to $3.95.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=1875
Optics Science Kit:
Beginners kit includes optical bench with 7 clips, a prism, concave lens, 2 convex lenses, 7 filters (color and polarizing), 2 mirrors, a penlight and holder, and a fiber optic strand
$19.95.

Hosting a Star Party

Hosting a star party is not as difficult as it sounds. Basically you are simply inviting your students (and possibly parents, other teachers, and the general public if you wish) to meet at night at a particular location to view the sky. Preferably the location should be dark and have a good view of the sky that is not hampered by light pollution. The peak of a hill near your school may work well. It is also important to have some type of restroom facilities available nearby if you are bringing a school group for extended period of time. If you plan to stay for an extended period of time (such as an overnight camping trip), electricity may be desirable in order to make hot chocolate and other hot beverages. Do not use bright flashlights while observing since these would destroy your night vision. If possible wrap the top of a dim flashlight with a red balloon or red cellophane. Red light is less detrimental to your night vision. Also warn your students in advance that any date scheduled definitely depends on the weather.

Do not allow a lack of equipment to dissuade you. Much can be observed simply with the naked-eye (e.g. - planets, constellations, the moon, meteor showers). However many students will have binoculars at home and some will probably have telescopes. Views of the Milky Way and the moon are greatly enhanced with binoculars. Some of the parents may even have some high quality telescopes at home that they would be willing to set up. If you have some quality binoculars or telescopes available, you will want to consult a list of deep sky objects for viewing. A list of over 100 interesting deep sky objects (such as galaxies and nebulae) can be found in the Messier Catalog. The group "Students for the Exploration and Development of Space" has a Messier catalog online at http://www.seds.org/messier/ with nice images of the objects.

A better idea than initially hosting your own star party would be to assist a local amateur astronomy group, planetarium, or university that may be holding one. This way you can invite your students with the assurance that others will be able to find interesting objects to view and discuss. Many amateur astronomy groups have listings in the telephone directory and on the web so a simple phone call or email message to ask when and where their next star party is being held should suffice. Be sure to introduce yourself as a teacher and offer to help since you anticipate attendance by a number of your students. Likewise feel free to call or email your local planetarium or university. If you are attempting to contact a university, first try to contact the astronomy department. If an astronomy department does not exist attempt to contact the physics department next and if all else fails try contacting a general science department. Newspapers and "Sky & Telescope" magazine (http://www.skypub.com/) will also list meetings of astronomy clubs, star parties, and open houses at nearby observatories.

Demonstration of Herschel's Discovery of Infrared Light

Although I have not yet tried this demonstration in my physics classroom it appears simple enough to do. You only need two basic pieces of equipment - a prism and a thermometer. A list of recommended equipment and prices from Edmund Scientific is found at the end of this section. It would certainly also be possible for students to do this as an experiment but the first time I attempt something I prefer it as a demonstration or a single cooperative group experiment especially since this depends on the weather. For those who already know how to produce a nice spectrum with a prism, a quick and easy demonstration is simply to project a spectrum and move a thermometer from color to color and record the temperature. Continue past the red into the infrared and the temperature here should be the highest. A more detailed activity is outlined below.

To demonstrate Herschel's discovery a bright sunny day is necessary. In a darkened room with the shades and blinds drawn you should open a slit in a small section of the blinds or shades to allow a narrow beam of sunlight pass into the room onto a table. If possible, open the window at this location to allow as much sunlight through the slit as possible. Place the prism in the path of the beam where it first enters the room. Rotate the angle of the prism until a broad spectrum of colors is projected onto the table. Placing a sheet of white paper on the table might make it easier to see the colors. If you are not getting good results try varying the size of the slit and the size and type of prism. Once you have a nice spectrum you may want to gently mount the prism in place with a clamp and ring stand (or simply use a student).

Herschel used three thermometers in his experiment - two as controls to monitor room temperature on either side of the colors and one to measure the temperature of the different colors. If you have three thermometers available I recommend this both for historical reasons and simply to demonstrate proper use of scientific equipment and collection of data. I recommend digital thermometers for ease of use and elimination of parallax error although other thermometers may also work well.

As part of the demonstration (or group experiment), I would ask a student to place a meter stick or ruler along the spectrum starting with the 0 cm mark at the farthest end of violet and measure the length of the spectrum. Students would then work in four pairs. One person in each pair would read data and one person would record data. Each pair would collect data for one column of a data table (see below). A pair would be assigned for each thermometer and one pair would be assigned to record the color and position along the meter stick of the thermometers.

Data Table for Use in Herschel's Experiment

Color	Position (cm)	Left temp. (ºF)	Color temp. (ºF)	Right temp. (ºF)
Violet				
Blue				
Green				
Yellow				
Orange				
Red				
Infrared				
Red				
Orange				
Yellow				
Green				
Blue				
Violet				
Ultraviolet				

To gather data I would ask students to place one thermometer around the center of the violet portion of the spectrum and the other two thermometers on the left and right of the color. After reaching equilibrium, assigned students should read the position of the thermometers and temperatures to their partners for recording. Proceed to move to the center of the next color and repeat. After reaching red, I would suggest that students move a bit further past red and notice if the temperature continues to rise. If so I'd ask them to record their data and continue a bit further and record again until they reach a point where it begins to drop. After this I would ask them to repeat this process a second time by working their way through the colors back to violet to reproduce their data and show that the other colors are still cooler. At this point I may ask them to suppose what may happen if they go beyond the violet into the ultraviolet and then collect appropriate data. [Many types of glass absorb ultraviolet so whether or not students would actually be measuring the temperature of ultraviolet light is questionable.]

The highest temperature should obviously be that recorded in the infrared red region and the use of infrared light as heat lamps could be discussed with students. Students should definitely be convinced of the physical reality of infrared light as this point despite their inability to see it. As a follow-up exercise to this activity, it might be interesting to plot and discuss temperature as a function of position for both the left and right controls and the color on a single graph. Any ultraviolet data will of course have a negative position so if included, the graph will not start at the origin unless the position data is appropriately shifted.

Other points that, though obvious, should be stated regards the position of the sun. It is not stationary! Therefore gather your data as quickly as possible before your conditions drastically change. Beware of clouds. They, and other obstructions such as smoke and shadows from trees, will readily change the data for your experiment. In these cases infrared light may seem to have the lowest, rather than the highest, temperature.

For information regarding some current research and observations of infrared sources I refer you to NASA's Infrared Telescope Facility. Their website at http://irtf.ifa.hawaii.edu/ includes a variety of fascinating infrared images of Mars, Jupiter, and other astronomical objects.

Equipment for Demonstration of Herschel's Experiment

Edmund Scientific
http://www.edmundscientific.com/
Commercial supplier of general science supplies.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=1176
Right angle prisms: 50mm/35mm/25mm – $9.95,
25mm/35mm/25mm – $6.95.

http://www.edmundscientific.com/Products/DisplayProduct.cfm?productid=587
Digital thermometer/clock - reads to the nearest 0.1 degree Fahrenheit
$19.95.

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