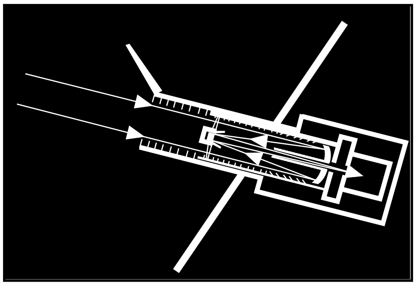


UNIT 3
COLLECTING ELECTROMAGNETIC RADIATION

Introduction

Except for rock samples brought back from the Moon by Apollo astronauts, cosmic ray particles that reach the atmosphere, and meteorites and comet dust that fall to Earth, the only information about objects in space comes to Earth in the form of electromagnetic radiation. How astronomers collect this radiation determines what they learn from it. The most basic collector is the human eye. The retina at the back of the eye is covered with tiny antennae—called rods and cones—that resonate with incoming light. Resonance with visible electromagnetic radiation stimulates nerve endings, which send messages to the brain that are interpreted as visual images. Cones in the retina are sensitive to the colors of the visible spectrum, while the rods are most sensitive to black and white.

Until the early 1600s, astronomers had only their eyes and a collection of geometric devices to observe the universe and measure locations of stellar objects. They concentrated on the movements of planets and transient objects such as comets and meteors. However, when Galileo Galilei used the newly invented telescope to study the Moon, planets, and the Sun, our knowledge of the universe changed dramatically. He was able to observe moons circling Jupiter, craters on the Moon, phases of Venus, and spots on the Sun. Note: Galileo did his solar observations by projecting light through his telescope on to a white surface—a technique that is very effective even today. **Never look directly at the Sun!**

Galileo's telescope and all optical telescopes that have been constructed since are collectors of electromagnetic radiation. The objective or front lens of Galileo's telescope was only a few centimeters in diameter. Light rays falling on that lens were bent and concentrated into a narrow beam that emerged through a second lens, entered his eye, and landed on his retina. The lens diameter was much larger than the diameter of the pupil of Galileo's eye, so it collected much more light than Galileo's unaided eye could gather. The telescope's lenses magnified the images of distant objects three times.

Since Galileo's time, many huge telescopes have been constructed. Most have employed big mirrors as the light collector. The bigger the mirror or lens, the more light could be gathered and the fainter the source that the astronomer can detect. The famous 5-meter-diameter Hale Telescope on Mt. Palomar is able to gather 640,000 times the amount of light a typical eye could receive. The amount of light one telescope receives compared to the human eye is its light gathering power (LGP). Much larger even than the Hale Telescope is the Keck Telescope that has an effective diameter of 10 meters. Its light gathering power is two and a half million times that of the typical eye. Although NASA's Hubble Space Telescope, in orbit above Earth's atmosphere, has only a LGP of 144,000, it has the advantage of an unfiltered view of the universe. Furthermore, its sensitivity extends into infrared and ultraviolet wavelengths.

Once a telescope collects photons, the detection method becomes important. Telescopes are collectors, not detectors. Like all other telescopes, the mirror of the Hubble Space Telescope is a photon collector that gathers the photons to a focus so a detector can pick them up. It has several filters that move in front of the detector so images can be made at specific wavelengths.

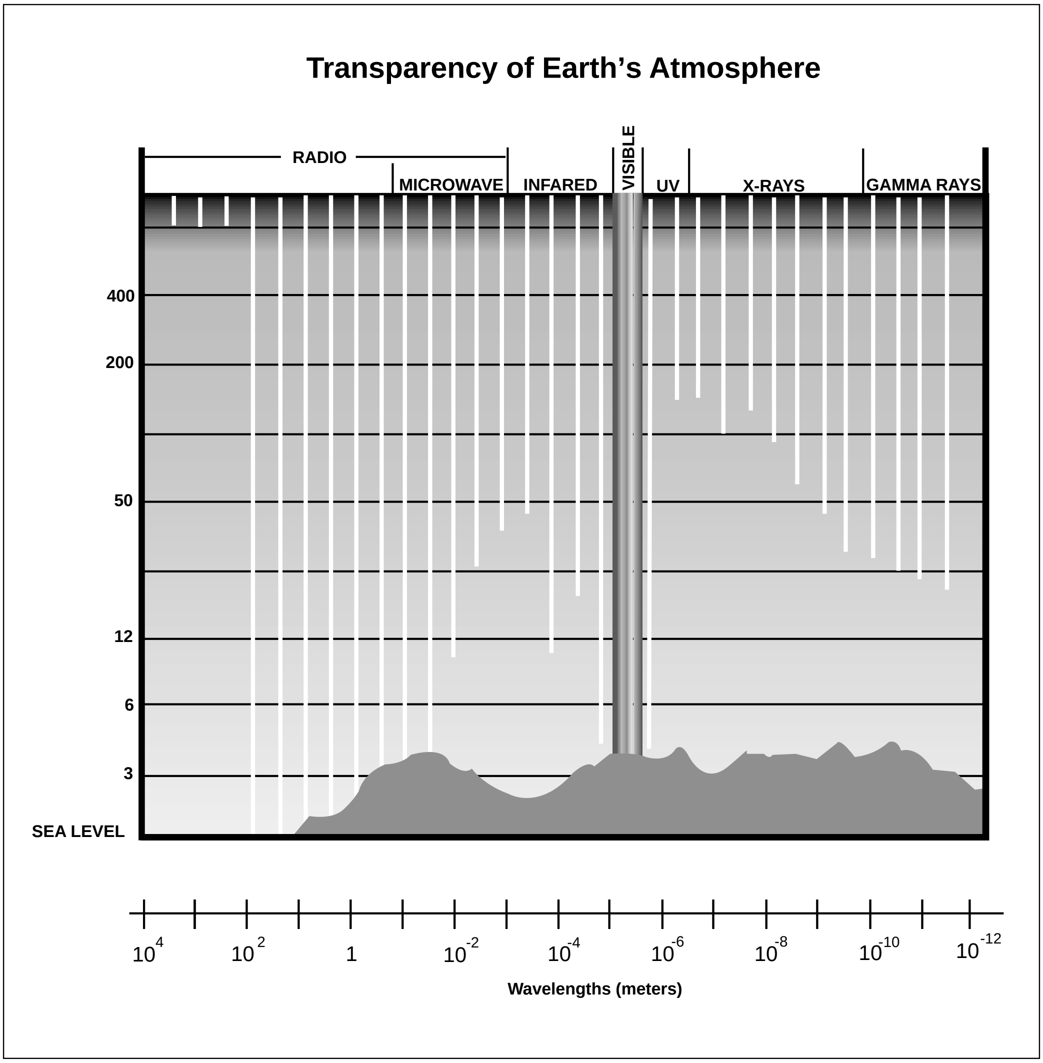
In the early days, astronomers recorded what they saw through telescopes by drawing pictures and taking notes. When photography was invented, astronomers replaced their eyes with photographic plates. A photographic plate is similar to the film used in a modern camera except that the emulsion was supported on glass plates instead of plastic. The emulsion collected photons to build images and spectra. Astronomers also employed the photo-multiplier tube, an electronic device for counting photons.

The second half of this century saw the development of the Charge Coupled Device (CCD), a computer-run system that collects photons on a small computer chip. CCDs have now replaced the photographic plate for most astronomical observations. If astronomers require spectra, they insert a spectrograph between the telescope and the CCD. This arrangement provides digital spectral data.

Driving each of these advances was the need for greater sensitivity and accuracy of the data. Photographic plates, still used for wide-field studies, collect up to about five percent of the photons that fall on them. A CCD collects 85 to 95 percent of the photons. Because CCDs are small and can only observe a small part of the sky at a time, they are especially suited for deep space observations.

Because the entire electromagnetic spectrum represents a broad range of wavelengths and energies (see illustration on page 55), no one detector can record all types of radiation. Antennas are used to collect radio and microwave energies. To collect very faint signals, astronomers use large parabolic radio antennas that reflect incoming radiation to a focus much in the same way reflector telescopes collect and concentrate light. Radio receivers at the focus convert the radiation into electric currents that can be studied.

Sensitive solid state heat detectors measure infrared radiation, higher in energy and shorter in wavelength than radio and microwave radiation. Mirrors in aircraft, balloons, and orbiting spacecraft can concentrate infrared radiation onto the detectors that work like CCDs in the infrared range. Because infrared radiation is



associated with heat, infrared detectors must be kept at very low temperatures lest the telescope’s own stored heat energy interferes with the radiation coming from distant objects.

A grazing-incidence instrument consists of a mirrored cone that directs high-energy radiation to detectors placed at the mirror’s apex. Different mirror coatings are used to enhance the reflectivity of the mirrors to specific wavelengths.

X-ray spacecraft, such as the Chandra X-ray Observatory, also use grazing-incidence mirrors and solid state detectors while gamma ray spacecraft use a detector of an entirely different kind. The Compton Gamma-Ray Observatory has eight 1-meter-sized crystals of sodium iodide that detect incoming gamma rays as the observatory orbits Earth. Sodium iodide is sensitive to gamma rays but not to optical and radio wavelengths. The big crystal is simply a detector of photons—it does not focus them.

Today, astronomers can choose to collect and count photons, focus the photons to build up an image, or disperse the photons into their various wavelengths. High-energy photons are usually detected with counting techniques. The other wavelengths are detected with counting (photometry), focusing methods (imaging), or dispersion methods (spectroscopy). The particular instrument or combination of instruments astronomers choose depends not only on the spectral region to be observed, but also on the object under observation. Stars are point sources in the sky. Galaxies are not. So the astronomer must select a combination that provides good stellar images or good galaxy images.

Another important property of astronomical instruments is resolution. This is the ability to separate two closely-spaced objects from each other. For example, a pair of automobile headlights appears to be one bright light when seen in the distance along a straight highway. Close up, the headlights resolve into two. Since telescopes, for example, have the effect of increasing the power of our vision, they improve our resolution of distant objects as well. The design and diameter of astronomical instruments determines whether the resolution is high or low. For stellar work, high resolution is important so the astronomer can study one star at a time. For galaxy work, the individual stars in a galaxy may often not be as important as the whole ensemble of stars.

Unit Goals

- To demonstrate how electromagnetic radiation can be collected and detected through the use of mirrors, lenses, and infrared detectors.
- To illustrate how the use of large instruments for collecting electromagnetic radiation increases the quantity and quality of data collected.

Teaching Strategy

Because many of the wavelengths in the electromagnetic spectrum are difficult or dangerous to work with, activities in this section concentrate on the visible spectrum, the near infrared, and radio wavelengths. Several of the activities involve lenses and mirrors. The Visible Light Collector activity provides many tips for obtaining a variety of lenses and mirrors at little or no cost.

ACTIVITY: Visible Light Collectors (Telescopes)

Description:

A simple refractor telescope is made from a mailing tube, Styrofoam tray, rubber cement, and some lenses and the principle behind a reflector telescope is demonstrated.

Objectives:

To build a simple astronomical telescope from two lenses and some tubes.
To use a concave mirror to focus an image.

National Education Standards:

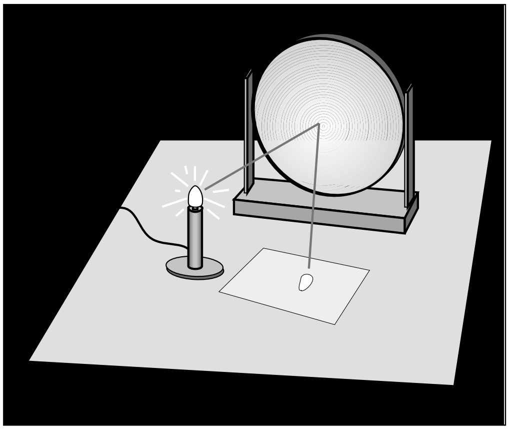
Mathematics
- Measurement
- Connections

Science
- Change, constancy, & measurement
- Abilities of technological design
- Understanding about science & technology
- History of science

Technology
- Understand relationships & connections among technologies & other fields
- Understand cultural, social, economic, & political effects of technology
- Understand the influence of technology on history
- Understand, select, & use information & communication technologies

Materials:

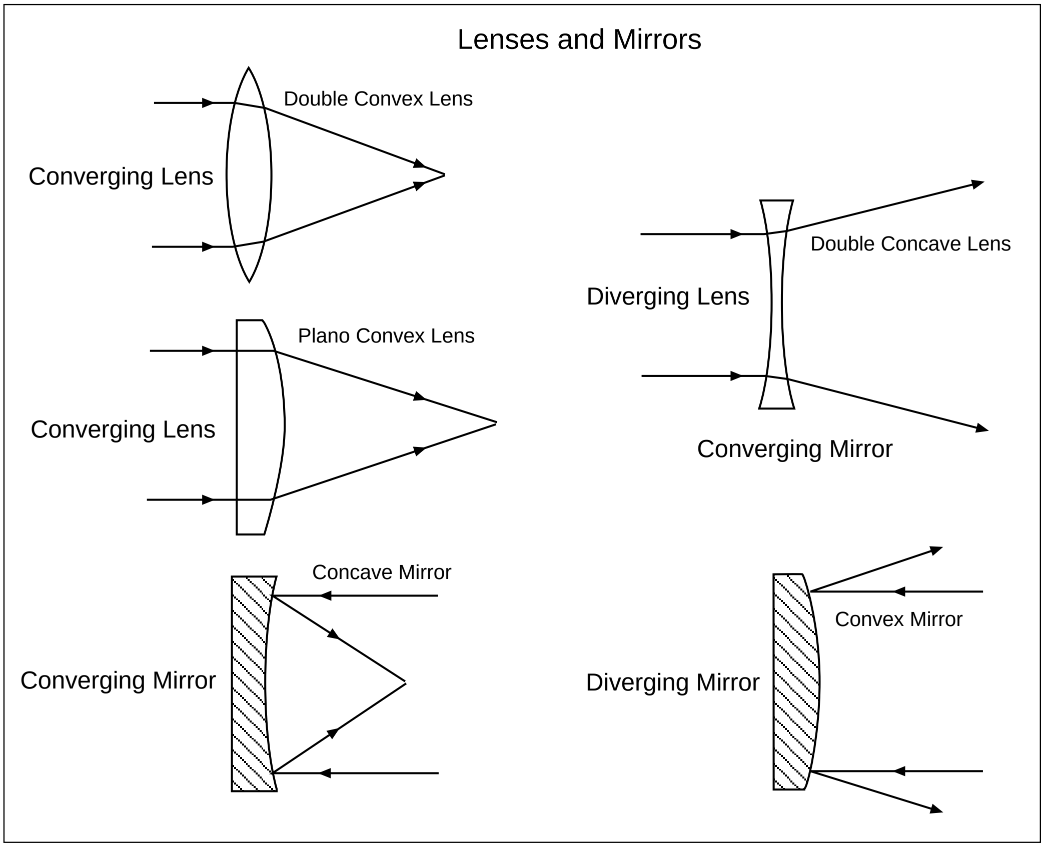
- Paper mailing tube (telescoping—1 inside tube and 1 outside tube)
- Styrofoam trays (1 thick and 1 thin)
- Lenses (1 large and 1 small. See note about lenses.)
- Metric ruler
- Razor blade knife
- Cutting surface
- Marker pen
- Rubber cement
- Fine grade sandpaper
- Concave makeup mirror
- Electric holiday candle or other small light source



- Dark room
- Sheet of white paper
- Assorted convex lenses (See section on Obtaining and Making Lenses and Mirrors.)

Part 1 - Procedure for Making a Refractor Telescope:

1. Cut a short segment from the end of the outside mailing tube. This circle will be used for tracing only. Place the circle from the larger tube on the thick tray. Using a marker pen, trace the inside of the circle on to the bottom of the tray three times.
2. Lay the large (objective) lens in the center of one of the three large circles. Trace the lens' outline on the circle.
3. Cut the circle with the lens tracing from the tray using the razor blade knife. Be sure to place the Styrofoam on a safe cutting surface. Cut out the lens tracing, but when doing so, cut inside the line so that the hole is slightly smaller than the diameter of the lens.
4. Before cutting out the other two large circles, draw smaller circles inside them approximately equal to 7/8ths of the diameter of the large lens. Cut out both circles inside and out.
5. Coat both sides of the inner circle (the one that holds the lens) with rubber cement and let dry. Coat just one side each of the other two circles with cement and let dry. For a better bond, coat again with glue and let dry.
6. Insert the lens into the inner circle. It will be snug. Press the other circles to either side. Be



careful to align the circles properly. Because the outside circles have smaller diameters than the lens, the lens is firmly held in place. You have completed the objective lens mounting assembly.

7. Repeat steps 1- 6 for the inside tube and use the smaller lens for tracing. However, because the eyepiece lens is thinner than the objective lens, cut the inner circle from the thin tray.
8. After both lens mounting assemblies are complete, lay the fine sandpaper on a flat surface and gradually sand the edges of each completed lens mounting assembly to make them smooth. Stop sanding when the assemblies are just larger than the inside diameter of the corresponding tube. With a small amount of effort, the assembly will compress slightly and slip inside the tube. (Do not insert them yet.) Friction will hold them in place. If the lens assemblies get too loose, they can be held firmly with glue or tape.
9. Hold the two lens assemblies up and look through the lenses. Adjust their distances apart and the distance to your eye until an image comes into focus. Look at how far the two lenses are from each other. Cut a segment from the outside and the inside tube that together equal two times the distance you just determined when holding up the lenses. Use the sandpaper to smooth any rough edges on the tubes after cutting.
10. Carefully, so as not to smudge the lenses, insert the large lens assembly into one end of the outside tube and the eyepiece lens assembly into the end of the inside tube. Slip the inside tube into the outside tube so that the lenses are at opposite ends. Look through the eyepiece towards some distant object and slide the small tube in and out of the large tube until the image comes into focus.
11. (Optional) Decorate the outside tube with marker pens or glue a picture to it.

Background:

The completed telescope is known as a refractor. Refractor means that light passing through the objective lens is bent (refracted) before reaching the eyepiece. Passing through the eyepiece, the light is refracted again.

This refraction inverts the image. To have an upright image, an additional correcting lens or prism is placed in the optical path. Astronomers rarely care if images are right-side-up or up-side-down. A star looks the same regardless of orientation. However, correcting images requires the use of extra optics that diminish the amount of light collected. Astronomers would rather have bright, clear images than right-side-up images. Furthermore, images can be corrected by inverting and reversing photographic negatives or correcting the image in a computer.

Management and Tips:

Refer to the end of this activity for ideas on how to obtain suitable lenses. PVC plumbing pipes can be used for the telescoping tubes. Purchase tube cutoffs of different diameters at a hardware store. Make sure the cutting of the outside circles in the Styrofoam is precise. A circle cut too small will fall through the tube. If students do cut circles too small, the diameter of the circles can be increased by adding one or more layers of masking tape.

Part 2 - Procedure for Demonstrating the Reflector Telescope Principle:

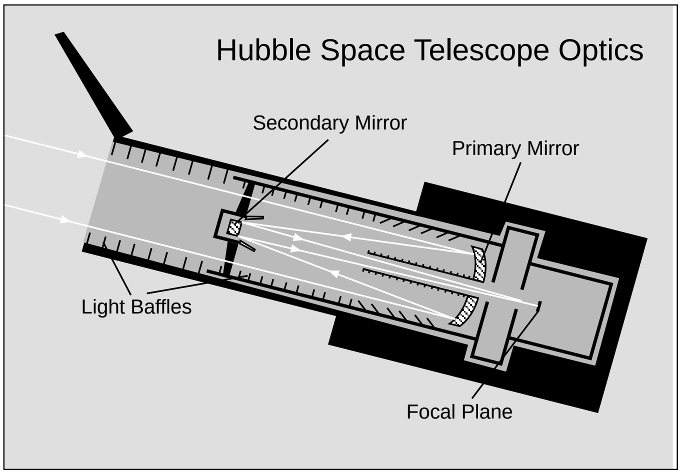
1. Light the electric candle in a darkened room.
2. Bring the concave makeup mirror near the candle flame and tilt and turn it so that reflected light from the lamp focuses on a sheet of white paper.
3. Experiment with different lenses to find one suitable for turning the makeup mirror into a simple reflector telescope. Hold the lens near your eye and move it until the reflected light from the mirror comes into focus.

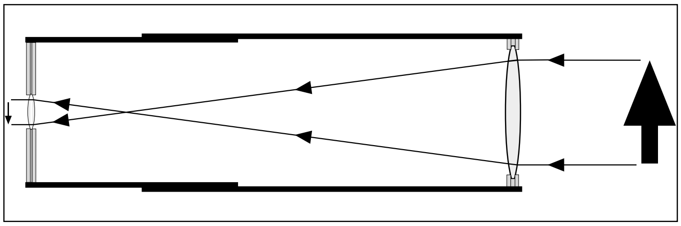
Background:

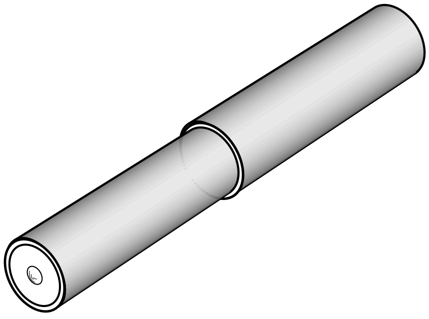
Many reflecting telescopes gather light from distant objects with a large concave mirror that directs the light toward a secondary mirror which then focuses the light onto a detector. The concave mirror used in this demonstration shows how a concave mirror can concentrate light to form a recognizable image. The image produced with a makeup mirror will not be well focused because such mirrors are inexpensively produced from molded glass rather than from carefully shaped and polished glass. Furthermore, proper focusing requires that the mirror be precisely shaped in a parabolic curve.

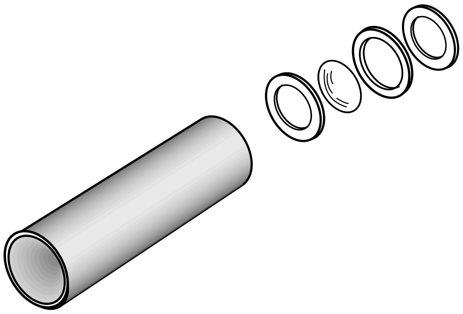
Reflecting telescope mirrors can be made very large and this increases the amount of light they can capture. Refer to the telescope performance activity that follows for information on light gathering power. Small telescopes can only detect bright or nearby stars. Large telescopes (over 4 meters in diameter) can detect objects several billion times fainter than the brightest stars visible to our naked eyes.

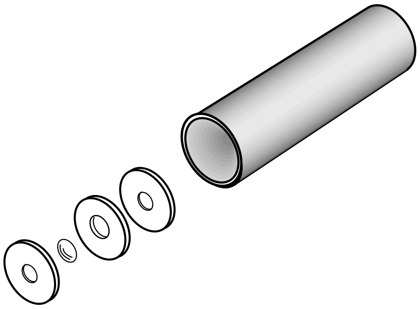
Large astronomical telescopes do not employ eyepieces. Rather, light falls on photographic film, photometers, or charged coupled devices (CCDs). This demonstration shows how an image forms on a flat surface. Covering the











surface with photographic film will produce a crude picture. Although astronomers have converted to CCDs for most observations, photography is still employed for some applications. Rather than film, astronomers usually prefer photographic emulsions on sheets of glass, which are more stable over time.

Assessment:

Examine the telescope for construction technique. Are the lenses parallel or canted to each other? Can the telescope focus on an image? Use the telescopes made here as samples for the telescope performance activities that follow.

Extensions:

- Bring commercially-made telescopes, spyglasses, and binoculars into the classroom. Compare magnification, resolution, and light gathering power to that of the telescope made here. Learn how these optical instruments function.
- Invite local amateur astronomy clubs to host "star parties" for your students.
- Why are the largest astronomical telescopes made with big objective mirrors rather than big objective lenses?
- Find out how different kinds of reflecting telescopes such as the Newtonian, Cassegrain, and Coude work.

Obtaining and Making Lenses and Mirrors:

An amazing collection of lenses and mirrors can be obtained at little or no cost through creative scrounging. Ask an optometrist or eyewear store if they will save damaged eyeglass lenses for you. Although not of a quality useful for eyewear, these lenses are very suitable for classroom experimentation. Bifocals and trifocals make fascinating magnifying lenses. Fill a spherical glass flask with water to make a lens. Water-filled cylindrical glass or plastic bottles make magnifiers that magnify in one direction only. Aluminized mylar plastic stretched across a wooden frame makes a good front surface plane mirror. A Plexiglas mirror can be bent to make a "funhouse" mirror. Low-reflectivity plane mirrors can be made from a sheet glass backed with black paper. Ask the person in charge of audiovisual equipment at the school to save the lenses from any broken or old projectors that are being discarded. Projector and camera lenses are actually made up of many lenses sandwiched together. Dismantle the lens mounts to obtain several usable lenses. Check rummage sales and flea markets for binoculars and old camera lenses. A wide assortment of lenses and mirrors are also available for sale from school science supply catalogs and from the following organization:

Optical Society of America
2010 Massachusetts Avenue, NW
Washington, D.C. 20036
(202) 223-8130

ACTIVITY: Telescope Performance

Description:

Students compare and calculate the light gathering power of lenses.

Objective:

To determine the ability of various lenses and mirrors to gather light.

National Education Standards:

Mathematics
- Patterns, functions, & algebra
- Geometry & spatial sense
- Measurement
- Problem solving
- Connections

Science
- Change, constancy, & measurement
- Abilities necessary to do scientific inquiry
- Understandings about science & technology

Technology
- Understand characteristics & scope of technology
- Understand, select, & use information & communication technologies

Materials:
- Gray circles on page 00
- White paper punchouts from a three-hole paper punch
- White paper
- Double convex lenses of different diameters
- Metric ruler
- Small telescope from previous activity
- Binoculars (optional)
- Overhead projector
- Transparency copy of master on page 00
- Resolving Power chart on page 00
- Astronomical telescope (optional)

Procedure – Light Gathering Power:

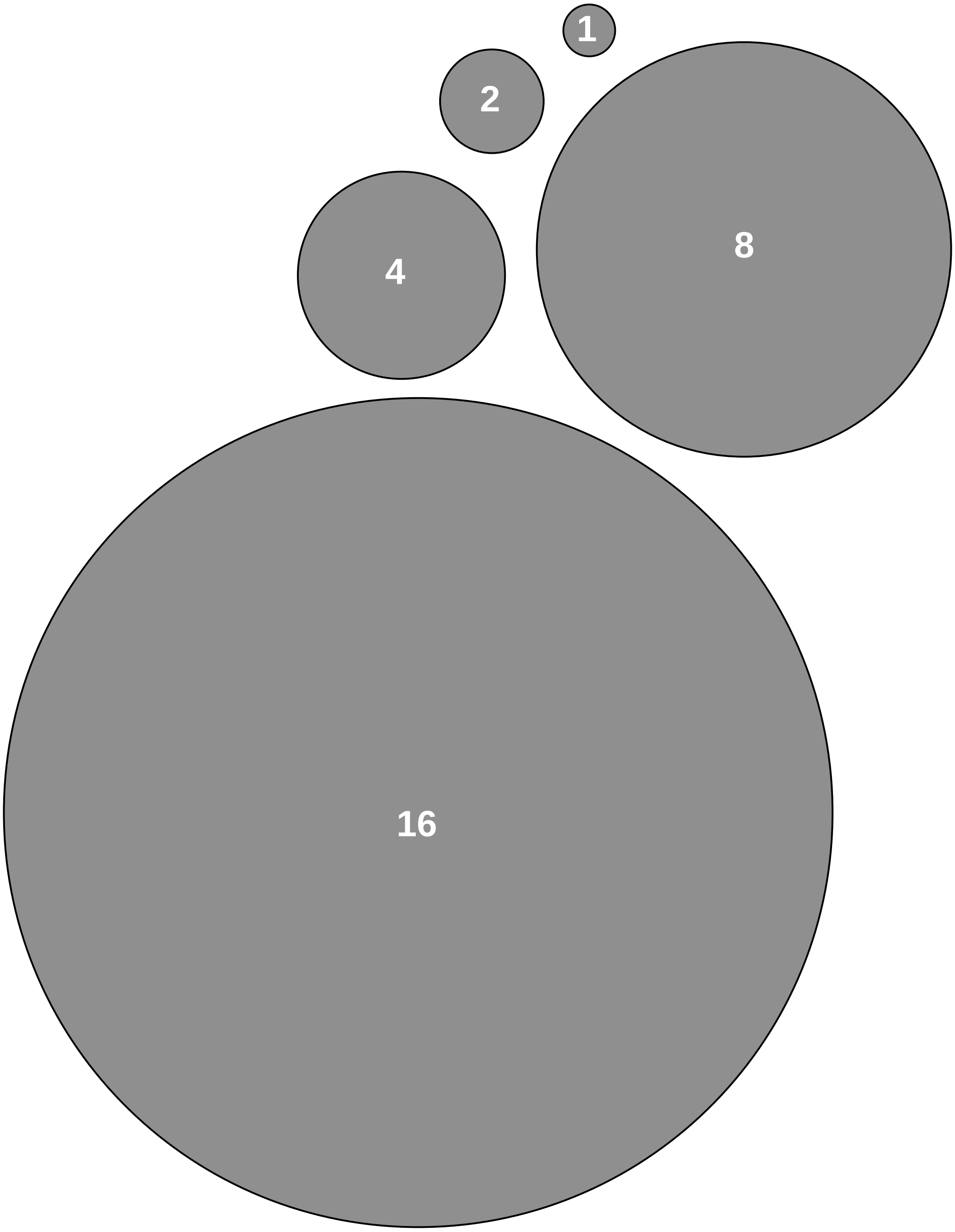
1. Have students examine several different double convex lenses.
2. Compare the ability of each lens to gather light by focusing the light from overhead fixtures onto a piece of white paper. Which lens produces a brighter image? Be sure to hold the lenses parallel to the paper.
3. Compare the light gathering power of five imaginary lenses (gray circles) by placing small white paper circles (punchouts) on each. The number of punchouts represents the number of photons collected at a moment of time. Students may draw their own circles with compasses for this step.
4. What is the mathematical relationship between the number of punchouts that a circle can hold and the circle's diameter? How did you arrive at this conclusion?

Procedure – Magnification:

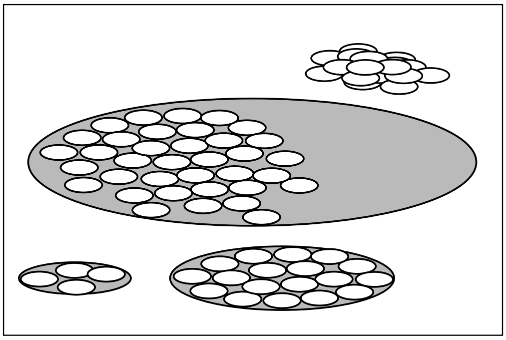
1. Make an overhead transparency of the grid on page 68. Project the transparency on a screen so that it is as large as possible and position the projector to reduce the "keystone" effect.
2. Roll a paper tube the same diameter as the front end of the telescope or binocular lens you are using. The length of the tube should be the same length as the telescope or binocular. Because binoculars use prisms to reduce their size (see illustration), make the tube two times longer than the distance between the front and rear lenses of the binoculars.
3. Have students stand in the middle or rear of the room. They should stand at a distance that will permit the telescope or binoculars to focus on the screen. Many optical instruments have minimum focal distances.
4. Looking first through the tube, have students count the number of squares they can see at a time from one side of the tube to the other.
5. Using the binoculars (one eye only) or the telescope, have students repeat the counting of squares.
6. The ratio of the number of squares seen in the tube versus the number seen in the binoculars is a rough approximation of the magnification power of the instrument. For example, if the student can see three squares with the tube and only one with the telescope, the magnification power of the telescope is approximately 3 because a single square spanned the telescope instead of three squares with a tube of a similar diameter and length.

Procedure – Resolving Power:

1. Tape page 63 to the front board.
2. Have students stand near the rear of the room


1
2
8
4
16

Magnification Grid



and look at the dots. Ask them to look at the squares and state how many dots they see.

3. Have students repeat the observation with the aid of a telescope or binoculars.

Background:

Light Gathering Power – In a dark room, the pupil of the eye gets bigger to collect more of the dim light. In bright sunlight, the pupil gets smaller so that too much light is not let into the eye. A telescope is a device that effectively makes the pupil as large as the objective lens or mirror.

A telescope with a larger objective lens (front lens) or objective mirror collects and concentrates more light than a telescope with a smaller lens or mirror. Therefore, the larger telescope has a greater light gathering power than the smaller one. The mathematical relationship that expresses *light gathering power* (LGP) follows:

$$\frac{LGP_A}{LGP_B} = \left(\frac{D_A}{D_B}\right)^2$$

In this equation, A represents the larger telescope and B the smaller telescope or human eye. The diameter of the objective lens or mirror for each telescope is represented by D. Solving this equation yields how much greater the light gathering power (LGP) of the bigger telescope is over the smaller one. For example, if the diameter of the large telescope is 100 cm and the smaller telescope is 10 cm, the light gathering power of the larger telescope will be 100 times greater than that of the smaller scope.

$$\frac{LGP_A}{LGP_B} = \left(\frac{100\text{ cm}_A}{10\text{ cm}_B}\right)^2 = \frac{10{,}000}{100} = 100$$

Light gathering power is an important measure of the potential performance of a telescope. If an astronomer is studying faint objects, the telescope used must have sufficient light gathering power to collect enough light to make those objects visible. Even with the very largest telescopes, some distant space objects appear so faint that the only way they become visible is through long-exposure photography or by using CCDs. A photographic plate at the focus of a telescope may require several hours of exposure before enough light collects to form an image for an astronomer to study. Unfortunately, very large ground-based telescopes also detect extremely faint atmospheric glow, which interferes with the image. Not having to look through the atmosphere to see faint objects is one of the advantages space-based telescopes have over ground-based instruments.

Magnification – Magnification is often misunderstood as a measure of a telescope's performance. One would think that a telescope with a higher magnification power would perform better than a telescope with a lower power. This is not necessarily so. A telescope with a high magnification power but a low light gathering power will produce highly magnified images that are too faint to see. A rule of thumb in obtaining a telescope is that the magnification of the telescope should be no greater than 25 times the diameter of the large (front) lens in centimeters. For example, a telescope with a front lens with a diameter of 5 centimeters should have a maximum magnification of no more than 125. Anything beyond that will produce a very poor view.

$$M = \frac{F_o}{F_e}$$

The magnification of a telescope is calculated by dividing the focal length of the front lens by the focal length of the eyepiece. The focal length is the distance from the center of the lens to the focal point. With astronomical telescopes, the focal lengths of the various lenses are marked on the housing.

$$\alpha = \frac{11.6}{D}$$

Resolving Power – With telescopes as powerful as the Hubble Space Telescope, resolving power becomes important. Resolving power is the ability of a telescope to separate two closely spaced objects. For example, a bright star to the naked eye might actually be two closely-spaced stars in a telescope. Resolving power is measured in arc seconds. An arc second is 1:3,600th of a degree.

Management and Tips:

In this light gathering power activity, younger students can use larger objects such as pennies, washers, or poker chips in place of the paper punchouts. Discs can be eliminated entirely by drawing the circles directly on graph paper and counting the squares to estimate light gathering power of different sized lenses and mirrors. When students notice that the punchouts do not entirely cover the circles, ask them what they should do to compensate for the leftover space.

For the activity on magnification and resolving power, use the small telescope constructed in the previous activity. Because of their minimum focal distance, astronomical telescopes will not work for this activity. A toy spyglass and spotter scopes should work.

Assessment:

Collect student sheets and compare answers.

Student Work Sheet Answers:

1A. The ratio of the amount of light a telescope can gather compared to the human eye.

1B. The ability of a telescope to make distant objects appear larger.

1C. The ability of a telescope to distinguish between two closely spaced objects.

2. 100

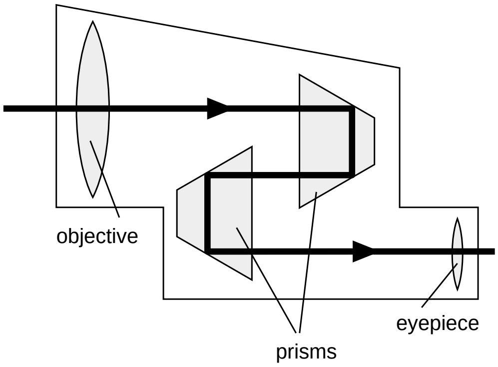
3. 100

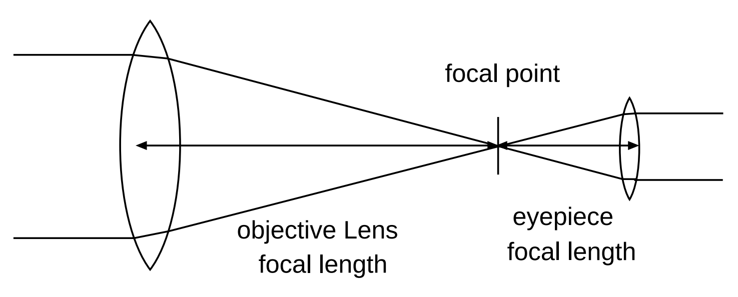
4. 0.058 arc seconds

Extensions:

- Compare the light gathering power of the various lenses you collected with the human eye. Have students measure the diameters, in centimeters, of each lens. Hold a small plastic ruler in front of each student's eye in the class and derive an average pupil diameter for all students. Be careful not to touch eyes with the ruler. If you have an astronomical telescope, determine its light gathering power over the unaided human eye.
- If an astronomical telescope is available, have students calculate the actual magnification power of the telescope with its various lenses.
- Have students calculate the focal length of the lenses used in the light gathering power portion of this activity. The students should focus light from overhead fixtures on the desk top and measure how far above the desk the lens is. This is the focal length.

Optical Path for Binoculars





Resolution Chart

Student Work Sheet

Telescope Performance

Name: ________________________

1. What do each of these terms mean?

    A. Light gathering power

    B. Magnification

    C. Resolving power

2. A telescope has a diameter of 10 centimeters. The iris of your eye has a diameter 1 centimeter. What is the light gathering power of the telescope compared to your eye. Show your work below.

3. Explain how to measure the focal length of a lens.

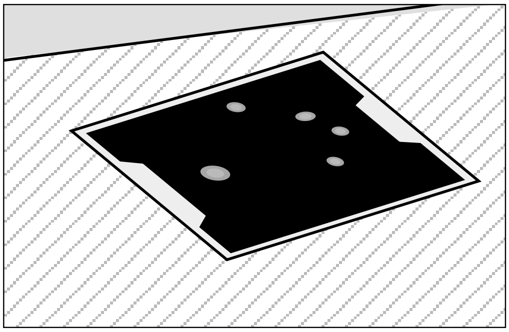
4. A telescope has an objective (front) lens with a focal length of 1,000 mm and an eyepiece with a focal length of 10 mm. What is the magnification power of the telescope? Show your work below.

5. A telescope has an objective lens with a diameter of 200 centimeters. What is the telescope's resolving power? Show your work below.

ACTIVITY: Liquid Crystal IR Detector

Description:

Students simulate the detection of infrared radiation using a liquid crystal sheet.



Objective:

To experiment with one method of detecting infrared radiation.

National Education Standards:

Science
- Evidence, models, & explanation
- Properties & changes of properties in matter
- Transfer of energy
- Understandings about science & technology

Technology
- Understand relationships & connections among technologies & other fields
- Understand, select, & use information & communication technologies

Materials:

- Liquid crystal sheet (available at museums, nature stores, and science supply catalogs)
- Table top

Procedure:

1. Have a student touch his or her fingertips on a tabletop for 30 seconds. Make sure the student has warm hands.
2. While handling the liquid crystal sheet only by its edges, place it where the fingertips touched the table. Observe what happens over the next several seconds.

Background:

Infrared telescopes have a detector sensitive to infrared light. The telescope is placed as high up in the atmosphere as possible on a mountaintop, in an aircraft or balloon, or flown in space because water vapor in the atmosphere absorbs some of the infrared radiation from space. The human eye is not sensitive to infrared light, but our bodies are. We sense infrared radiation as heat. Because of this association with heat, telescopes and infrared detectors must be kept as cool as possible. Any heat from the surroundings will create lots of extra infrared signals that interfere with the real signal from space. Astronomers use cryogens such as liquid nitrogen, liquid helium, or dry ice to cool infrared instruments.

This activity uses a liquid crystal detector that senses heat. Also known as cholesteric liquid crystals, the liquid inside the sheet exhibits dramatic changes in colors when exposed to slight differences in temperature within the range of 25 to 32 degrees Celsius. The sheet detects the heat associated with infrared rays.

In the case of an infrared telescope in space, the energy is detected directly by instruments sensitive to infrared radiation. Usually, the data is recorded on computers and transmitted to Earth as a radio signal. Ground-based computers reassemble the image of the objects that created the radiation.

Management and Tips:

Liquid crystal sheets come in many forms. The best sheets for this activity are large enough to fit an entire hand. These sheets also come as postcards and as thermometers. You may be able to find a forehead thermometer made of a strip of liquid crystals.

Do not allow the sheet to come into direct contact with very hot materials as they may damage the sheet. It is important that the student has hands warm enough to leave a heat signature on the tabletop. Also, it is important that the tabletop be relatively cool to start with. If the table is already warm, the image of the fingertips will be masked by the tabletop's heat. This is similar to the situation that would occur inside a spacecraft that is not cooled. Stray infrared signals from the spacecraft would cloud the infrared image from distance objects.

Assessment:

Ask your students why it is important to keep infrared telescopes very cool for accurate observations.

Extensions:

- How was infrared radiation discovered?
- Why do infrared detectors have to be kept cold?
- Learn about cholesteric liquid crystals. An Austrian botanist Freidrich Reinitfer discovered them in 1888.
- Obtain an infrared thermometer for measuring temperatures from a distance. Such thermometers are available from science supply companies. Use the thermometer to measure the temperature of various objects such as a candle flame, beaker of warm water, or ground surfaces in and out of the sunlight.
- Invite a thermal scanning company to demonstrate their equipment to your students. These companies use infrared scanners to form infrared images of homes to isolate areas of heat loss.