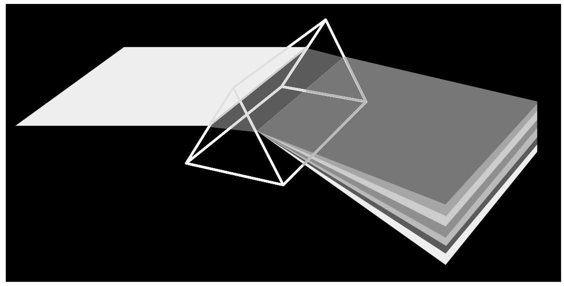


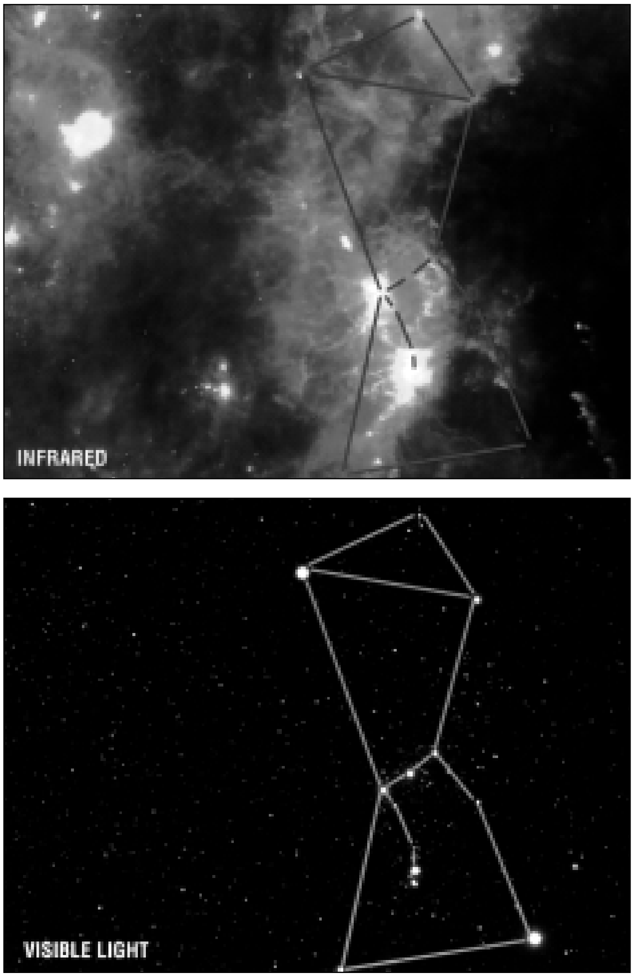
UNIT 2 THE ELECTROMAGNETIC SPECTRUM

Introduction

Contrary to popular belief, outer space is not empty space. It is filled with electromagnetic radiation that crisscrosses the universe. This radiation comprises the spectrum of energy ranging from radio waves on one end to gamma rays on the other. It is called the electromagnetic spectrum because this radiation is associated with electric and magnetic fields that transfer energy as they travel through space. Because humans can see it, the most familiar part of the electromagnetic spectrum is visible light—red, orange, yellow, green, blue, and violet.

Like expanding ripples in a pond after a pebble has been tossed in, electromagnetic radiation travels across space in the form of waves. These waves travel at the speed of light—300,000 kilometers per second. Their wavelengths, the distance from wave crest to wave crest, vary from thousands of kilometers across (in the case of the longest radio waves) to fractions of a nanometer, in the cases of the smallest x-rays and gamma rays.

Electromagnetic radiation has properties of both waves and particles. What we detect depends on the method we use to study it. The beautiful colors that appear in a soap film or in the dispersion of light from a diamond are best described as waves. The light that strikes a solar cell to produce an electric current is best described as a particle. When described as particles, individual packets of electromagnetic energy are called photons. The amount of energy a photon of light contains depends upon its wavelength. Electromagnetic radiation with long



These two views of the constellation Orion dramatically illustrate the difference between what we are able to detect in visible light from Earth's surface and what is detectable in infrared light to a spacecraft in Earth orbit. Photo Credits: Akira Fujii—visible light image; Infrared Astronomical Satellite—infrared image.

wavelengths contains little energy. Electro-magnetic radiation with short wavelengths contains a great amount of energy.

Scientists name the different regions of the electromagnetic spectrum according to their wavelengths. (See figure 1.) Radio waves have the longest wavelengths, ranging from a few centimeters from crest to crest to thousands of kilometers. Micro-waves range from a few centimeters to about 0.1 cm. Infrared radiation falls between 700 nanometers and 0.1 cm. (Nano means one billionth. Thus 700 nanometers is a distance equal to 700 billionths or 7×10^{-7} meter.) Visible light is a very narrow band of radiation ranging from 400 to 700 nanometers. For comparison, it would take 50 visible light waves arranged end to end to span the thickness of a sheet of household plastic wrap. Below visible light is the slightly broader band of ultraviolet light that lies between 10 and 300 nanometers. X-rays follow ultraviolet light and diminish into the hundred-billionth of a meter range. Gamma rays fall in the trillionth of a meter range.

The wavelengths of x-rays and gamma rays are so tiny that scientists use another unit, the electron volt, to describe them. This is the energy that an electron gains when it falls through a potential difference, or voltage, of one volt. It works out that one electron volt has a wavelength of about 0.0001 centimeters. X-rays range from 100 electron volts (100 eV) to thousands of electron volts. Gamma rays range from thousands of electron volts to billions of electron volts.

Using the Electromagnetic Spectrum

All objects in space are very distant and difficult for humans to visit. Only the Moon has been visited so far. Instead of visiting stars and planets, astronomers collect electromagnetic radiation from them using a variety of tools. Radio dishes capture radio signals from space. Big telescopes on Earth gather visible and infrared light. Interplanetary spacecraft have traveled to all the planets in our solar system except Pluto and have landed on two. No spacecraft has ever brought back planetary material for study. They send back all their information by radio waves.

Virtually everything astronomers have learned about the universe beyond Earth depends on the information contained in the electromagnetic radiation that has traveled to Earth. For example, when a star explodes as in a supernova, it emits energy in all wavelengths of the electromagnetic spectrum. The most famous supernova is the stellar explosion that became visible in 1054 and produced the Crab Nebula. Electromagnetic

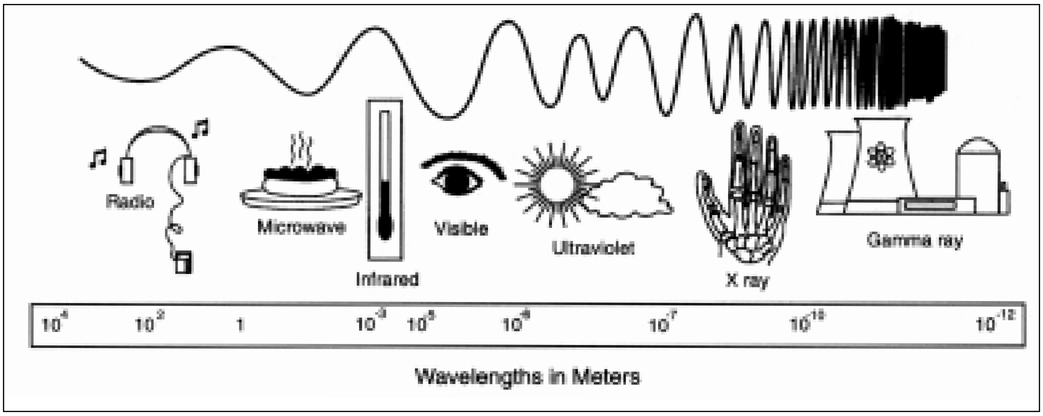


Figure 1: Electromagnetic Spectrum

radiation from radio to gamma rays has been detected from this object, and each section of the spectrum tells a different piece of the story.

For most of history, humans used only visible light to explore the skies. With basic tools and the human eye, we developed sophisticated methods of time keeping and calendars. Telescopes were invented in the 17th century. Astronomers then mapped the sky in greater detail—still with visible light. They learned about the temperature, constituents, distribution, and the motions of stars.

In the 20th century, scientists began to explore the other regions of the spectrum. Each region provided new evidence about the universe. Radio waves tell scientists about many things: the distribution of gases in our Milky Way Galaxy, the power in the great jets of material spewing from the centers of some other galaxies, and details about magnetic fields in space. The first radio astronomers unexpectedly found cool hydrogen gas distributed throughout the Milky Way. Hydrogen atoms are the building blocks for all matter. The remnant radiation from the Big Bang, the beginning of the universe, shows up in the microwave spectrum.

Infrared studies (also radio studies) tell us about molecules in space. For example, an infrared search reveals huge clouds of formaldehyde in space, each more than a million times more massive than the Sun. Some ultraviolet light comes from powerful galaxies very far away. Astronomers have yet to understand the highly energetic engines in the centers of these strange objects.

Ultraviolet light studies have mapped the hot gas near our Sun (within about 50 light years). The high energy end of the spectrum—x-rays and gamma rays—provide scientists with information about processes they cannot reproduce here on Earth because they lack the required power. Nuclear physicists use strange stars and galaxies as a laboratory. These objects are pulsars, neutron stars, black holes, and active galaxies. Their study helps scientists better understand the behavior of matter at extremely high densities and temperatures in the presence of intense electric and magnetic fields.

Each region of the electromagnetic spectrum provides a piece of the puzzle. Using more than one region of the electromagnetic spectrum at a time gives scientists a more complete picture. For example, relatively cool objects, such as star-forming clouds of gas and dust, show up best in the radio and infrared spectral region. Hotter objects, such as stars, emit most of their energy at visible and ultraviolet wavelengths. The most energetic objects, such as supernova explosions, radiate intensely in the x-ray and gamma ray regions.

There are two main techniques for analyzing starlight. One is called spectroscopy and the other photometry. Spectroscopy spreads out the different wavelengths of light into a spectrum for study. Photometry measures the quantity of light in specific wavelengths or by combining all

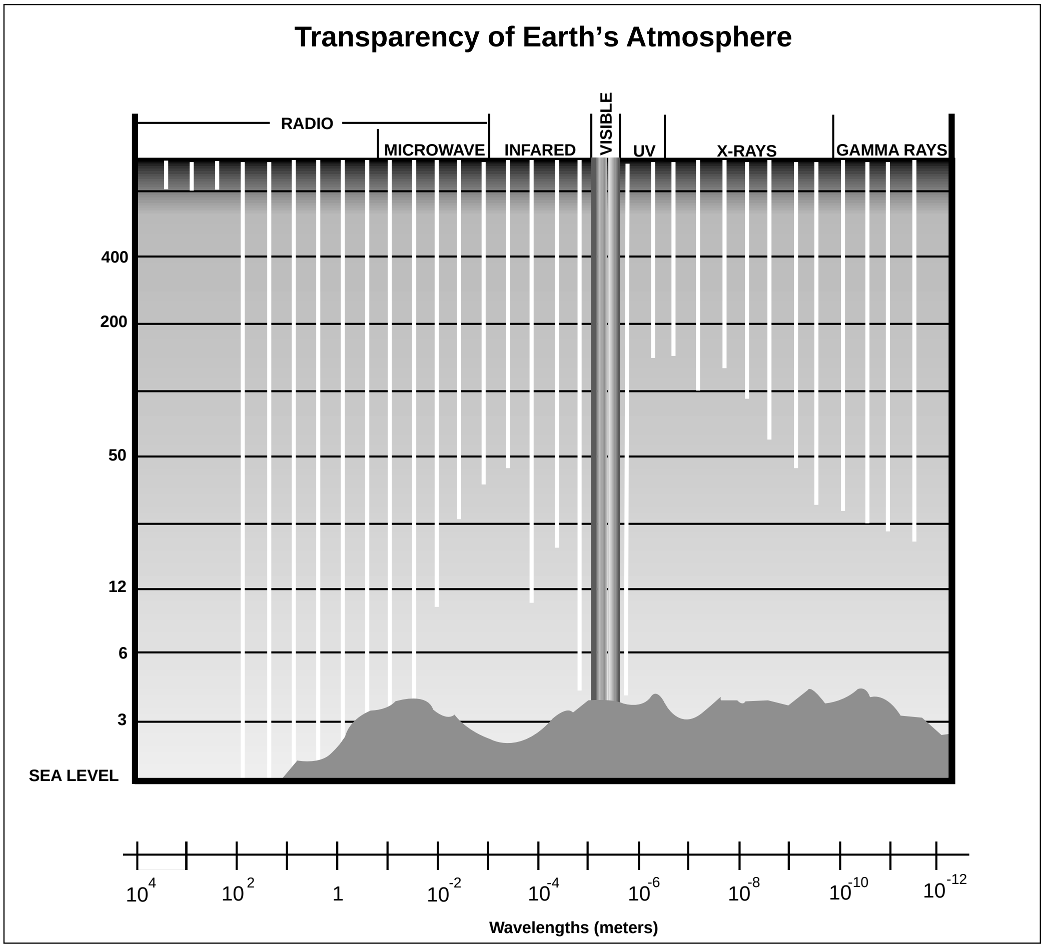


Figure 2: Transparency of Earth's Atmosphere

wavelengths. Astronomers use many filters in their work. Filters help astronomers analyze particular components of the spectrum. For example, a red filter blocks out all visible light wavelengths except those that fall around 600 nanometers (it lets through red light).

Unfortunately for astronomical research, Earth's atmosphere acts as a filter to block most wavelengths in the electromagnetic spectrum. (See Unit 1.) Only small portions of the spectrum actually reach the surface. (See figure 2.) More pieces of the puzzle are gathered by putting observatories at high altitudes (on mountain tops) where the air is thin and dry, and by flying instruments on planes and balloons. By far the best viewing location is outer space.

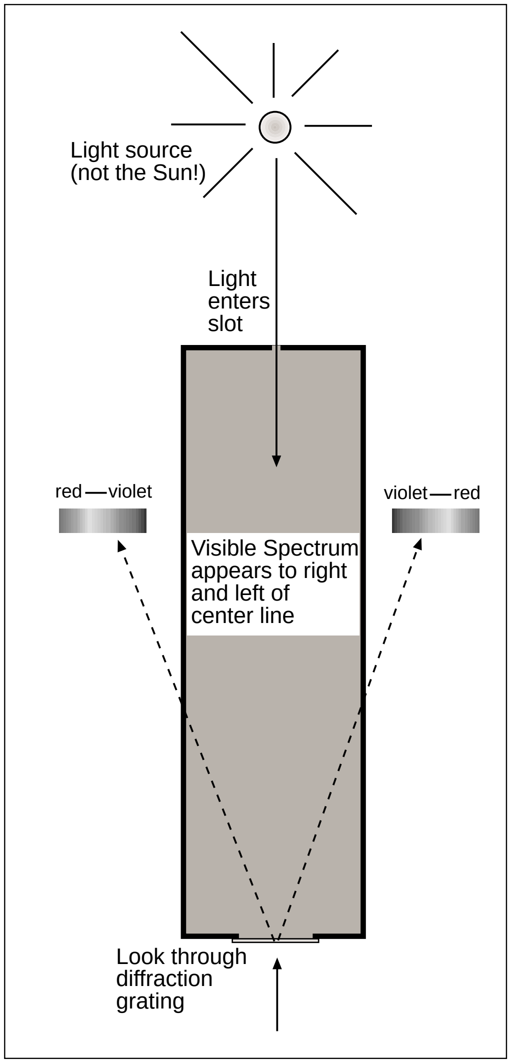
Unit Goals

- To investigate the visible light spectrum.
- To demonstrate the relationship between energy and wavelength in the electromagnetic spectrum.

Teaching Strategy

Because of the complex apparatus required to study some of the wavelengths of the electromagnetic spectrum and the danger of some of the radiation, only the visible light spectrum will be studied in the activities that follow. Several different methods for displaying the visible spectrum will be presented. Some of the demonstrations will involve sunlight, but a flood or spotlight may be substituted. For best results, these activities should be conducted in a room where there is good control of light.

ACTIVITY: Simple Spectroscope



Description:

A basic hand-held spectroscope is made from a diffraction grating and a paper tube.

Objective:

To construct a simple spectroscope with a diffraction grating and use it to analyze the colors emitted by various light sources.

National Education Standards:

Mathematics
- Measurement
- Connections

Science
- Systems, order, & organization
- Change, constancy, & measurement
- Abilities necessary to do scientific inquiry
- Abilities of technological design

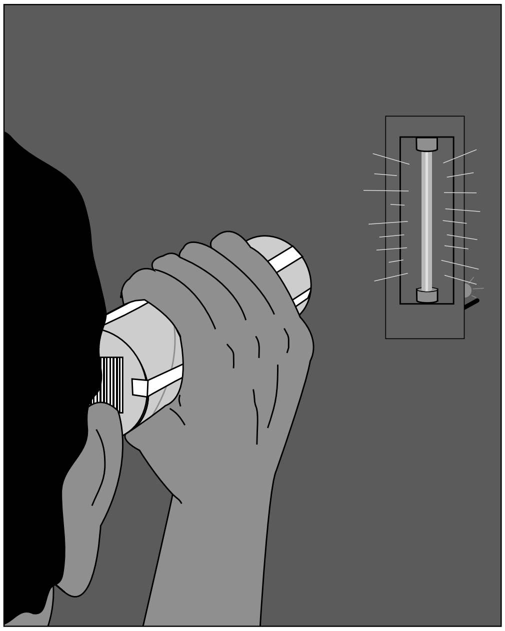
Technology
- Understand engineering design

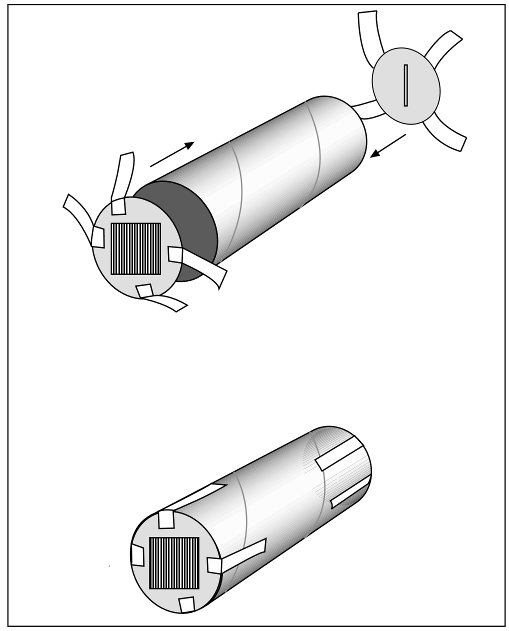
Materials:

- Diffraction grating, 2-cm square (See management and tips section.)
- Paper tube (tube from toilet paper roll)
- Poster board square (5 by 10-cm)
- Masking tape
- Scissors
- Razor blade knife
- 2 single-edge razor blades
- Spectrum tubes and power supply (See management and tips section.)
- Pencil

Procedure:

1. Using the pencil, trace around the end of the paper tube on the poster board. Make two circles and cut them out. The circles should be just larger than the tube's opening.
2. Cut a 2-centimeter square hole in the center of one circle. Tape the diffraction grating square over the hole. If students are making their own spectroscopes, it may be better if an adult cuts the squares and the slot in step 4 below.
3. Tape the circle with the grating inward to one end of the tube.
4. Make a slot cutter tool by taping two single-edge razor blades together with a piece of poster board between. Use the tool to make parallel cuts about 2 centimeters long across the middle of the second circle. Use the razor blade knife to cut across the ends of the cuts to form a narrow slot across the middle of the circle.
5. Place the circle with the slot against the other end of the tube. While holding it in place, observe a light source such as a fluorescent tube. Be sure to look through the grating end of the spectroscope. The spectrum will appear off to the side from the slot. Rotate the circle with the slot until the spectrum is as wide as possible. Tape the circle to the end of the tube in this position. The spectroscope is complete.





6. Examine various light sources with the spectroscope. If possible, examine nighttime street lighting. Use particular caution when examining sunlight. Do not look directly into the Sun.

Background:

Simple spectroscopes, like the one described here, are easy to make and offer users a quick look at the color components of visible light. Different light sources (incandescent, fluorescent, etc.) may look the same to the naked eye but will appear differently in the spectroscope. The colors are arranged in the same order but some may be missing and their intensity will vary. The appearance of the spectrum displayed is distinctive and can tell the observer what the light source is.

Management and Tips:

The analytical spectroscope activity that follows adds a measurement scale to the spectroscope design. The scale enables the user to actually measure the colors displayed. As will be described in greater detail in that activity, the specific location of the colors are like fingerprints when it comes to identifying the composition of the light source. Refer to the background and management tips section for the Analytical Spectroscope activity for information on how diffraction gratings produce spectra.

Spectroscopes can be made with glass prisms but prisms are heavy. Diffraction grating spectroscopes can do the same job but are much lighter. A diffraction grating can spread out the spectrum more than a prism can. This ability is called dispersion. Because gratings are smaller and lighter, they are well suited for spacecraft where size and weight are important considerations. Most research telescopes have some kind of grating *spectrograph* attached. Spectrographs are spectroscopes that provide a record, photographic or digital, of the spectrum observed.

Many school science supply houses sell diffraction grating material in sheets or rolls. One sheet is usually enough for every student in a class to have a piece of grating to build his or her own spectroscope. Holographic diffraction gratings work best for this activity. Refer to the note on the source for holographic grating in the next activity. A variety of light sources can be used for this activity, including fluorescent and incandescent lights and spectra tubes with power supplies. Spectra tubes and the power supplies are available from school science supply catalogs. It may be possible to borrow tubes and supplies from another school if your school does not have them. The advantage of spectrum tubes is that they provide spectra from different gases such as hydrogen and helium. When using the spectroscope to observe sunlight, students should look at reflected sunlight such as light bouncing off clouds or light colored concrete. Other light sources include streetlights (mercury, low-pressure sodium, and high-pressure sodium), neon signs, and candle flames.

Assessment:

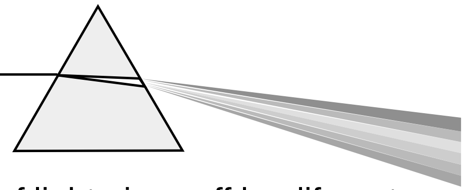
Compare student drawn spectra from different light sources.

Extensions:

- How do astronomers measure the spectra of objects in space? What do those spectra tell us about these objects?
- Investigate other applications for the electromagnetic spectrum.

Student Sheet - Simple Spectroscope

Name: ______________________________________



Use your spectroscope to analyze the colors of light given off by diferent sources. Reproduce the spectra you observe with crayons or colored markers in the spaces below. Identify the light sources. (**When using the Sun as a light source, do not look at it directly with your spectroscope. You can harm your eye. Instead, look at sunlight reflected from a white cloud or a sheet of white paper.**)

Light Source: ______________________

Light Source: ______________________

Light Source ______________________

1. Describe how the spectra of the three light sources you studied differed from each other. How were they similiar?

2. Would you be able to identify the light sources if you only saw their visible spectra?

ACTIVITY: Projecting Visible Spectra

Description:

Two methods for projecting the visible spectrum are explained.

Objective:

To study the range of colors in the visible spectrum.

National Education Standards:

Mathematics
- Measurement
- Connections

Science
- Change, constancy, & measurement
- Abilities necessary to do scientific inquiry

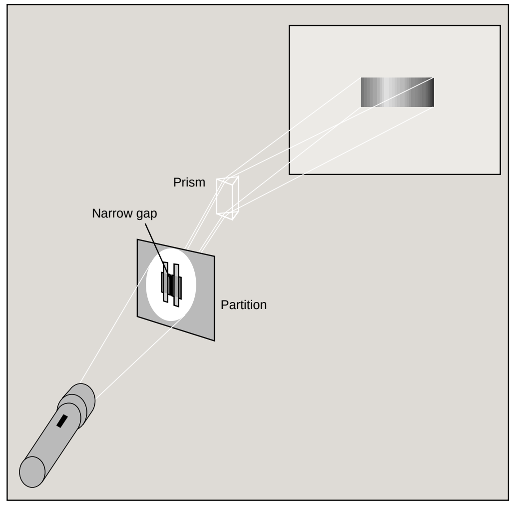
Materials:

Method 1
- Flashlight (focusing kind)
- Stiff poster board
- 2 single-edge razor blades
- tape
- Glass prism
- Projection screen

Method 2
- Overhead projector
- Holographic diffraction grating (See next page for sources.)
- 2 sheets of opaque paper
- Tape
- Projection screen

Procedure: Method 1

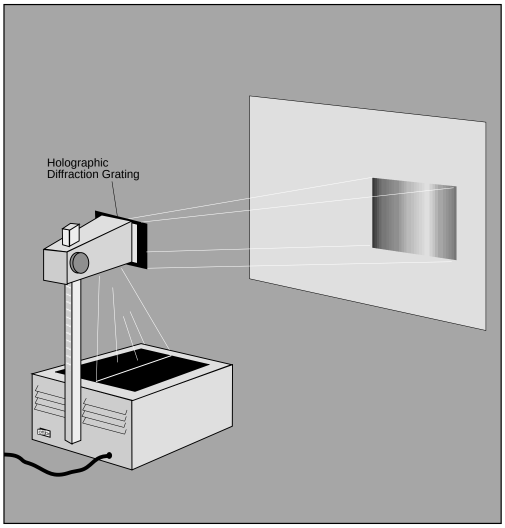
1. Make a partition with a narrow slot in its center to block all but a narrow beam from the flashlight. Cut out a 4 by 1-centimeter vertical rectangle out from a 10 by 10-centimeter piece of poster board. Tape the two single-edge razor blades to the poster board so that their edges face each other and there is a 1- to 2-millimeter gap between them.
2. Darken the classroom (the darker the better).
3. Brace the partition so that it stands upright with the gap in the vertical direction.
4. Aim the flashlight beam at the screen and focus it into a tight beam. Direct the beam of the flashlight directly through the gap in the partition so that a narrow vertical slot of light falls on the screen.



5. Stand the glass prism upright and place it in the narrow beam of light on the opposite side of the partition.
6. Slowly rotate the prism until the narrow slot of light disperses the visible spectrum. Depending upon the exact alignment, the spectrum may fall on a wall rather than on the screen. Adjust the setup so that the spectrum is displayed on the projection screen.

Procedure: Method 2

1. For this method, you must obtain a piece of holographic diffraction grating—a grating produced by accurate holographic techniques. See page 33 for the source of the grating. **Note:** Method 2 will not work well with a standard transmission grating.
2. Place two pieces of opaque paper on the stage of an overhead projector so that they are almost touching. There should be a narrow gap between them that lets light through. Aim the projector so that a narrow vertical beam of light falls on the projection screen.
3. Hang a square of holographic grating over the projector lens with tape.
4. Darken the classroom (the darker the better).
5. Look for the color produced by the grating. It will fall on the screen or the wall on both sides of the center line of the projector. You may have to adjust the aiming of



the projector to have one of the two spectra produced fall on the screen.

6. If the spectra produced is a narrow line of color, rotate the holographic film 90 degrees and remount it to the projector lens so that a broad band of color is projected.

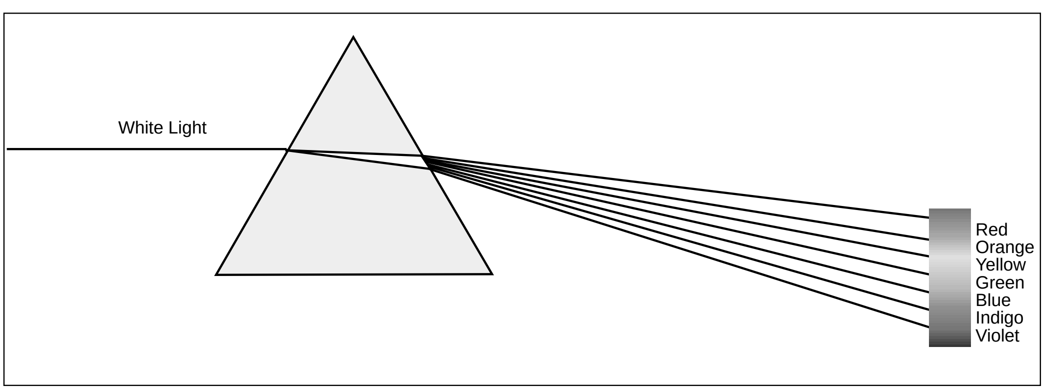
Background:

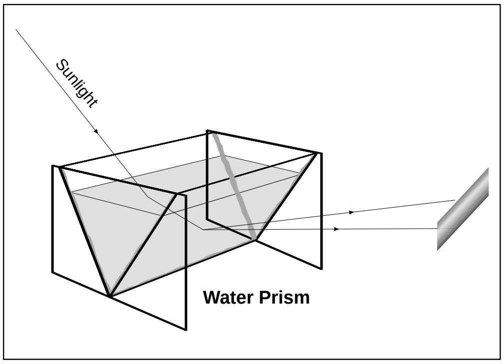
Visible light, passing through a prism at a suitable angle, is dispersed into its component colors. This happens because of *refraction.* When visible light waves cross an interface between two media of different densities (such as from air into glass) at an angle other than 90 degrees, the light waves are bent (refracted). Different wavelengths of visible light are bent different amounts and this causes them to be dispersed into a continuum of colors. (See diagram.)

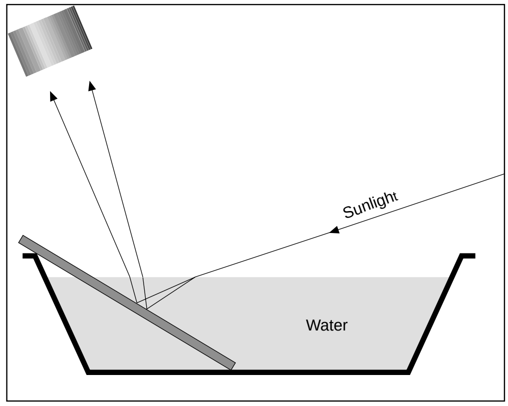
Diffraction gratings also disperse light. There are two main kinds of gratings. One transmits light directly. The other is a mirror-like reflection grating. In either case, diffraction gratings have thousands of tiny lines cut into their surfaces. In both kinds of gratings, the visible colors are created by constructive and destructive interference. Additional information on how diffraction gratings work is found in the Analytical Spectroscope activity and in many physics and physical science textbooks.

Management and Tips:

When projecting spectra, be sure to darken the room as much as possible. If it is not possible to darken the room, a large cardboard box can be used as a light shield for method 1. Cut a small peep-hole to examine the spectra. Method 2 produces a much larger spectra than method 1. In both cases, the size of the spectral display can be enlarged by increasing the distance from the prism or diffraction grating to the screen. The disadvantage of enlarging the display is that only so much light is available from the light source and increasing its dispersion diminishes it intensity. A better light source for method 1 is the Sun. If you have a window with direct sunlight, you can block most of the light except for a narrow beam that you direct through the gap in the partition. You will probably have to place the partition with the slot on its side to display a visible spectra. A slide projector can also be used as a light source for method 1. Refer to the Analytical Spectroscope activity for more information on how the diffraction grating works.







Assessment:

Have students use crayons or marker pens to sketch the visible spectrum produced. Ask students to identify each color present and to measure the widths of each color band. Have them determine which colors bend more and which bend less as they come through the prism or diffraction grating.

Extensions:

- Who discovered the visible spectrum? How many colors did the scientist see?
- A compact disk acts like a reflection diffraction grating. Darken the room and shine a strong beam of white light from a flashlight on the disk. The beam will be dispersed by the grating and be visible on a wall.
- Construct a water prism out of four sheets of glass. Glue the sheets together as shown in the illustration with clear silicone aquarium cement. When the cement is dry, fill the V-shaped trough with water and check for leaks. Set the finished water prism in a window with direct sunlight. A visible spectrum will appear somewhere in the classroom. You can reposition the visible spectrum by bouncing the sunlight off a mirror before it enters the prism in order to change the sunlight angle.
- A pocket mirror placed in a shallow pan of water can also project a spectrum. Set up the mirror and pan as shown in the illustration.

Sources:

Diffraction gratings are available from most school science catalogs. Holographic diffraction grating are available from:

Learning Technologies, Inc.
40 Cameron Avenue
Somerville, MA 02144
Phone: 1-800-537-8703

Reference:

Sadler, P. "Projecting Spectra for Classroom Investigations," *The Physics Teacher,* October 1991, 29(7), pp423–427.

Student Work Sheet

Projecting Spectra

Name ______________________________

Using colored markers or crayons and the chart below, reproduce the electromagnetic spectrum as you see it. Be sure to maintain the proportions of the color widths. Write the names of the colors beneath the chart.

Which color bent the most after passing through the prism or diffraction grating? Why?

Which color bent the least? Why?

ACTIVITY: Cereal Box

Analytical Spectroscope

Description:

A spectroscope is constructed (from a cereal box and diffraction grating) that permits the analysis of visible light.

Objective:

To construct an analytical spectroscope and analyze the spectrum produced when various substances are heated or excited with electricity.

National Education Standards:

Mathematics
- Measurement
- Data analysis, statistics, & probability

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

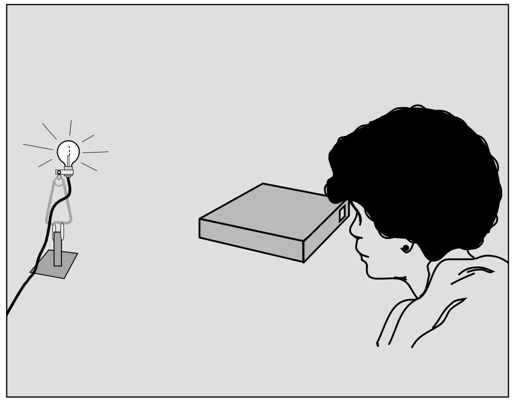
Technology
- Understand relationships & connections among technologies & other fields
- Understand engineering design

Materials:

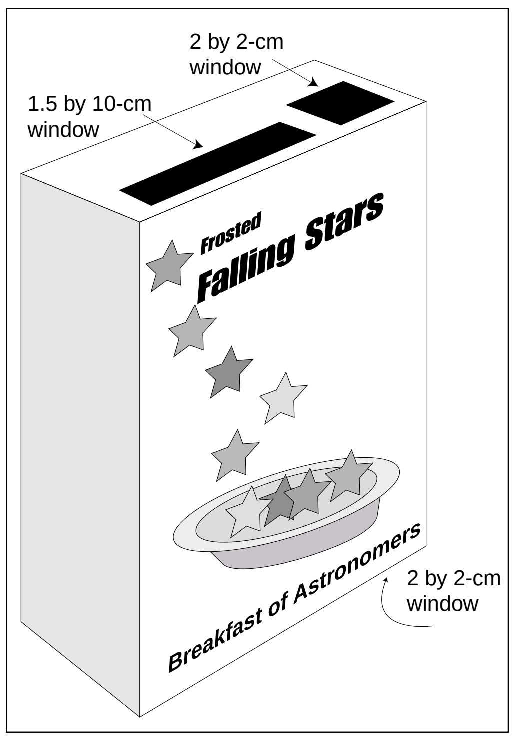
Cereal box (13-15 ounce size)
Holographic diffraction grating (See the Projecting Spectra activity for the source.)
Aluminum foil
Measurement scale
Marker pen
Ruler
Masking tape
Scissors
Razor blade knife
Cutting surface
Spectrum tubes and power supply (See the background and management tips section for information on sources.)

Procedure:

1. Cut a 2 by 2-centimeter window from the bottom lid of the cereal box. The window should be near one side.
2. Cut a second window from the upper box lid directly above the lower window.



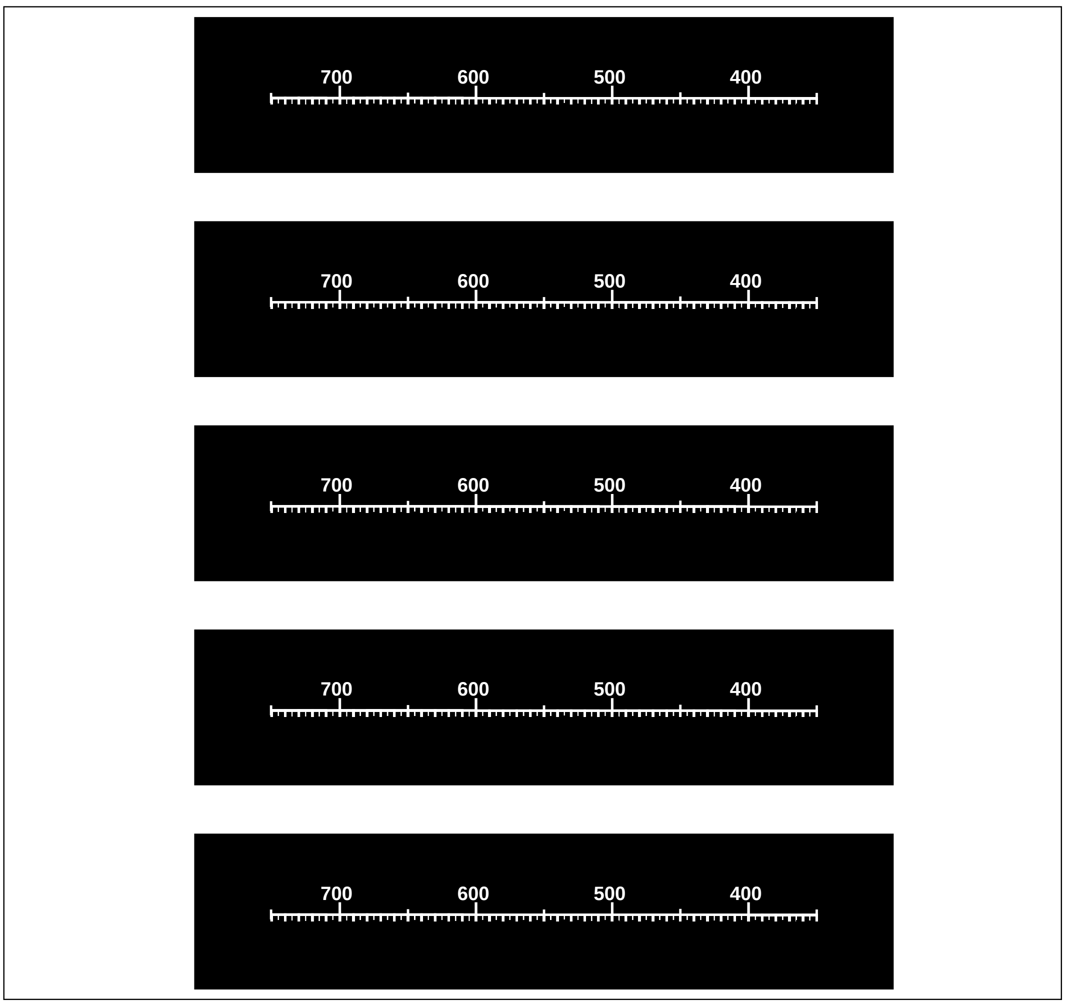
3. Cut a third window in the upper lid. This window should be 1.5 by 10-centimeters in size. Refer to the cutting diagram for placement information of the window.
4. Cut a piece of diffraction grating large enough to cover the window in the box bottom. Handle the grating by the edges if possible; skin oils will damage it. Look at a fluorescent light through the grating. Turn the grating so that the rainbow colors you see appear in fat vertical bars to the right and left of the light. Tape the grating in place.



5. Place a 4 by 4-centimeter square of aluminum foil on a cutting surface. Cut a narrow slot into the foil with the razor blade knife. If you made the slot-cutting tool for the simple spectroscope activity, use it here for cutting slots as well.
6. Tape the foil over the upper 2 by 2-centimeter hole in the box lid. The slot should be positioned directly over the hole and aligned perpendicular to the cereal box front.
7. Copy the black measurement ruler on an overhead projector transparency. Several rulers are reproduced in the guide to reduce the number of transparencies needed.
8. Lightly tape the measurement ruler over the rectangular window in the box lid. When you look through the diffraction grating into the box, you should be able to read the numbers on the ruler with 400 on the right and 700 on the left.

Adjusting and Calibrating the Spectroscope:

1. Aim the slot end of the spectroscope towards a fluorescent light. Look through the diffraction grating. A continuous spectrum will be seen off to the side of the spectroscope falling under or partially on top of the measurement ruler. If the spectrum appears as a narrow rainbow-colored line, remove the diffraction grating from the window and rotate it 90 degrees. Tape it back in place.
2. While looking at the fluorescent light, check the position of the measurement ruler. There will be a bright green line in the green portion

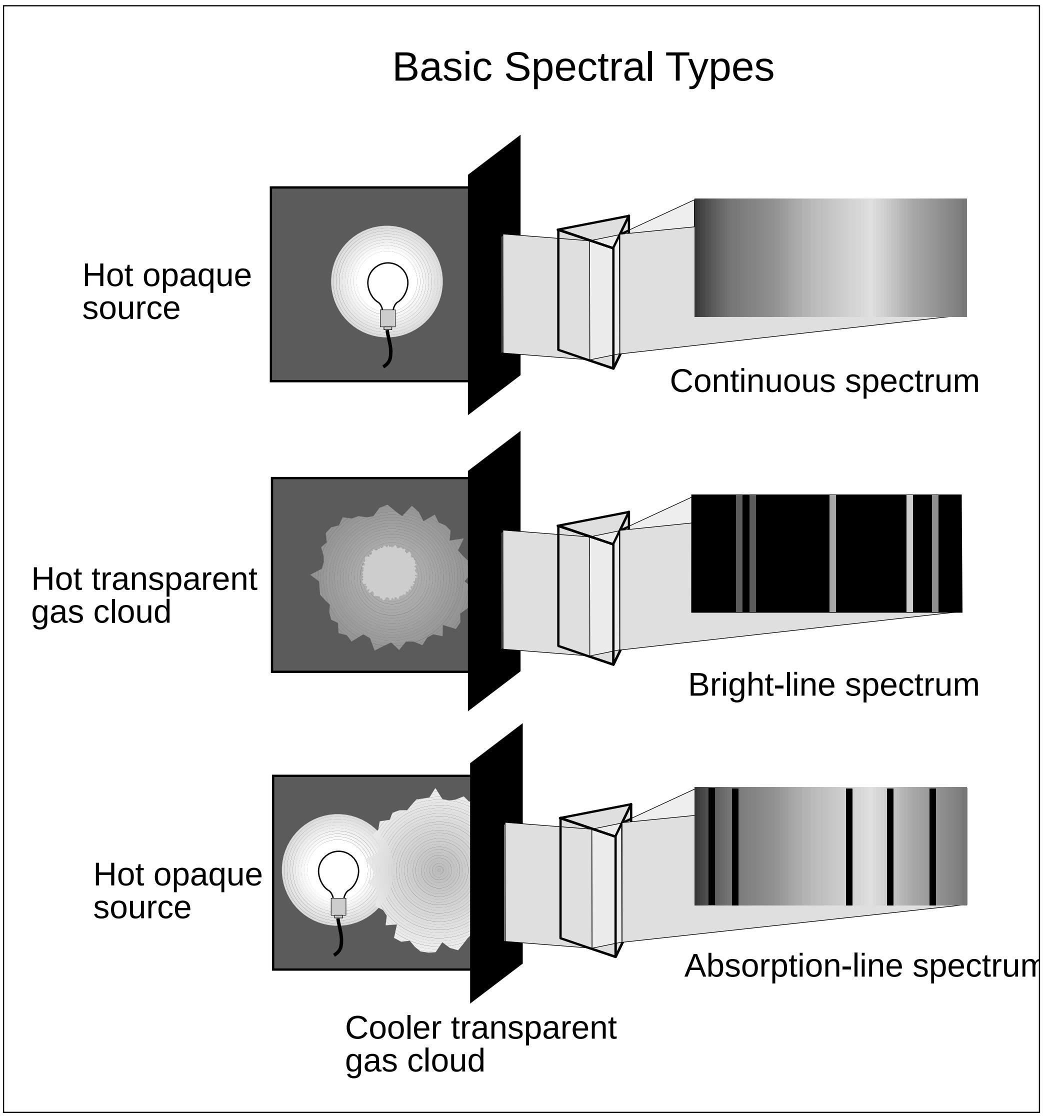


of the spectrum. Adjust the position of the ruler so that the line falls between 540 and 550 on the ruler. Tape the ruler permanently in place. The spectroscope is calibrated.

Background:

Unlike a prism, which disperses white light into the rainbow colors through refraction, the diffraction grating used in this spectroscope disperses white light through a process called interference. The grating used in this activity consists of a transparent piece of plastic with many thousands of microscopic parallel grooves. Light passing between these grooves is dispersed into its component wavelengths and appears as parallel bands of color on the retina of the eye of the observer.

Spectroscopes are important tools for astronomy. They enable astronomers to analyze starlight by providing a measure of the relative amounts of red and blue light a star gives out. Knowing this, astronomers can determine the star's temperature. They also can deduce its chemical composition, estimate its size, and even measure its motion away from or toward Earth (See the activity Red Shift, Blue Shift.)



Starlight (photons) originates from the interior of a star. There, pressures are enormous and nuclear fusion is triggered. Intense radiation is produced as atoms, consisting of a surrounded nucleus, collide with each other millions of times each second. The number of collisions depends upon the temperature of the gas. The higher the temperature, the greater the rate of collision.

Because of these collisions, many electrons are boosted to higher energy levels. This process is called excitation. The electrons spontaneously drop back to their original energy level. In doing so, they release energy as photons. This is what happens to the filament of an electric light bulb or to an iron bar when it is heated in a furnace. As the temperature of the filament rises, it begins to radiate reddish light. When the filament becomes much hotter, it radiates bluish light. Thus, the color it radiates is an indicator of the filament's temperature. Stars that radiate a great amount of red light are much cooler than stars that radiate a great amount of blue light. Stellar spectra therefore serve as star thermometers.

Excitation of electrons can also occur if they absorb a photon of the right wavelength. This is what happens when certain materials are exposed to ultraviolet light. These materials then release new photons at different wavelengths. This is called fluorescence.

One of the important applications of spectroscopes is their use for identifying chemical elements. Each element radiates light in specific wavelength combinations that are as distinctive as fingerprints. Knowing the "spectral signatures" of each element enables astronomers to identify the elements present in distant stars by analyzing their spectra.

There are three kinds of spectra: continuous, absorption, and emission. The continuous spectrum appears as a continuous band of color ranging from red to violet when observed through a spectroscope. An absorption spectrum occurs when the light from a star passes through a cloud of gas, hydrogen for example, before reaching the spectroscope. As a result, the hydrogen atoms absorb some wavelengths of light. This selective absorption produces a spectrum that is a broad band of color interrupted by dark lines representing certain wavelengths of light that were absorbed by the hydrogen cloud. Such a situation occurs when a star is located inside or behind a gas cloud or nebula. An emission spectrum is observed when energy is absorbed by the gas atoms in a nebula and is re-radiated by those atoms at specific wavelengths. This spectrum consists of bright lines against a black background. The light from fluorescent tubes and neon lights produce emission spectra.

Stellar spectra allow astronomers to determine star temperature, chemical composition, and motion along the line of sight. This enables astronomers to classify stars into spectral categories and estimate their age, reconstruct their histories, and postulate their future evolution. When available, astronomers prefer stellar spectra collected by orbiting spacecraft over spectra collected by Earth-based telescopes since they are not affected by atmospheric filtering and are therefore more accurate. Included in the spectra collected by spacecraft are infrared, ultraviolet, x-ray, and gamma ray bands that simply do not reach ground-based spectroscopes.

Management and Tips:

This spectroscope works better with a holographic diffraction grating than with standard diffraction gratings. Refer to the source for holographic gratings listed in the Projecting Spectrums activity. The spectroscope can be used to analyze the wavelengths of light from many light sources. Compare incandescent light, fluorescent light, and sunlight. If you have spectrum tubes and a power supply (available from science supply houses), examine the wavelengths of light produced by the different gases in the tubes. Many high school physics departments have this equipment and it may be possible to borrow it if your school does not. Use the spectroscope to examine neon signs and streetlights. Science supply houses sell spectrum flame kits consisting of various salts that are heated in the flame of a Bunsen burner. These kits are much less expensive than spectrum tubes but are more difficult to work with because the flames do not last very long.

This spectroscope can also be used to study the spectrum of the Sun. Do not look directly at the Sun with the spectroscope as this could damage your eye. Instead, look at reflected sunlight such as a white cloud or piece of white paper in sunlight (but not in a mirror!). When using the spectroscope in a very dark environment with spectrum tubes, it may be difficult to read the measurement scale. A small flashlight aimed at a white wall behind the spectrum power supply will provide just enough light to read the ruler.

The first student page requires the use of spectrum tubes and a power supply. Have students make spectrographs of five different spectrum tubes. Randomly select one of the five tubes and ask students to make a spectrograph of it. Tell the students to identify this unknown element from their previous spectrographs. The second student page shows several typical bright line spectra from spectrum tubes. This worksheet can be done without the tubes. It is important that students identify more than one line from each element shown in the spectrograph. Some elements have several lines in common. It is the entire combination of lines that makes the identification possible.

Work Sheet 2 answers:

Spectrograph A: Hydrogen, Helium
Spectrograph B: Sodium, Barium, Lithium
Spectrograph C: Calcium, Helium, Hydrogen, Oxygen, Krypton

Assessment:

Examine student spectroscopes to see if the gratings are properly aligned and the measurement ruler is calibrated. Collect the student sheets and compare student answers.

Extensions:

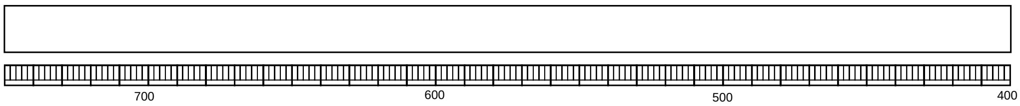
- Compare the solar spectrum at midday and at sunset. Are there any differences? Caution: Be careful not to look directly at the Sun.
- What do spectra tell us about the nature of stars and other objects in space?
- Show how temperature and radiation are related by connecting a clear light bulb to a dimmer switch. Gradually increase the current passing through the filament by turning up the dimmer. Observe the color and brightness of the filament as the temperature of the filament climbs with increasing current.

Mystery Spectra

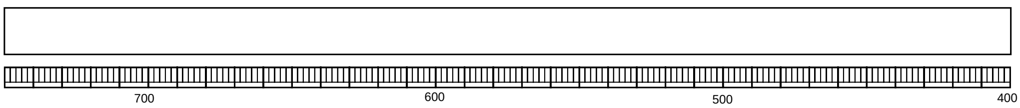
Name:______________

Use your spectroscope to examine the five elements displayed to you by your teacher. Make sketches of the bright lines visible in the spaces below.

Element Name:______________



Element Name:______________



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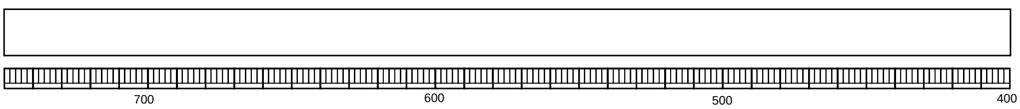

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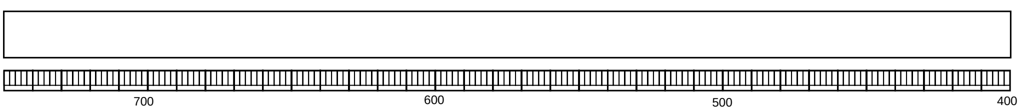
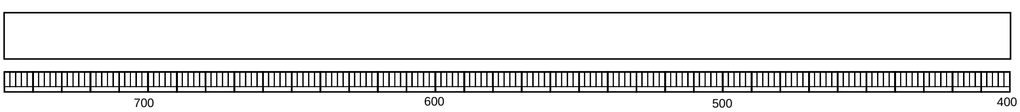
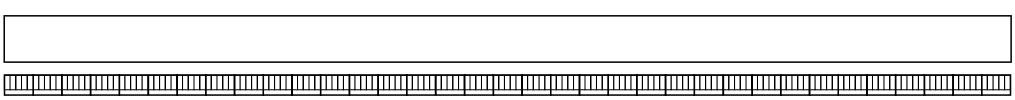


Element Name:______________



Use your spectroscope to examine the unknown element displayed to you by your teacher. Make a sketch of the bright lines visible in the space below. Compare your unknown element to the spectra above. Identify the element.

Element Name:______________



Student Work Sheet 2

Mystery Spectra

Name:______________

Identify the elements in spectra A, B, and C by comparing the bright lines present with the bright lines in the spectra for know elements.

Spectra A Elements:____

Spectra B Elements:____

Spectra C Elements:____

ACTIVITY: Red Shift, Blue Shift

Description:

A Whiffle® ball containing a battery-operated buzzer is twirled in a circle to demonstrate the Doppler effect. This same effect causes starlight to shift toward the blue or red end of the spectrum if a star is moving towards or away from us.

Objective:

To demonstrate how stellar spectra can be used to measure a star's motion relative to Earth along the line of sight.

National Education Standards:

Mathematics
- Patterns, functions, & algebra
- Geometry & spatial sense
- Measurement
- Data Analysis, statistics, & probability
- Connections

Science
- Change, constancy, & measurement

Abilities necessary to do scientific inquiry
- Motions & forces

Technology
- Understand relationships & connections among technologies & other fields

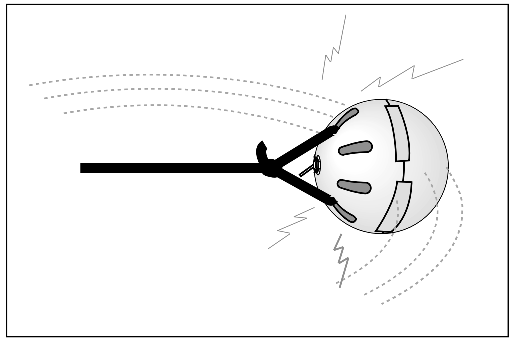
Materials:

- Plastic Whiffle® ball (12-15 cm in diameter)
- Microswitch*
- Small buzzer*
- 9-volt battery*
- Cord (3 meters long)
- Solder and soldering iron
- Sharp knife or hacksaw blade
- Masking tape

* See Management Tips note about electronic parts.

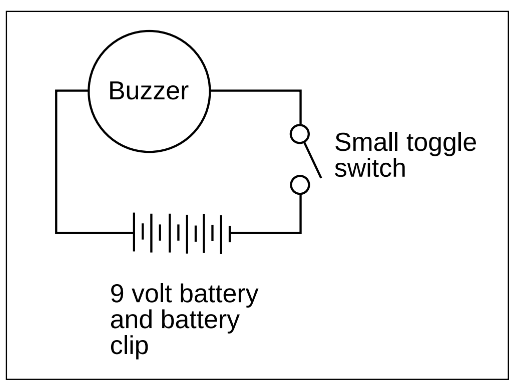
Procedure:

1. Splice and solder the buzzer, battery clip, and microswitch in a series circuit. See the wiring diagram for details on the connections. Be sure to test the circuit before soldering. Many small buzzers require the electric current to flow in one direction and will not work if the current flows in the other direction.
2. Split the Whiffle® ball in half along the seam with the knife or saw blade.



3. Remove the nut from the microswitch and insert the threaded shaft through one of the holes as shown in the diagram. If a hole is not present in the location shown, use a drill to make one the correct diameter. Place the nut back over the threaded shaft on the microswitch and tighten.
4. Join the two halves of the ball together with the switch, buzzer, and battery inside. Tape the halves securely together.
5. Tie one end of the cord to the ball as shown.
6. Station students in a circle about 6 meters in diameter. Stand in the middle of the students, turn on the buzzer, and twirl the ball in a circle. Play out 2 to 3 meters of cord.
7. Ask the students to describe what they hear as the ball moves towards and away from them.
8. Let different students try twirling the ball. Ask them to describe what they hear.

As an alternate suggestion to the Whiffle® ball, cut a cavity inside a foam rubber ball and insert the battery and buzzer. The ball can then be tossed from student to student while demonstrating the Doppler effect.



Background:
This is a demonstration of the phenomenon called the Doppler effect. It results from the motion of a source (star) relative to the observer and causes its spectra to be shifted toward the red (going away) or toward the blue (coming towards) end of the spectra.

Like light, sound travels in waves and therefore provides an excellent model of the wave behavior of light. The number of waves reaching an observer in one second is called the frequency. For a given speed, frequency depends upon the length of the wave. Long waves have a lower frequency than short waves. As long as the distance between the source of the waves and the observer remains constant, the frequency remains constant. However, if the distance between the observer and the source is increasing, the frequency will decrease. If the distance is decreasing, the frequency will increase.

Imagine that you are at a railroad crossing and a train is approaching. The train is ringing a bell. The sound waves coming from the bell are squeezed closer together than they would be if the train were still, because of the train's movement in your direction. This squeezing of the waves increases the number of waves (increases the frequency) that reach your ear every second. But after the train's engine passes the crossing, the frequency diminishes and the pitch lowers. In effect, the sound waves are stretched apart by the train's movement in the opposite direction. As the observer, you perceive these frequency changes as changes in the pitch of the sound. The sound's pitch is higher as the train approaches and lower as it travels away. The illustration below provides a graphical representation of what happens.

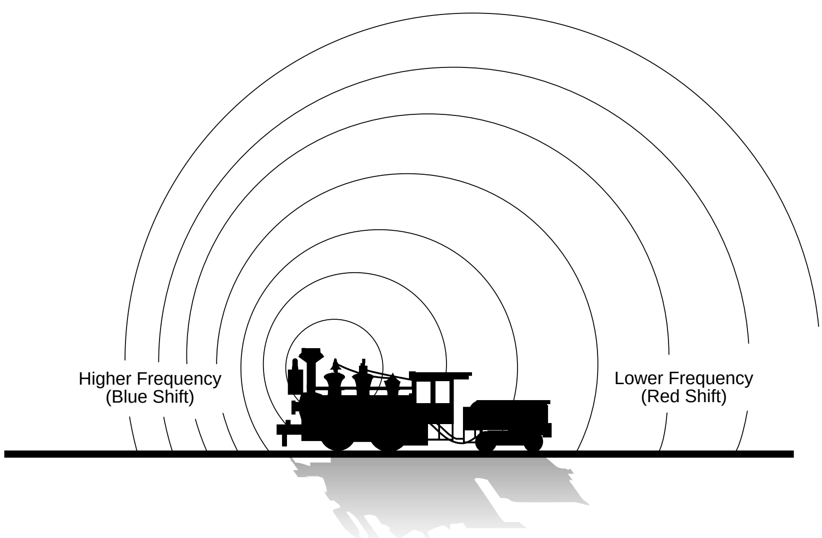
$$\frac{v_r}{c} = \frac{\Delta\lambda}{\lambda_o}$$

Vr - radial velocity of the source with respect to the observer.
c - speed of light (3×10^5 km/sec)
$\Delta\lambda$ the amount of the shift in nanometers
λ_0- unshifted wavelength in nanometers

$$v_r = \frac{0.1\ nm \times 3\text{x}10^5 \text{km /sec}}{600\ nm} = 50 \text{ km/sec}$$

For example, if a line in a spectrum should fall at 600.0 nanometers but instead lies at 600.1, what would the radial velocity be?

The solution to this equation only tells us the velocity of the source relative to the spectroscope. Whether the distance is increasing or decreasing is revealed by the direction of the shift to the red or blue end of the visible spectrum. It does not tell, however, if one or both objects are moving relative to some external reference point.



Management and Tips:

The amount of pitch change as the buzzer twirls is directly related to how fast you twirl the buzzer. Twirling the buzzer faster means that the buzzer approaches and travels away from the observer faster. The person twirling the buzzer does not hear the pitch change no matter how fast the buzzer is twirled; it remains the same distance from the twirler. The observers standing away from the twirler will hear the pitch change as the buzzer goes toward and away from the observer's ear.

Note About Electronic Parts:

The electronic parts for this device are not specified exactly since there are many combinations that will work. Go to an electronic parts store and select a buzzer, battery holder, battery, and switch from what is available. Remember to purchase parts that will fit in a Whiffle® ball. The store clerk should be able to help you make a workable selection if you need assistance. If possible, test the buzzer before purchasing it to determine if it is loud enough. Test the buzzer and battery before soldering connections. The buzzer may be polarized. Reverse the connections if you do not hear a sound the first time.

Answers to Work Sheets:

Sheet 1

1. The greater the difference in the pitch above or below the normal pitch, the faster the vehicle is moving.
2. A – lower, B – higher, C – the same
3. Stars moving toward us become slightly bluer. Stars moving away become slightly redder.
4. Astronomers look at the spectrograph of a star and compare the position of bright lines in the spectrograph with where the lines should be if the star were not moving at all. A shift to the red end of the spectrum indicates a star is moving away and a shift toward the blue end indicates the star is moving towards us. The amount of the shift indicates relative velocity. The greater the shift, the greater the velocity.
5. No. The movement can be determined if the distance to the star is known. How fast the star moves against the background of more distant stars can be measured and the speed of the star calculated.

Sheet 2

Star 1 – 100 km/sec away

Star 2 – 260.7 km/sec toward

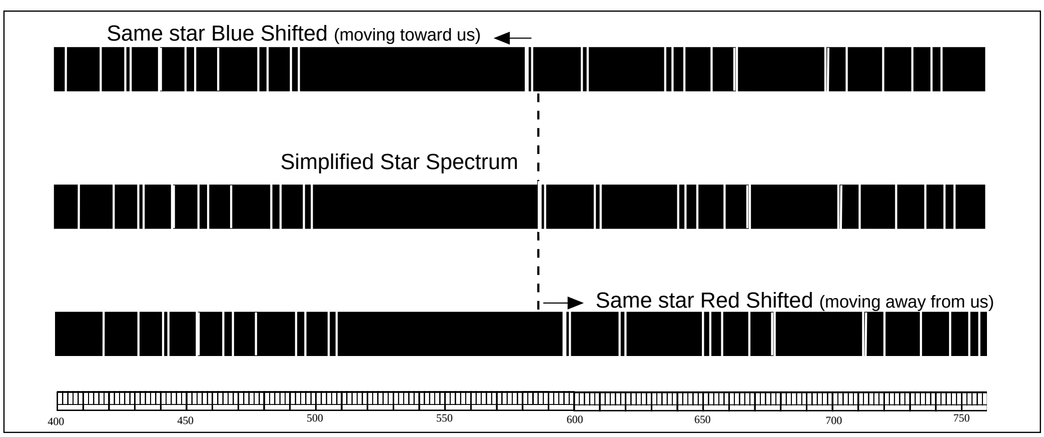
Star 3 – 418.6 km/sec away

Assessment:

Collect student worksheets and compare the answers.

Extensions:

- Can the red/blue shift technique be used for objects other than stars? Can you tell which way an emergency vehicle is traveling by the pitch of its siren?
- Transverse velocity is a motion that is perpendicular to radial velocity. Can this motion be detected by the Doppler effect?
- What has the Doppler effect told astronomers about the size of the universe?



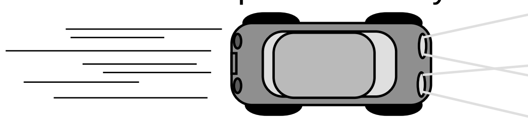
Student Work Sheet 1

Red Shift, Blue Shift

Name: ___________________________

1. How can you estimate the speed of a car that has passed you just by listening to the pitch of its whine?

2. Label the diagram below and tell if the observer perceives a pitch that is higher, lower, or just the same as the pitch heard by the driver.



A: _________

C: _________

B: _________

3. How does the doppler shift affect the color of a star?

4. Describe how astronomers can use the doppler shift to determine if a star is moving toward us or away and how fast?

5. If a star is moving perpendicular to our line of sight, can you use the doppler shift to determine its speed? If not, how might you determine its speed?

Red Shift, Blue Shift

Name: ____________________________

Use the equation below to determine the velocity of several stars whose spectra have shifted. Are the stars moving toward or away from us? Show your work on the back side of this page.

$$V_r = \frac{\Delta\lambda \times C}{\lambda_0}$$

V_r = radial velocity

C = speed of light (3×10^5 km/sec or 300,000 km/sec)

$\Delta\lambda$ = amount of shift in nanometers

λ_0 = unshifted wavelength in nanometers

Star 1: The spectrum has shifted from 600.0 to 600.2 nm

Velocity = ________ km/sec

Moving toward or away from us? ____________

Star 2: The spectrum has shifted from 575.3 to 574.8 nm

Velocity = ________ km/sec

Moving toward or away from us? ____________

Star 3: The spectrum has shifted from 501.6 to 502.3 nm

Velocity = ________ km/sec

Moving toward or away from us? ____________

ACTIVITY: Wavelength and Energy

Description:

Shaking a rope permits students to feel the relationship between wavelength, frequency, and energy.

Objective:

To demonstrate the relationship between wave frequency and energy in the electromagnetic spectrum.

National Education Standards:

Mathematics
- Measurement
- Data analysis, statistics, & probability

Science
- Evidence, models, & explanation
- Change, constancy, & measurement
- Abilities necessary to do scientific inquiry
- Motions & forces
- Transfer of energy

Technology
- Understand relationships & connections among technologies & other fields

Materials:

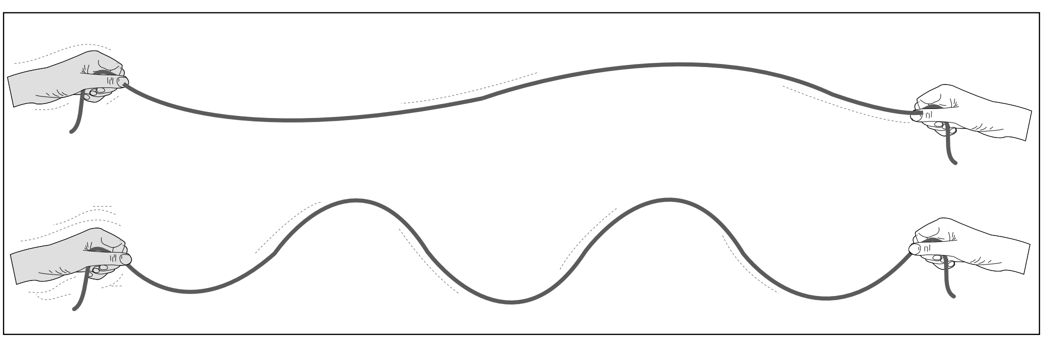
Rope – 50-ft. length of cotton clothesline
Tape measure
Stopwatch or clock with second hand

Procedure:

1. Select two students to hold the rope. Have each student stand in an aisle or in opposite corners of the classroom so that the rope is taut between them.
2. While one end of the rope is held still, have the other student shake the opposite end up and down at a moderate but steady rate.
3. Ask other students to observe the wave patterns created in the rope. Point out wave crests and troughs. Ask your students to measure the *wavelength* and *frequency* of waves reaching the other student. The wavelength is the distance from wave crest to wave crest (or wave trough to wave trough). The wavelength can be measured by having one student stand next to the rope where a wave crest is repeatedly formed and having a second student stand where the next crest is formed. Measure the distance between the students. Frequency is the number of waves reaching the far end of the rope each second. Frequency can be estimated by counting the number of times the student shakes the rope each second.
4. Tell the student shaking the rope to shake it faster. Again estimate the wavelength and frequency.
5. Tell the student shaking the rope to shake the rope as fast as he or she can. Again, estimate the wavelength and frequency.
6. Stop the demonstration and ask the student shaking the rope if it is easier to produce low frequency (long wavelength) or high frequency (short wavelength) waves.

Background:

This activity provides a graphic demonstration of the relationship between energy and wavelength. The student shaking the rope will find that creating many waves each second takes much more energy than producing only a few waves per second. High-frequency waves (short wavelength) represent more energy than low-frequency (long wavelength) waves. Astronomers find the relationship between wavelengths, frequency, and energy very useful. Radio waves



$$E = \frac{hc}{\lambda}$$

$$E = hf$$

Planck's Constant = $6.63 \times 10^{-34}\ \mathrm{J \cdot s}$

f is the frequency in hertz

λ is the wavelength in meters

from astronomical objects have very long wavelengths and low frequencies. The waves are generated by relatively quiet processes. Gamma rays, on the other end of the electromagnetic spectrum, have very short wavelengths and high frequencies and represent the most violent processes in space. The frequency of electromagnetic energy coming from an object tells astronomers much about how that object was created and what was happening at the time the energy was emitted into space.

Management and Tips:

The quality of the demonstrations can be greatly enhanced by using a wave demonstration spring. These springs are available from school science supply catalogs for a few dollars. The springs are long coils and when stretched and agitated, produce excellent waves. The increased mass of the spring over the cotton clothesline enhances the wave motions. If a strobe light is available, the appearance of the wave motions can be enhanced by playing the light on the moving rope or spring and adjusting the strobe frequency. A Slinky® can also be used to demonstrate wave motion but it will work best if the Slinky® is placed on a long table and the spring is shaken from side to side.

Permit other students to shake the rope so they can feel, as well as see, the relationship between frequency, wavelength, and energy.

Assessment:

Make sure students understand the relationship between frequency and wavelength and the amount of energy required to produce the waves. Collect and compare the student sheets.

Extensions:

- Invite a hospital medical imaging specialist to talk to the class about the use of high-frequency electromagnetic waves in medical diagnosis.
- Make an overhead projector transparency of the spectrum chart on page 00. Ask the students to relate energy to the electromagnetic wavelengths depicted.

ACTIVITY: Resonating Atmosphere

Description:

Students construct a paper and tape device that demonstrates the property of resonance.

Objective:

To show how atoms and molecules of gas in Earth's atmosphere absorb electromagnetic energy through resonance.

National Education Standards:

Mathematics
- Measurement

Science
- Evidence, models, & explanation
- Change, constancy, & measurement
- Motion & forces
- Transfer of energy
- Structure of the Earth system

Materials:

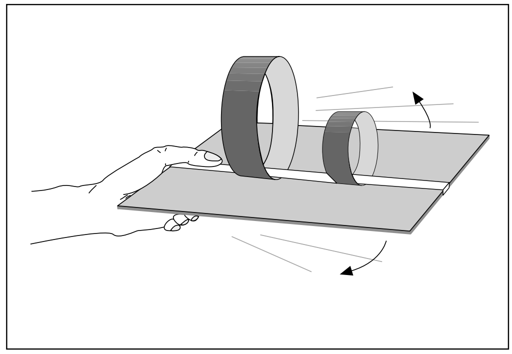
- Used lightweight file folder
- Cardboard sheet about 20 by 30 cm
- Masking tape
- Scissors

Procedure:

1. Cut two strips of paper from the file folder. Each strip should be 3 cm wide. Make one strip approximately 30 cm and the other 35 cm long.
2. Curl each strip into a cylinder and tape the ends together.
3. Tape the cylinders to the cardboard as shown in the diagram.
4. Holding the cardboard along one of its edges, slowly shake the rings back and forth. Observe the movements of the rings as you gradually increase the frequency (rate) of the shaking.

Background:

All objects and materials have a natural frequency at which they vibrate. With some materials, the vibration is easily observed. Many students have discovered that a plastic ruler extended over the edge of a desk will vibrate when it is deflected and released. If the extension of the ruler over the desk edge is reduced, the frequency of the vibration is increased. When students shake the cardboard and paper rings, the number of times it moves back and forth in a second is the frequency. At first, the movement of the rings will be erratic. However, by increasing or decreasing the frequency of the shaking, the students will eventually match the natural frequency of one of the rings. That ring will begin bouncing back and forth in time with the shaking. The movement of the other ring will continue to be erratic until its frequency is matched. When that happens, the first ring's movement will become erratic again. As the frequency of one of the rings is matched, it absorbs some of the energy the student is adding into the system through shaking. The absorption only occurs when the correct frequency is reached. This effect is called resonance. Resonance takes place when energy of the right frequency (or multiples of the right frequency) is added to an object causing it to vibrate.



When electromagnetic radiation enters Earth's atmosphere, certain wavelengths match the natural frequencies of atoms and molecules of various atmospheric gases such as nitrogen and ozone. When this happens, the energy in those wavelengths is absorbed by those atoms or molecules, intercepting this energy before it reaches Earth's surface. Wavelengths that do not match the natural frequencies of these atmospheric constituents pass through.

Resonance is important to astronomy for another reason. All starlight begins in the center of the star as a product of nuclear fusion. As the radiation emerges from the photosphere or surface of the star, some wavelengths of radiation may be missing. The missing components produce dark lines, called *absorption lines,* in the star's spectra. The lines are created as the radiation passes through the outer gaseous layers of the star. Some of that radiation will be absorbed as various gas atoms present there resonate. Absorption lines tell what elements are present in the outer gaseous layers of the star.

Management and Tips:

Students may experience a little difficulty in making the paper ring resonator work at first. The main thing is to be consistent in the shaking of the rings. Although they will be changing from low to high frequencies, after the changes are made, the frequencies should be held constant and vary significantly. Erratic shaking will produce erratic movement in the rings.

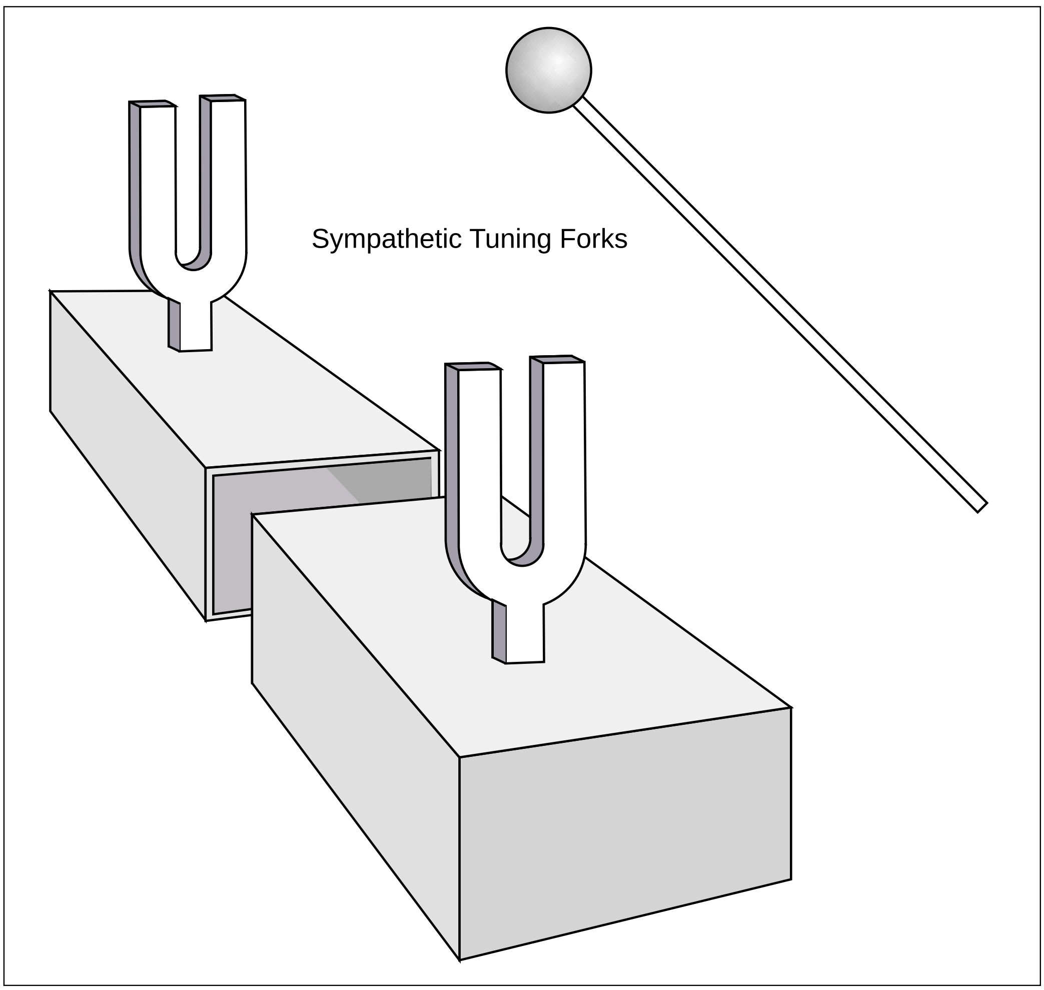
See the extensions below for other ways of demonstrating resonance.

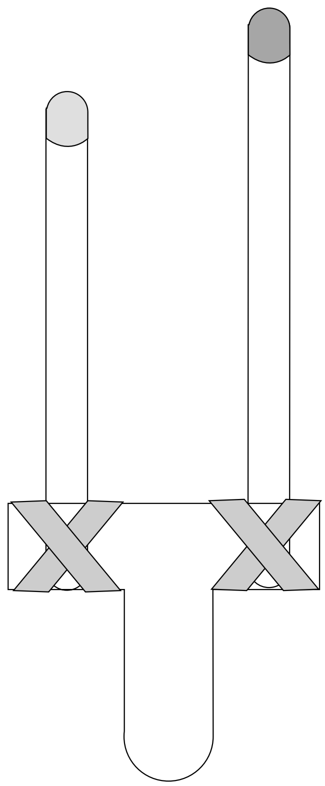
Assessment:

Ask students to explain the concept of resonance and how it applies to electromagnetic radiation coming to Earth from space.

Extensions:

- Resonance can be demonstrated in a number of ways. If you have sympathetic tuning forks (available from school science supply companies), arrange the bases so that they face each other. Strike one fork and the other fork, set to the same frequency, will begin vibrating as well. Touch the first fork to dampen its vibration and you will hear the





Hacksaw Blade Resonator

sound produced by the second fork even though you did not strike. The second fork will absorb energy from the first fork and begin vibrating as well.

- Construct a hacksaw blade resonator. Make a small handle of 1/4-inch plywood or 1/8-inch masonite. Tape two hacksaw blades to the handle as shown. Use a 10-inch and a 12-inch hacksaw blade. Add colored tape or paint the ends of the blades to make them more visible. Shake the handle from side to side. The handle should be held vertically so that the flat side of the blades is perpendicular to the movement. Like the paper ring device, the blades will begin moving when their natural frequencies are matched.
- Investigate the natural frequencies of various objects such as bells, wine goblets, and tuning forks.
- Why has the playing of the song “Louie, Louie” been banned at several college football stadiums? Why do marching soldiers crossing a bridge “break cadence?”
- What gas in Earth’s upper atmosphere blocks ultraviolet radiation? Why is that important?

Student Work Sheet

Resonating Atmosphere

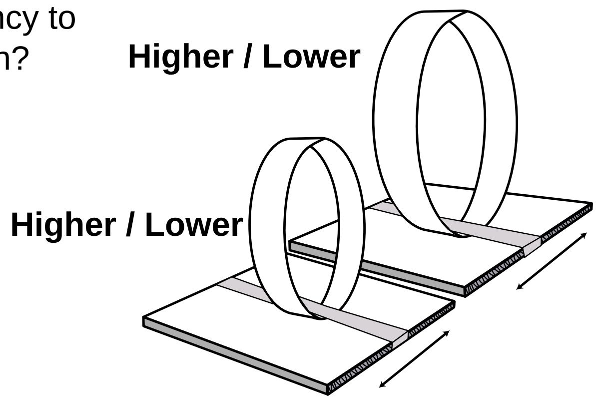
Name: ______________________________

1. Describe what happened to the paper rings as you shook the cardboard base back and forth.

2. What happened when you increased the frequency of the shaking motion?

3. What happened when you decreased the frequency of the shaking motion?

4. Which ring requires the higher-frequency to move in phase with the shaking motion? Which ring moves in phase with the lower-frequency shaking motion? Circle the correct answer.



5. Define resonance. You may use the experiment with the paper rings in your explanation.

6. Explain how resonance of some of the atoms and molecules in Earth's atmosphere interferes with astronomical observations.