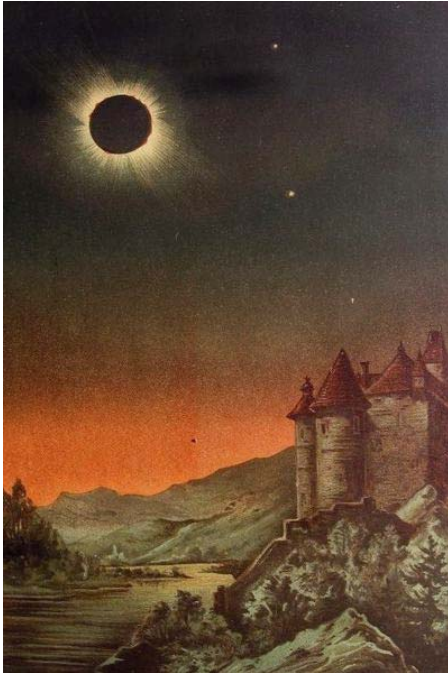


Chapter 8: The Nature of Light



Introduction

One can only imagine the terror experienced by ancient skywatchers during solar and lunar eclipses. Eclipses were regarded by many cultures as the death of the Sun; both solar and lunar eclipses were thought to be caused by monsters or wild animals attacking and devouring the Sun or Moon. Eclipses were also associated with the outbreak of epidemics and plagues.

To watch darkness descend over the world in the middle of the day was regarded by all ancient cultures as a sign of cosmic disorder. Angry gods and monsters were threatening to destroy light and plunge the world into eternal darkness. The Mayans especially feared solar eclipses, considering them to be the violent triumph of night beings over the day.

To Mayans, form-changers demons prowled the night, and supernatural beings tried to communicate with mortals. Even late into the 1600's, people were fearful of eclipses, hiding in cellars, and covering their wells to prevent sky poisons from dripping into their drinking water.

Eclipses are fascinating to watch. It truly is an uncanny experience to see midday turn into a night dotted with stars. One astronomer from the 19th century, in describing an eclipse, stated: "*A profound calm reigned in the air; the birds sang no more.*"

Eventually, skywatchers understood that lunar eclipses were the result of the Moon moving into the Earth's shadow, and that solar eclipses occurred when the Earth moved through the Moon's shadow. Thales of Miletus, a philosopher, made the first known prediction for a total solar eclipse in 585 BC. Thales only had the knowledge to predict the year, not the month or day of the eclipse.

The Anasazi Indians of Chaco Canyon had many solar observatory stations. In the harsh climate of the desert, where living conditions were marginal at best, the annual journey of the Sun was important for survival. In 1096 and 1097, total solar eclipses were observed in the American Southwest and recorded in painted rock art and designs chiseled into stone. The dependence on the Sun and its religious importance to the Anasazi induced them to become knowledgeable solar skywatchers.



Battle between the Lydians and Medes halted by the total eclipse of the Sun, May 28, 585 BC

However, it is now known to have occurred on May 28th. It is the first historical event dated to the day by computing times of previous eclipse events. At the time, a lengthy war was taking place between the Lydians and the Medes, and a battle was in progress on the day the eclipse occurred. The abrupt transformation of day into night shocked the two sides into ceasing their fighting. They immediately formulated a peace treaty involving two marriages between the opposing sides. Neither side knew about Thales' prediction.

Humankind has had a long and convoluted journey towards understanding the true nature of light. A common belief of the Greeks was that the eyes were the source of light, and therefore illuminated objects that their gaze fell upon. Plato maintained that the sensation of sight was caused by the union of three beams. The first

was a stream of divine fire" emanating from the eye itself; the second, light issuing from the seen object; and third, the radiance from the Sun. Plato looked upon these beams as something like tentacles blindly seeking one another, until they came into contact and united. Others thought that light was an invisible fluid present at all times and in all places, but which had to be somehow ignited to be seen.

Isaac Newton hypothesized that light consisted of vast quantities of invisible particles thrown off from a luminous source. Ten years later Christian Huygens, a Dutch physicist, formulated the first clear statement of the wave theory—that light consisted of waves emanating from a luminous surface. But because Huygens could not explain all observable behaviors of light with his theory, and because Newton's authority as a scientist was so great, Newton's corpuscular theory of light was widely accepted. Unfortunately, this retarded the development of the wave theory for the next one hundred years. Proponents of both the particle and wave theories believed that light required a medium through which it would travel, and since light travels across space in which there is no matter, then the whole of space must be filled with this medium, called "ether." Huygens conceived of the ether as an elastic solid through which the waves were transmitted from the luminous source. We now know that "ether" is not necessary: light requires no medium through which to travel. Both Huygens and Newton were partially correct about the nature of light—light exhibits the characteristics of waves when traveling, and the characteristics of particles when interacting with a surface—and the *wave-particle duality* of light is now commonly accepted.

The effort to understand light has been accompanied by the desire to control it, as people strove to extend daylight by illuminating the night. At the end of the 1700's, life was still regulated by the hours of daylight, and tallow candles were the primary means of providing limited visibility at night. Wax candles were made from honeycombs and bayberries. During this time it was discovered that whale oil was more efficient than

candles, and whale oil lamps provided street lighting in large cities. The demand for whale oil was so great that whales were hunted to near extinction.

The invention of each successive light source, from candles to whale oil to kerosene and gas, was a refinement of the previous method, but resulted in a greater danger of fire, explosions, and asphyxiation. It was not until after the nature of light was finally understood that the development of Edison's safe and efficient electric light was possible. An explanation was provided in 1873, when James Clerk Maxwell presented his equations dealing with electromagnetic theory. Maxwell, through his mathematical equations, was the first person to understand that visible light was just one of the many wavelengths of electromagnetic radiation.

Our understanding of light has changed dramatically since natural philosophers in ancient Greece first studied and speculated about its nature. Since we see the universe as light traveling through spacetime, we will now focus on its wavelike nature.

Investigation 8.1: The “Flavors” of Light

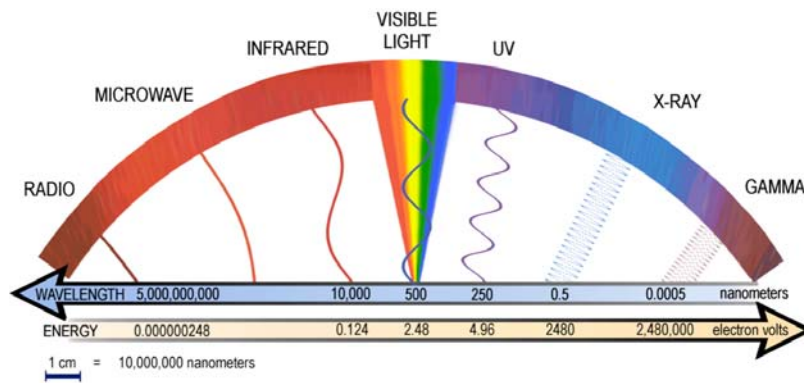
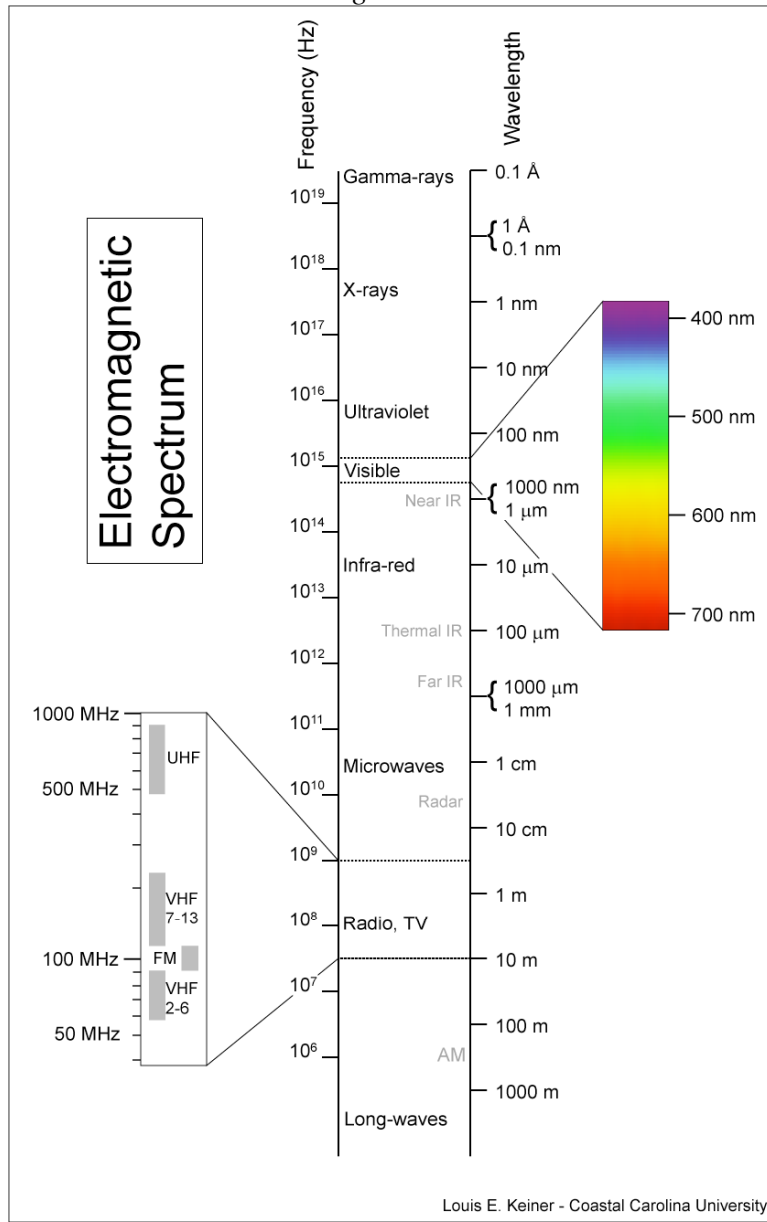
You will be given a set of objects by your instructor. Using these objects, investigate the light sources around you. Make a list of characteristics that these objects help reveal about light. Discuss your observations with the rest of the class.

The Electromagnetic Spectrum

Visible light, when separated into its individual parts, exhibits a rainbow or *continuous spectrum* of colors. Each color is associated with a different *wavelength*. These wavelengths of light continue on either side of the visible spectrum beyond our abilities to detect them visually, but we can “see” them by using specialized instruments. All of these wavelengths together form the *electromagnetic spectrum*, and are also referred to as *electromagnetic radiation* (EMR).

According to the wave model of electromagnetic radiation, the different parts of the electromagnetic spectrum differ from each other only by their wavelengths. The wavelengths of EMR sources differ (going from longer to shorter) as follows: radio, microwave, infrared, visible (red, orange, yellow, green, blue, violet), ultraviolet, x-ray, and gamma ray. Non-visible wavelengths are not called “colors” but are referred to as “bands” of radiation; for example, the *microwave band* (see Figure 8.1 on the next page).

Figure 8.1



A band of radiation is defined by its *wavelength*. One wavelength is the distance between adjacent troughs or crests (see Figure 8.2 below).

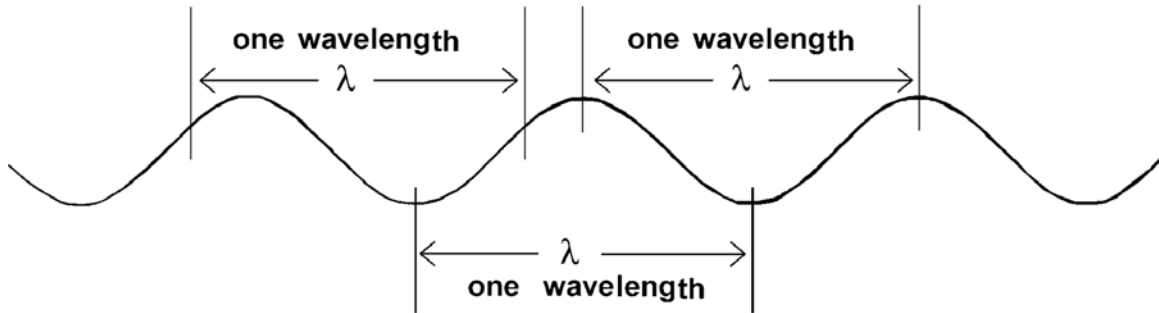


Figure 8.2

All EMR travels at the speed of light, 3×10^8 m/s, when traveling through space. In addition to wavelength (λ) and speed (c), another important property of waves is their frequency (f). This is a measure of how many waves pass a given point in one second. In other words, frequency is the number of cycles that occur in one second. The shorter the wavelength, the more that can occur in one second, and thus the higher the frequency. The longer the wavelength, the fewer that can occur in one second, and thus the lower the frequency. Frequency is measured in cycles per second (cps) or Hertz (Hz). Since all wavelengths travel at the speed of light, the relationship among speed c (the abbreviation for *celerity*), frequency (f), and wavelength (λ), can be stated as follows:

$$c = f \lambda$$

The different bands of EMR consist of little packets of energy—called *photons*—traveling through space. The amount of energy (E) they possess is directly related to their frequency (f). Radio photons have a low frequency and correspondingly low energy; gamma ray photons have the highest frequency and therefore the highest energy. This simple relationship can also be stated mathematically:

$$E = hf,$$

where h is a universal constant called Planck's constant and equals 6.626×10^{-34} Joule-sec. (The metric unit for energy is the Joule (J), and 3.6×10^6 J is equivalent to 1 kilowatt-hour, or kw-hr.)

“Seeing” the Electromagnetic Spectrum

As the visible band of EMR strikes our eyes, it is focused by the lens onto the retina in the back of the eye. The rods and cones in the retina then stimulate nerve impulses which travel to the cerebrum, which converts this information into an image. We do not have the ability to convert any of the other bands of EMR into a visual image; we must use suitable sensors to capture radio, microwave, IR, UV, X-ray, and gamma ray wavelengths. Another barrier to our detecting nonvisual bands of radiation from outer space is the Earth's atmosphere. The atmosphere is opaque to most forms of radiation—except for small “windows” where those parts of the spectrum can penetrate to the

surface of the Earth (see Figure 8.1). Balloons, rockets, and satellites are launched carrying telescopes and other instruments to detect other bands of radiation such as UV and IR. Even optical telescopes such as the Hubble Space Telescope (HST) are launched into orbit to avoid atmospheric conditions which interfere with the “seeing” of radiation from celestial objects.

The visible light we *can* detect from stars and other celestial objects gives us much more information than a simple image. One of the most powerful tools available to astronomers is the *spectroscope*, a device through which light is passed to produce the *spectrum*. Sometimes it is recorded on a photographic plate. The analysis of the spectrum from a star tells astronomers its mass, age, composition, motions, temperature, and evolutionary history. The study of the analysis of spectra is called *spectroscopy*.

The most common type of spectrum is the *continuous spectrum*, which we commonly refer to as the “rainbow.” As you would observe outdoors, there are no parts of a rainbow that are either very dark or very bright compared to the rest of it. Likewise, there are no dark lines that stand out in the continuous spectrum where any wavelengths of color are missing (*absorption lines*); and there are no bright lines that stand out in the continuous spectrum where certain wavelengths of color are being produced (*emission lines*). If neither emission nor absorption lines appear, then the light source is glowing in all colors equally and is said to be giving off “white light.” A common example of such a source of white or continuous light is an incandescent light bulb.

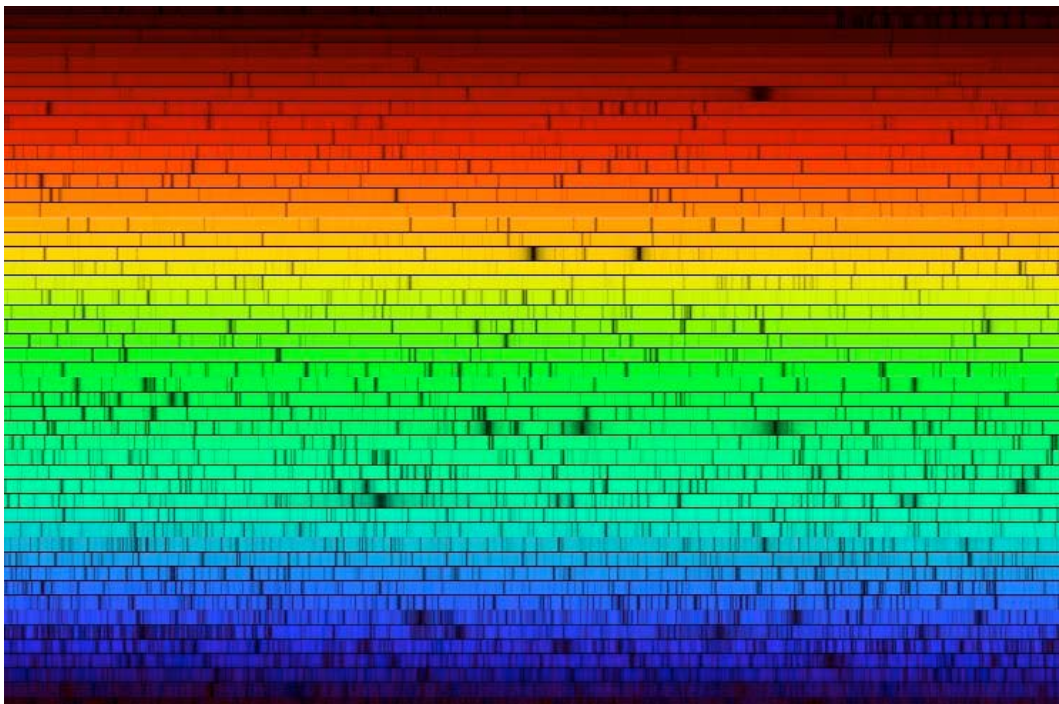
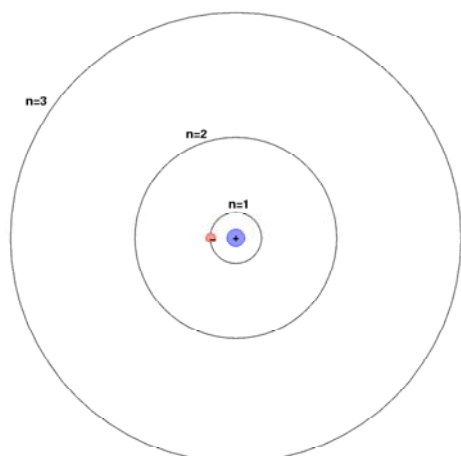


Figure 8.3 – Optical Solar Spectrum with Absorption Lines, Kitt Peak



Bohr Model of the hydrogen atom

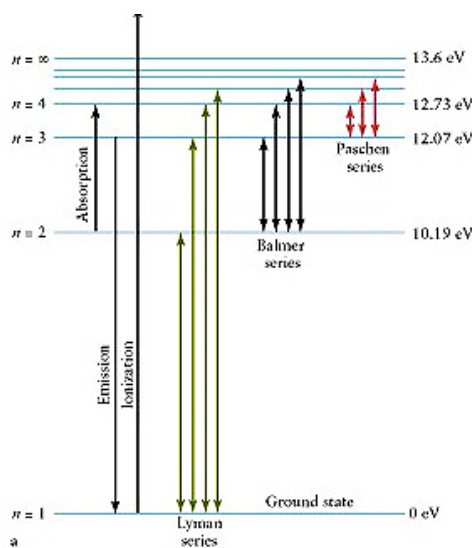
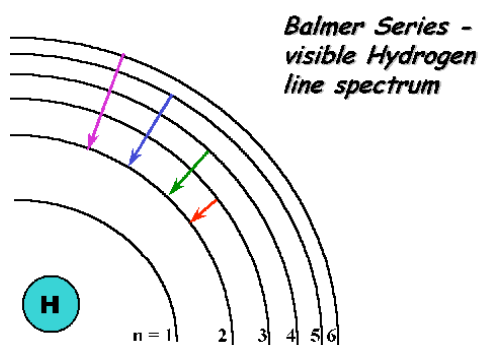


Figure 8.4 –
Four views of the hydrogen atom

If a single source, such as hydrogen gas, is heated or otherwise excited to luminescence, and this light is passed through a spectroscope, you would see that only certain colors or spectral lines are produced instead of a continuous band of colors. This is called an emission or bright line spectrum (see above). The reason for the presence of emission lines can be understood by looking at the atomic structure of the hydrogen atom. The Bohr model (at left) is a greatly simplified schematic representation of the hydrogen atom.

The next two accompanying energy level diagrams are different representations of the Bohr hydrogen atom model.

The single electron of the hydrogen atom can exist at different energy states (levels) or orbits around the nucleus. Each of these levels corresponds to a specific amount of energy, and no electron may occupy the spaces between these levels or orbits. In the diagram, the electron is in the first energy level, referred to as the *ground state*. Five other “allowed” states are represented. As the hydrogen atoms within the hydrogen gas are heated, collisions take place between electrons, and some of the electrons become “excited” by absorbing energy from these collisions. Some electrons will absorb the exact amount of energy necessary to “jump” to a higher energy state. The electron(s) will then spontaneously drop back down to a lower energy level, releasing their excess energy as electromagnetic radiation in the form of *photons*. The energy of the photons is equal to the difference in energy between the two energy levels, and is associated with a specific wavelength and frequency. The electron does not have to fall back to ground state all at once and give off one wavelength of radiation; it can fall back in “steps” from one energy level to another on its way back down. Every time it lands on an energy

level, it gives up a wavelength equal to difference between the two energy levels. If the electron gets “bumped” up to energy level 4, it can drop down in any of the following ways: 4 to 1 *or* 4 to 3 to 2 to 1 *or* 4 to 3 to 1 *or* 4 to 2 to 1. (See Figure 8.4.) Electrons dropping back down to energy level 1, or ground state (the *Lyman series*), produce wavelengths in the UV part of the spectrum and are not visible. Those dropping back down to the second energy state are referred to as the *Balmer series* and result in wavelengths in the visible part of the infrared (or IR) band.

Because every element has a different number of protons in the nucleus, the first “allowed” energy level where the electrons can orbit is at a different distance for every single element. The distance from the nucleus of all the remaining orbital levels or energy states for electrons depends on the first orbital level or energy state. Since the distances are different between energy states (orbital levels) for all elements, the wavelengths of radiation produced by electrons falling down from one energy level to another energy level are different. Therefore, compared to other elements, the distance between any two energy states or orbital levels for *every single element is unique*. Since the energy is different, the wavelengths of radiation produced are different. Therefore the emission lines produced by every single element are unique to that element, like your fingerprints are unique to you.

In 1868, during an eclipse of the Sun, the French astronomer P. J. C. Jansen saw a bright line in the yellow part of the Sun’s spectrum, coming from a prominence on the Sun’s limb. The line was different from any previously-observed spectral line. It was also seen by the English astronomer Sir Norman Lockyer, who concluded that it originated in a gas as yet unknown on Earth. He named the unknown element “helium,” after “helios,” the Greek word for the Sun. It wasn’t until 27 years later, in 1895, that Sir William Ramsay found a laboratory gas which produced the same bright line in the yellow part of the spectrum. Helium is the second most abundant element in the stars; however, it occurs rarely on Earth, and so was originally discovered through analysis of the Sun’s spectral lines.

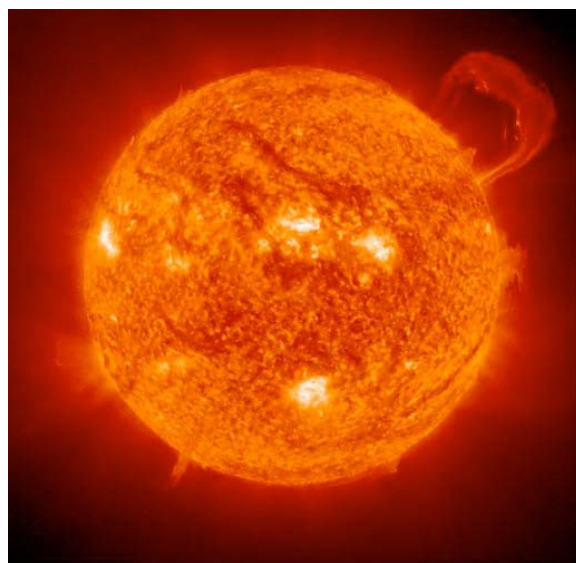


Figure 8.5 - A solar prominence captured on September 14, 1999.

Core Activity 8.2: Spectra of the Elements

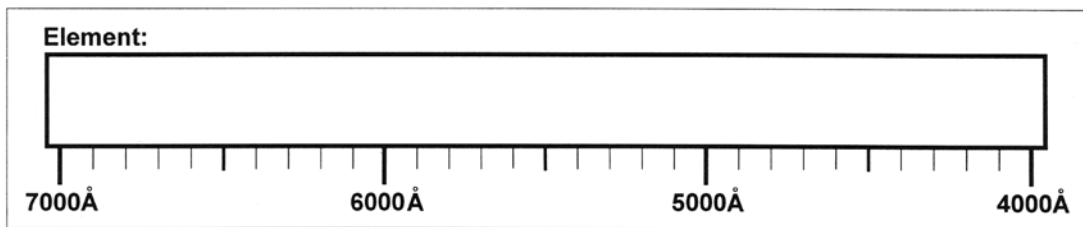
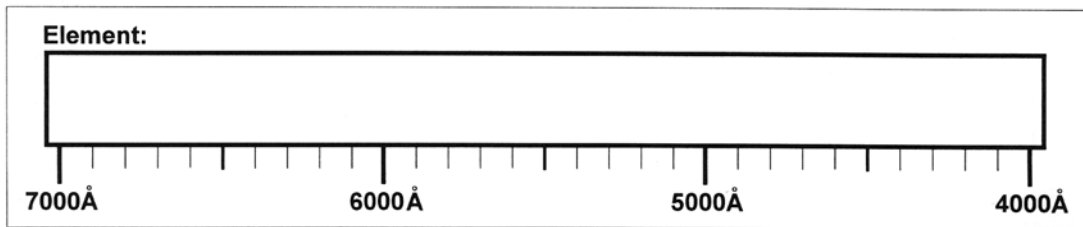
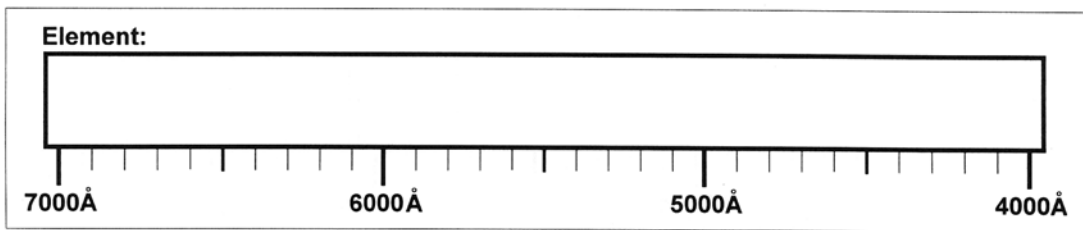
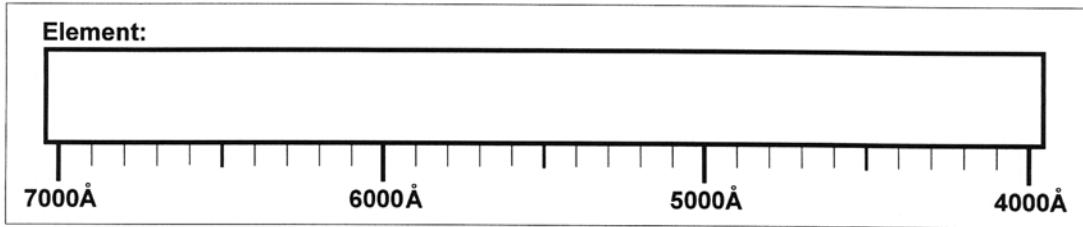
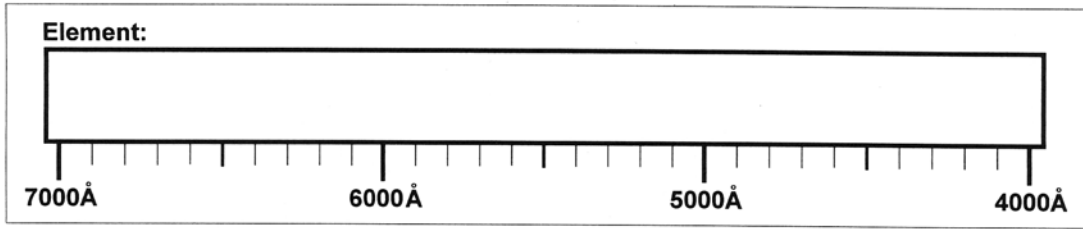
To access a set of activities, materials, and resources about the electromagnetic spectrum: *Modeling the Spectrum* at <http://chandra.harvard.edu/edu/formal/ems/>

- A. You will be provided with a spectroscope. Light enters the spectroscope through a narrow slit and becomes separated into its component colors. Look at the light from an incandescent light source with the spectroscope and you will see the full spectrum of colors. Notice there is a scale inside the spectroscope for the wavelength range of visible light. The scale is either in nanometers or angstroms ($400 \text{ nm} = 4000\text{\AA}$). You will be provided with several spectrum tubes that contain elemental gases. For each element, draw in the emission lines in color at the appropriate wavelengths which you see on the blank spectra sheet provided. Use the same colors you see, and record the names for the elements.

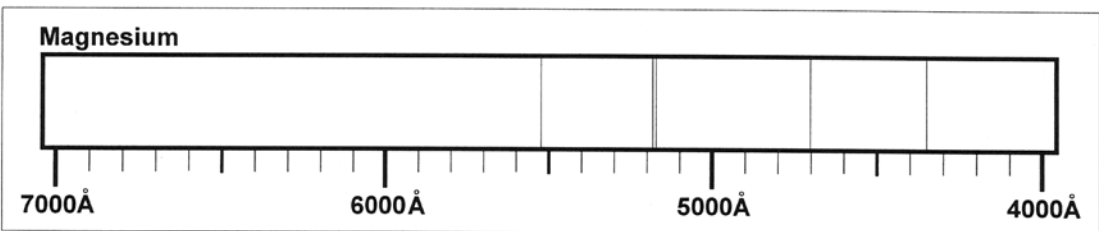
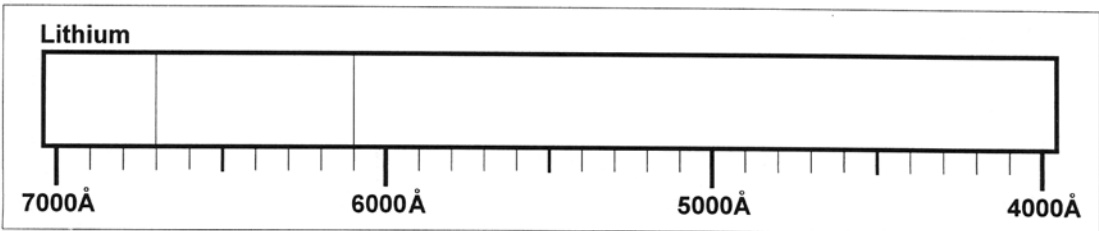
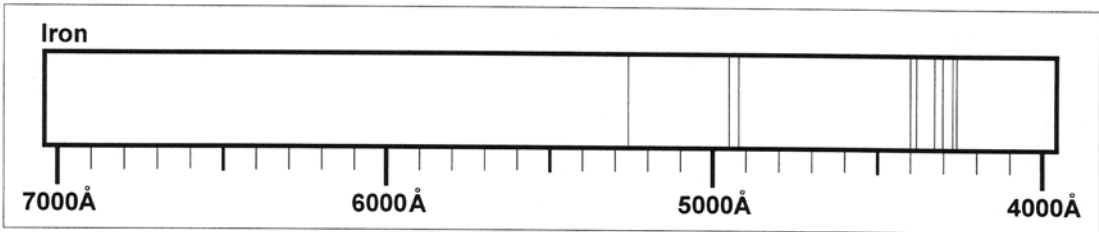
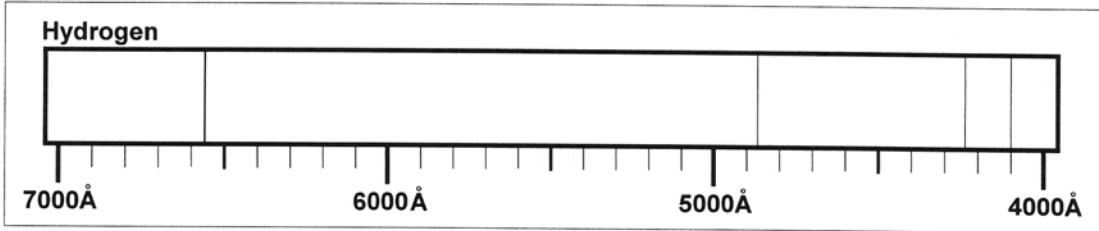
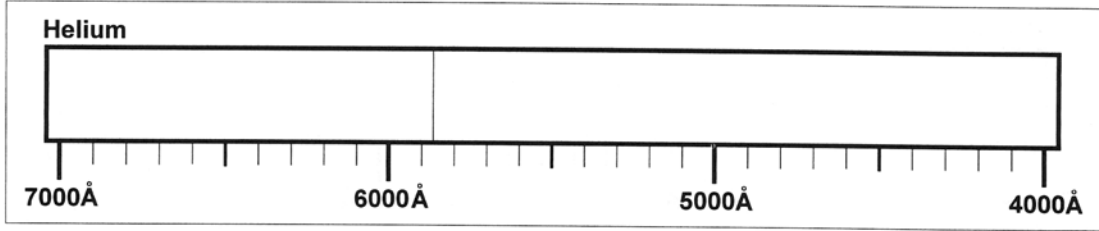
Study the spectra that you have recorded. Are the emission lines different for each element?

- B. Study the spectra of the elemental gases given in the following pages. Some characteristic emission lines have been represented. If you have observed some of these elements already, you may notice that the emission lines you have recorded differ from the ones represented on the following pages. Your spectroscope is precise enough to show only the most dominant lines. Most elements have many lines, and the most dominant lines may not have been selected. Two mixtures have also been included.
- C. Since the emission lines of elements are unique, their spectra can be identified when there are several elements mixed together. Five unknown mixtures of the elements above are represented. Identify which of the elements in part B are in the unknown spectra (numbered 1–5) in part C on the pages following.

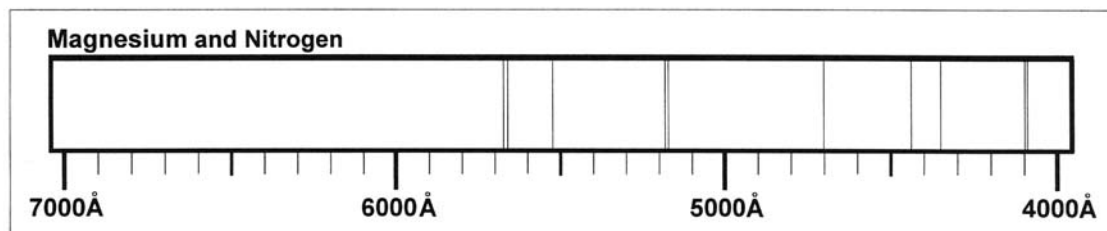
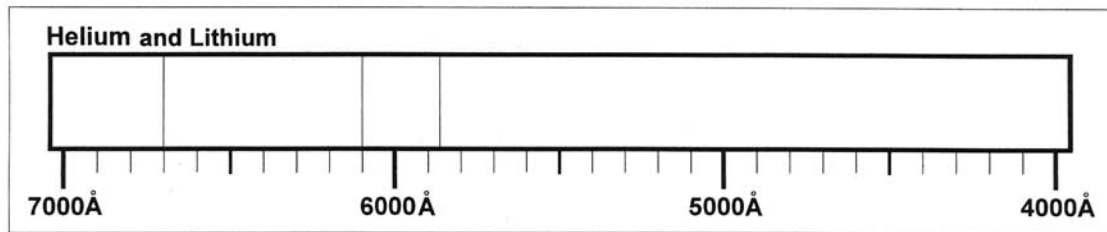
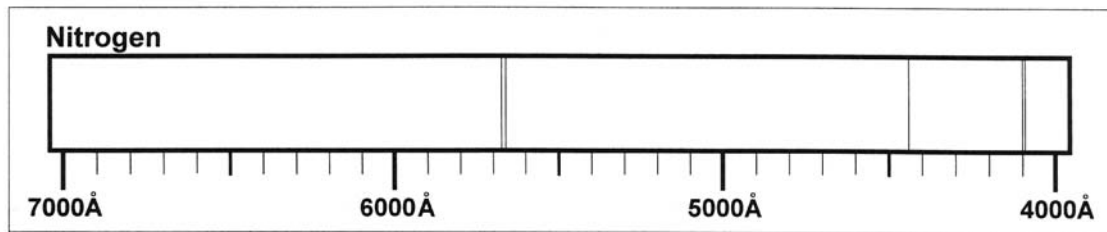
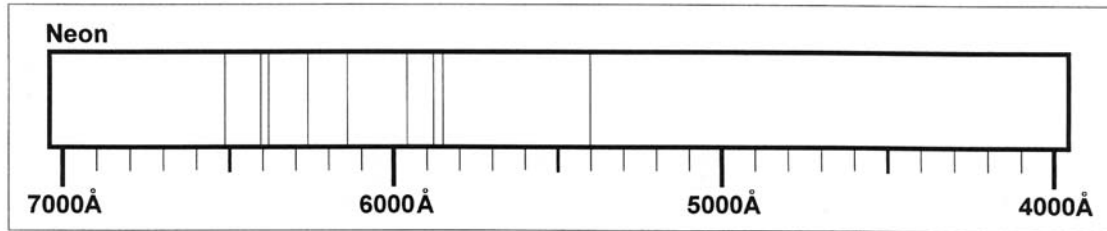
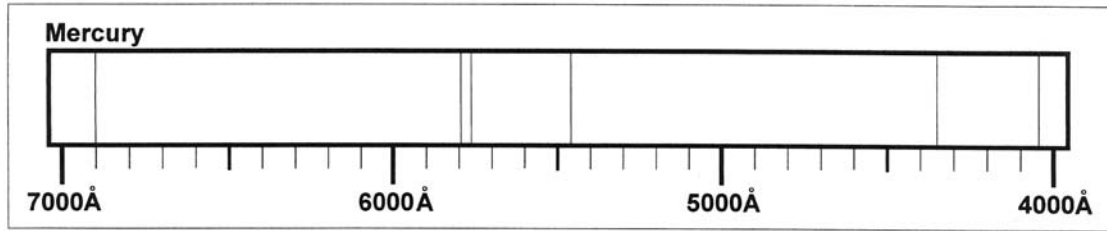
A. BLANK SPECTRA



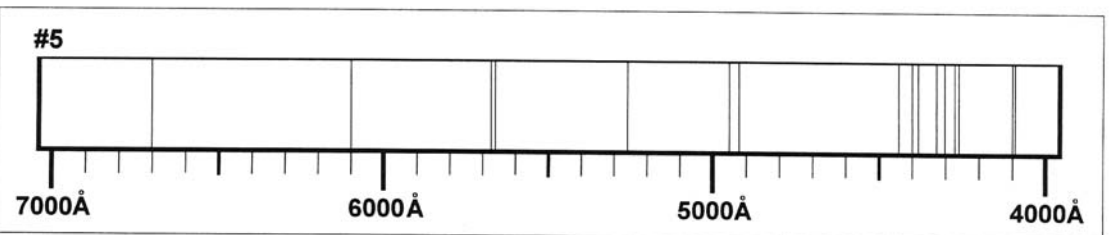
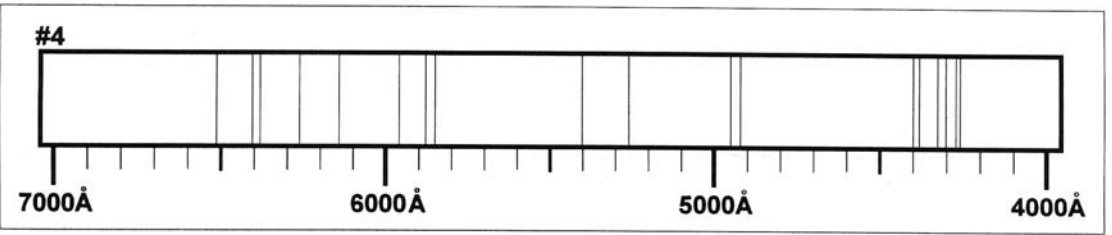
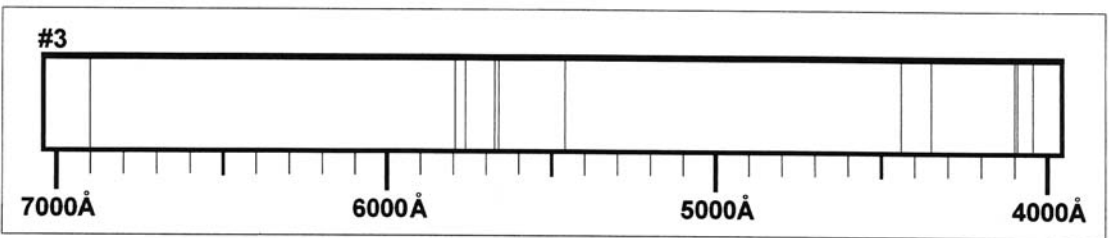
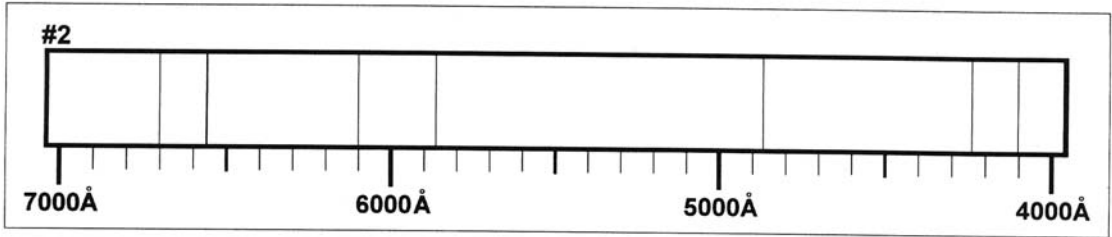
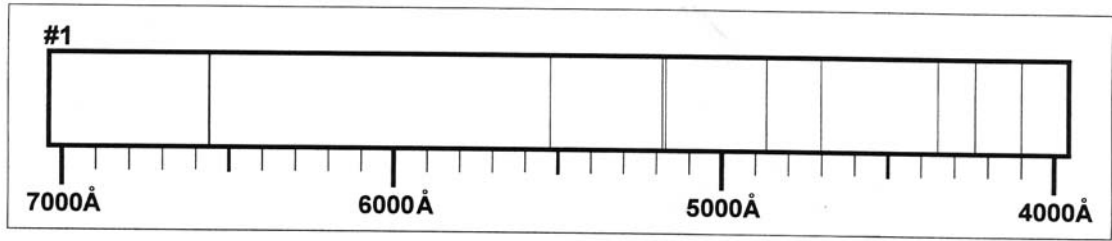
B. IDENTIFIED SPECTRA, PAGE 1



B. IDENTIFIED SPECTRA, PAGE 2



C. UNIDENTIFIED SPECTRA



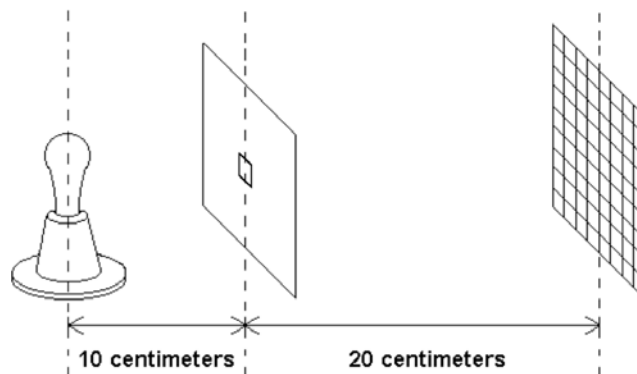
Core Activity 8.3: The Inverse Square Law

If two quantities being compared to each other both increase or decrease correspondingly, we say they are *directly related* to each other. If one quantity increases while the other quantity decreases correspondingly, we say they are *inversely related* to each other.

As the distance from the source of electric fields or gravitation fields increases, the strength of those fields will decrease. This is not a direct relationship, but an inverse one. The strength of electrical and gravitational fields are inversely proportional to the square of the distance from their source. Light intensity follows this same relationship, known as the *inverse square law*. This relationship is a characteristic of most phenomena that radiate out in all directions from a single source, including sound. The inverse square relationship is expressed mathematically as

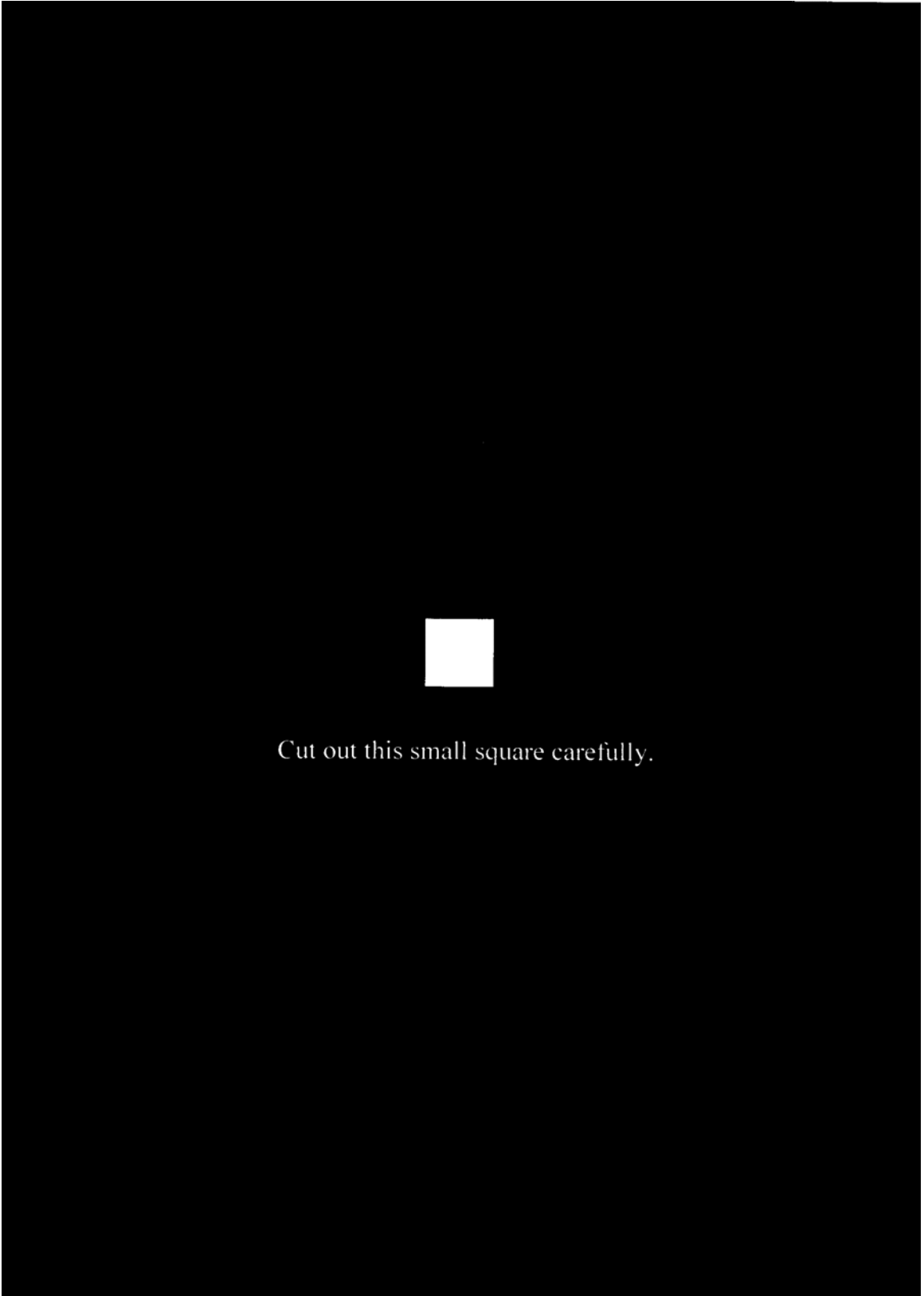
$$1/r^2 \text{ (with } r = \text{ distance)}$$

Your instructor will give you a piece of cardboard and a piece of paper, each with a small square outlined in the center, along with a second piece of cardboard and a piece of grid paper. Carefully cut out the two squares, leaving no rough edges. Line up the two openings and glue the paper to the cardboard. Next, glue the piece of grid paper to the second piece of cardboard. Your instructor will turn on a clear 200-watt light bulb or other bright source and will darken the room. Have a partner hold the cardboard so that the opening is 10 cm away from the light source, keeping the cardboard perpendicular to the direction of the light. The cardboard will stay in this same location for the entire activity. Hold the grid right up next to the first piece of cardboard, on the side away from the light source, so that the square in the first piece will line up with one of the middle squares of the second piece. (In other words, the distance between the two pieces will be 0.) Keeping the two pieces of cardboard parallel to each other, slowly back the grid-card away from the first card, and record the number of squares illuminated at distances of 20, 30, 40, and 50 cm.

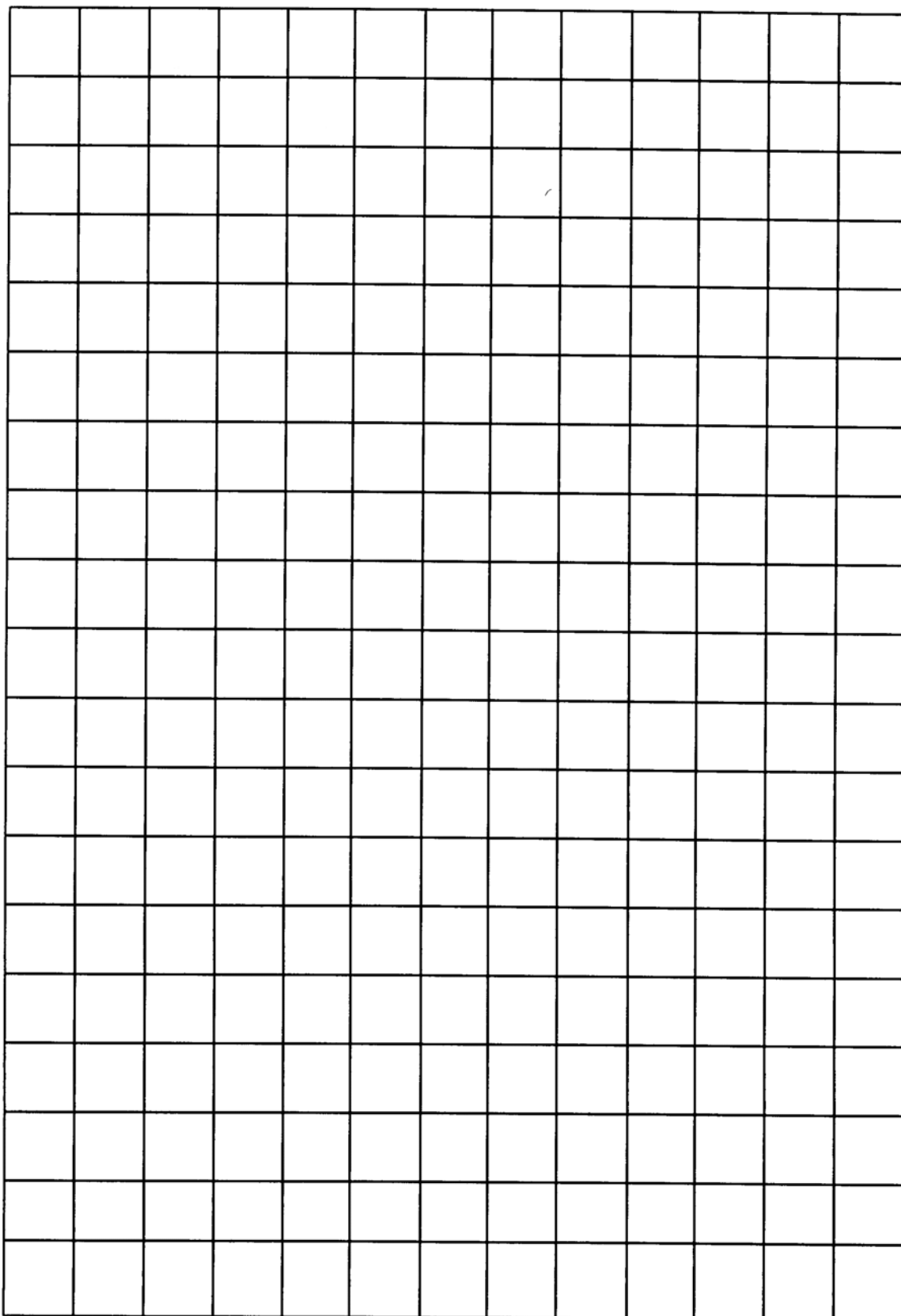


Answer the following questions:

1. For each one of the distances above, what fraction of light was falling on just one of the squares?
2. Can you now calculate what fraction of light would illuminate one square at a distance of 100 cm?
3. In order to have each square receive the same amount of illumination or brightness as it did at 10 cm, how many identical light bulbs would have to be placed at the same location as the original light for each one of the distances in 1 and 2?
4. The planet Pluto is 40 times farther from the Sun than the Earth is from the Sun. If you were on Pluto, how bright would the Sun be compared to how bright the Sun appears from the Earth? How many additional similar Suns would have to be placed next to the Sun for it to shine as brightly on Pluto as it does on Earth?



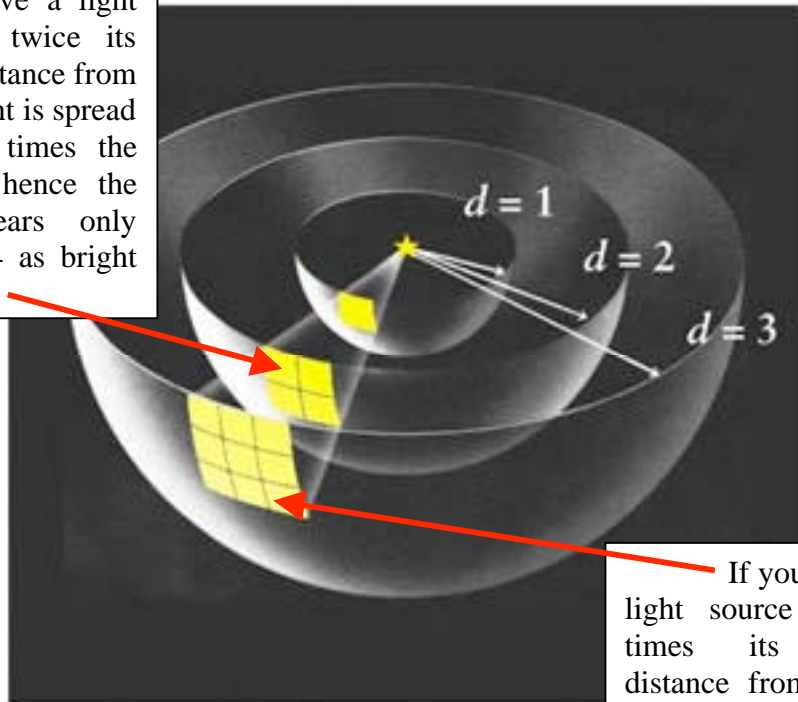
Cut out this small square carefully.



The Inverse Square Property of Light

Light intensity, like gravity, electromagnetic radiation, and sound, diminishes by the square of the distance.

If you move a light source to twice its original distance from you, its light is spread over four times the area, and hence the light appears only $1/2^2$ or $1/4$ as bright as before.



If you move the light source to three times its original distance from you, its light is spread over nine times the area, and it would appear $1/3^2$ or $1/9$ as bright as before.

As the distance from the source increases, the radiation continues to spread and its intensity decreases even more, but the amount of energy never quite reaches zero.

*This **inverse square** property of light is characteristic of anything that spreads out in straight lines in all directions.*



Poster Page: Inverse Square Relationships

As one gets further and further from a source of electromagnetic radiation, the intensity of the source decreases. As the energy emitted from the source spreads out into space it spreads over the surface of an imaginary sphere of larger and larger radius. Since the surface area of a sphere is proportional to the square of the radius of the sphere (area = $4\pi r^2$), the intensity of the radiation at any point on the sphere decreases as the sphere enlarges. In other words, the intensity of a source of electromagnetic radiation (EMR) decreases with the square of the distance from the source. For example, if we move twice as far from a source, its intensity decreases by a factor of four.

All phenomena which radiate out in all directions from the source follow the same inverse square relationship, including sound, gravity, and electrical forces. Consider the similarities of the two following mathematical equations:

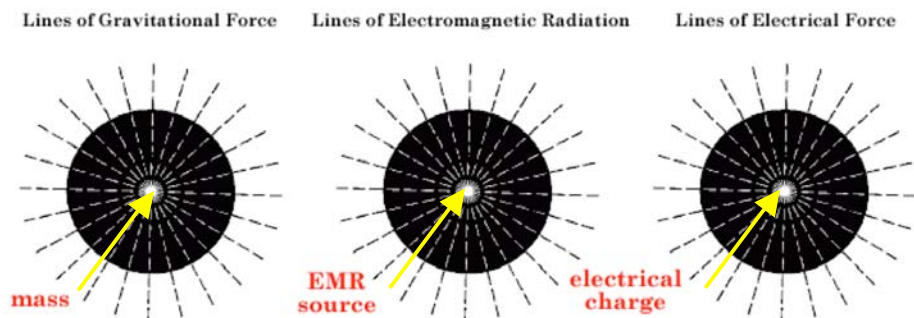
$$\text{Newton's law of universal gravitation: } F = (G m_1 m_2) / r^2$$

This equation states that to calculate the force due to gravity (F) on any object by any other object, multiply the masses of the two objects (m_1 and m_2) and the gravitational proportionality constant ($G = 6.67 \times 10^{-11} \text{ N m}^2 / \text{kg}^2$), and divide by the square of the distance between the two objects (r^2). Note: A *Newton* (N) is a metric unit of force equal to about one-fourth of a pound.

$$\text{Coulomb's law for electrical forces: } F = (k q_1 q_2) / r^2$$

This equation states that to calculate the electric force between any two objects (F), multiply the amount of charge on the two objects (q_1 and q_2) and the proportionality constant ($k = 9.0 \times 10^9 \text{ N M}^2 / \text{C}^2$), and divide by the square of the distance between the two objects (r^2). Note: A *Coulomb* (C) is the metric unit of charge and is equal to the charge of 6.25×10^{18} protons, i.e., one proton has a charge of $1.60 \times 10^{-19} \text{ C}$.

In the graphic representation of the inverse square law below, you can see that as you draw concentric circles around masses, the lines of gravitational force get farther and farther apart, or weaker. The same decrease in strength happens to radiation and electrical forces as they increase in distance from their points of origin.



Activity 8.4: Light Pollution

Light has been traveling for billions of years, carrying information from remote parts of the universe. But when this ancient light finally reaches the Earth, many of us never see it. It is lost in the glare of *light pollution*. Anyone who lives in or near large cities has seen that the night has been conquered by *skyglow*. For them, the dark, star-cluttered skies of the ancient skywatchers no longer exist. Many people have never seen the clusters of stars and stellar clouds of the Milky Way. Light pollution is a problem for us all, not just for professional and amateur astronomers. Light pollution interferes with everybody's view of the universe.

1. Your instructor will provide a set of slides or pictures showing different types of outdoor lighting. Study the spectra of light sources that you observed in Investigation 8.1 and elemental gases in Core Activity 8.2. Your instructor may provide additional light sources and gas emission tubes.
2. With a portable spectroscope, look at outdoor lighting around your school, home, and/or neighborhood. Determine what types of light sources you see by drawing the spectral patterns you see and comparing them to the ones you drew in class. Draw a map of the area showing where lights are located. Are there areas of bad lighting? Good lighting? Light pollution? Discuss and compare what you find with your classmates.
3. From your observations made in parts 1 and 2 above, discuss what changes you would recommend to improve lighting and reduce the amount of light pollution in each particular lighting situation.

SPACE TALK

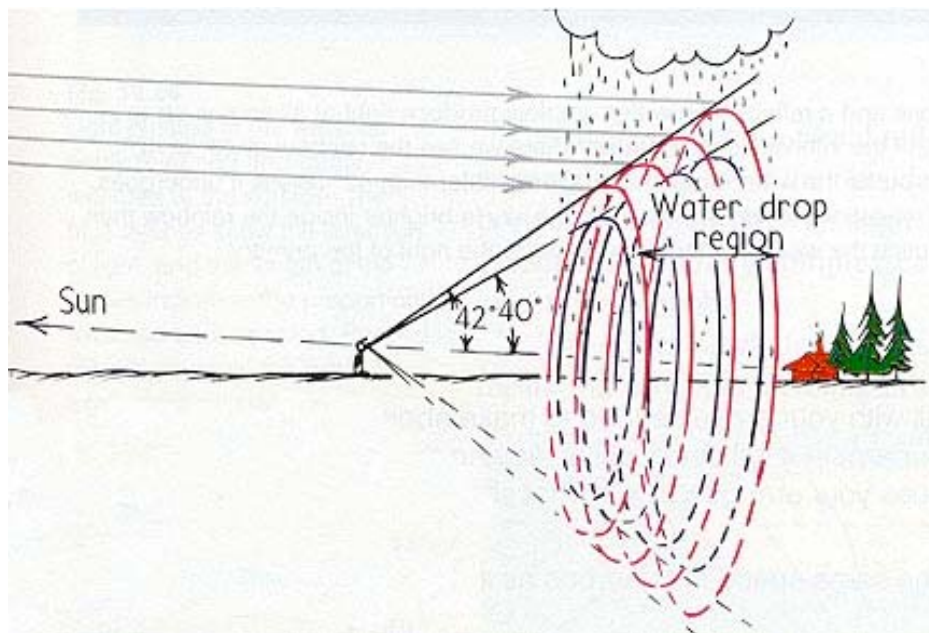
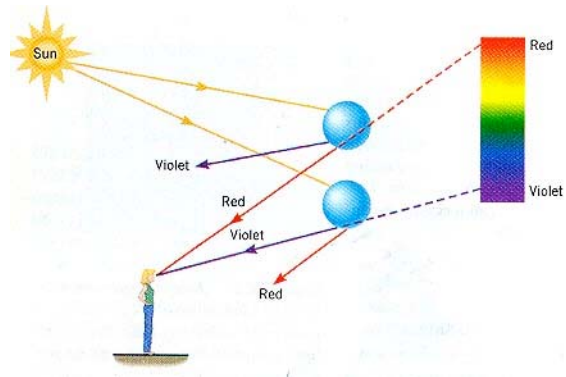
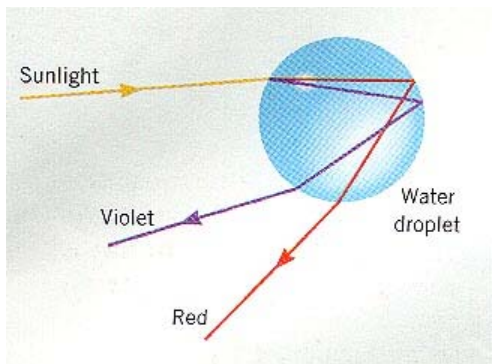
Iris was the Greek goddess of the rainbow. Her appearance was associated with tumult and mischief for humans, and considered an omen of war and storms. She was the daughter of Thaumus, the god of wonder, marvel, and magic. The rainbow is certainly a marvelous and magical thing to behold, a subject for poets, painters, and photographers, as well as for meteorologists and physicists. Understanding some of the physical properties of light that produce this colorful array can help us see that the paintings and pictures depict something that isn't really there. The rainbow is only one manifestation of the ways the properties of light deceive our senses. The seven colors of the rainbow are as imaginary as the pot of gold at its end.

The man who first understood the physics of the rainbow was Theodoric of Freiberg, who lived in the latter part of the 13th century. After meticulous study, Theodoric concluded that the rainbow was produced by the **dispersion** of light into separate colors by individual raindrops. Since gravity pulls raindrops to the ground and rainbows don't fall out of the sky, he further decided that falling raindrops are continuously replaced by other raindrops and the eye cannot detect the motion of the changing raindrops producing the image. Because raindrops are difficult to study in the lab, Theodoric substituted crystalline stones to make a model of rainbows. Although Theodoric could produce the visible **spectrum**, he did not know what caused the individual colors to appear.

When you see a rainbow, the falling raindrops are usually ~1.6 to 2.4 km away from you, and the Sun is always behind you. The rainbow appears as a circular arc, beginning and ending at the horizon. A straight line drawn from the Sun, through your eyes, and through the Earth to the center point or radius of the arc, will end at the location of the *antisun*, or **antisolar point**. This line represents an axis through the center of the rainbow, which appears at a 40°–42° angle from the axis. You only see one piece of the rainbow, which is actually an entire circle. The lower the Sun sets, the higher the antisun rises above the horizon. The higher the antisun rises, the greater the amount of arc or circumference that can be seen, until a full semicircle can be seen at sunset. When the Sun is higher than 42° in the sky, the entire rainbow disappears below the horizon; during summer solstice at latitudes lower than 42°, rainbows can never appear in the middle of the day (see diagram on following page).

The fact that the rainbow always appears to be perfectly round is evidence that is not a tangible object. The arc always looks as if it is exactly in front of the observer. If it were really there, it would appear in more elliptical shapes to other observers standing on either side. Each observer is actually seeing a different rainbow. If one hundred people are observing a rainbow, there are one hundred different rainbows in the sky. If you walk along while watching a rainbow, it moves along with you, always at 40°–42° from the axis between the Sun and antisun. If you walk towards the rainbow, it retreats from you. If you back away, it moves forward. Since the rainbow is an illusion, has no end, and changes position as you move, that pot of gold will forever elude you.

When white light from the Sun enters a spherical raindrop, the light is *refracted* or bent. The amount of **refraction** is different for each **wavelength** of color, so each color is bent by different amounts. When the wavelengths of light reach the back of the raindrop, they are *reflected* back towards the front of the raindrop. The **reflection** of the wavelengths



does not change their angle, they do not get bent. At the surface of the raindrop the wavelengths emerge and once again get refracted or bent as they travel into the air. Wavelengths always get refracted when they leave or enter a medium which has a different density from the medium in which they were traveling. Each raindrop disperses a full spectrum of colors. Yet an observer on the ground, facing away from the Sun, sees only one color of light coming from each raindrop. If you see red light from a raindrop, the violet light from that drop is being deflected above your head. Further down you can see violet light coming from the raindrops; the red light from these drops is being deflected below your eyes into the ground. You see red light when the angle of the axis from the Sun to the antisolar point is at a 42° angle to the observer, and violet light when the angle is 40° . Other wavelengths of color are seen at intermediate angles between 40° and 42° .

The colors of the rainbow gradually blend into each other. Rainbows display a wide range of colors, and a rainbow can even change colors while you are watching. There are not equal amounts of each color, and their intensities are also not equal. Whether the colors

appear bright or dull depends on atmospheric conditions. Since rainbows are always the same distance from you, and visible light follows the **inverse square law** just like all **electromagnetic radiation**, brighter colors are not the result of more light reaching you. The order of colors is always the same, red at the top followed by orange, yellow, green, blue, and violet. (Isaac Newton also included the color indigo between blue and violet.) If you watch a rainbow during a thunderstorm, pay close attention during the sound of thunder. The boundaries between the colors will blur and disappear as a result of vibrations of air molecules which cause the raindrops either to vibrate or to merge together.

Rainbows are merely a beautiful illusion created by three of the wavelike properties of light: reflection, refraction, and dispersion. Because of their jewel-like brilliance, rainbows have often been portrayed in mythology as dispensers of wealth, such as gold, silver, or pearls. Many cultures, however, have regarded the rainbow as having malevolent aspects. In Greek mythology, Zeus instigated the renewal of the quarrel between the Trojans and the Greeks, then spread a rainbow across the sky to announce the outbreak of war. Celtic legends portray the rainbow as a snake with flaming eyes. The Celts believed that the devil assumed the snake disguise when he came to Earth and dried up all the lakes to satisfy his thirst. Aboriginal Australian lore also associated a serpent with the rainbow, and thought it responsible for bringing disease. They believed, too, that gods resided in the sky on crystal thrones, and the only way to reach them was to climb up a rainbow. In some places across Europe, it was considered dangerous to point at a rainbow—one's finger could become inflamed or lost, depending on the prevailing mood of the rainbow deity. Sailors thought if they sailed by one end of the rainbow while it was thought to be taking in water, they would be swallowed also.

Early cultures did not know that the rainbow is not a real object. Now it is described and modeled by complex mathematical equations, and explained in textbooks on physics and optics. Nevertheless, the rainbow, an elusive apparition of light, has not lost its allure.

One of the most important dragons of creation mythology is the Australian Rainbow Serpent, its symbol being the rainbow bridging Heaven and Earth. The Australian Aboriginal people believe the universe has two aspects - the physical world in which we live and another connected world from which it is derived called the Dreamtime. Since the Dreamtime is connected to our world, the creation story of the Ancestors and their mythical past is simultaneously the creation of the present and the future. There are as many legends of the Rainbow Serpent as there are tribes of people.



The Rainbow Serpent