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The Space Cadet's Laboratory: Using Electromagnetic Energy to Study Astronomy

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Introduction

Light is a very strange phenomenon. It is difficult to classify using our current ideas about the world because it seems to be schizophrenic in its nature. At times it acts like a wave; in other circumstances it acts like a particle. This dual nature can be difficult to understand for students who are at a concrete stage in their thinking. This curriculum unit is designed to make the absorption of these somewhat complex ideas easier. The curriculum unit is written to be taught in a high school physics class; however, most of the ideas could be adapted for use in a middle school or a general science class. Many of the students for whom this unit is intended struggle with basic algebra and read, write and think at about an 8th or 9th grade level. Most of these students have had very little background in science of any kind, so there will be a fair amount of basic and introductory information covered in this unit as well as some of the more advanced topics.

Light is a very important tool in many scientific pursuits. It is, however, essential in the study of astronomy. Astronomical distances are so large that humans have only traveled to our closest astronomical body, our own moon. We have been able to travel via robot to several close astronomical objects in our own solar system, but even those journeys require years of travel. As a result, most of what we know of the universe comes from the study of light emanating from, or reflected by, distant bodies. Thus, to understand the study of astronomical bodies, a sound understanding of light is essential.

This unit will begin with the basic concepts of light, its nature, anatomy and composition. Then, the information we derive from distant light sources will be discussed. Finally, the unit will conclude with a piece on how light is used to make our lives better.

Objectives

There are three major objectives in this curriculum unit. In the first section students will gain a basic understanding of the phenomena of waves and photons, in other words, the nature of electromagnetic energy. In the second section students will gain an understanding of the ways that we use the electromagnetic spectrum to learn about the world around us. Finally, in the third section, students will gain an understanding of the ways that the electromagnetic spectrum is used in society today.

The standards addressed in this curriculum unit are detailed at the end of the unit in the Appendix. They are derived from the Connecticut state standards for physics and for Earth science. However, Connecticut's standards are based on the California standards for the same topics. Therefore, I have included a reference to California's standards as well as quotations from the Connecticut standards. The standards being addressed will be referenced in the sections to which they apply.

The Nature of Electromagnetic energy

Electromagnetic waves are a strange phenomenon. As I stated earlier, electromagnetic energy has a dual nature; it is both finite like a particle, in the form of a photon, and infinite, in the form of a wave. It moves in a straight line, yet it also exists as a field. This duality is discussed in the sections that follow.

This part of the curriculum unit addresses the physics standards listed in the appendix. These are fundamental concepts, so you will probably find similar standards listed in other regions.

Waves

Waves come in a variety of different forms. As stated in the standard quoted in the appendix, all waves transport energy from one place to another. In fact, only traveling waves transport energy; standing waves do not. However, in this unit, we will not be discussing standing waves; we will only be discussing traveling waves. For example, a sound wave is generated when air is vibrated; the wave continues to vibrate other air molecules until the energy of the moving molecules is absorbed by some object like an ear drum or acoustic tile. While all waves share similar anatomical characteristics, which are discussed below, there are important distinctions which need to be considered.

Three waves which are most familiar to my students are sound waves, surface waves in water and visible light waves. In two of these cases, my students generally don't realize that the phenomena are actually waves, but they recognize their interactions with the waves. This prior experience makes these three waves a good starting point for discussions. In two of the three cases, the waves are mechanical, meaning the wave requires a medium through which it can travel. The third wave is a non-mechanical wave, meaning that it does not require a medium for existence. Both sound waves and water waves are mechanical; the visible light wave is non-mechanical. Because there is very little concentrated matter in space, the waves used to study astronomy are necessarily non-mechanical.

Anatomy

All waves share a similar anatomy. As illustrated in figure 1, all waves have crests and troughs. The length of a wave, one of its defining features is the distance between on crest and the next or between one trough and the next. In the figure below, the wavelength is measured from one crest to the next. The amplitude of the wave is half the distance from the height of the crest to the depth of the trough. The amplitude is another defining feature of a wave. The next defining feature of a wave, its rate, can be defined in two ways. It can be defined as a frequency or as a period. The frequency tells how many crests or troughs pass a certain point in a given amount of time; it is generally measured in Hertz (crests/second) abbreviated as Hz. The period tells how long it takes an entire wave (two crests or two troughs) to pass a given point; it is generally measured in some form of time (minutes, second, hours, etc.). The period and frequency are inversely related. The appendix contains a list of variables and formulas generally used to work with waves. It may be helpful to introduce the Greek alphabet before teaching this section.

Figure 1: Anatomy and Wave

(image available in print form)

Transverse, Longitudinal, Circular and Twisting Waves

There are several forms of waves. Electromagnetic waves are transverse waves, but the others are useful as comparisons. Transverse waves are waves that look like the pictures in the upper part of figure 1. In this type of wave, the amplitude is perpendicular to the direction of the motion of the wave. They are two dimensional. In the case of electromagnetic energy, electric and magnetic waves form fields that are perpendicular to each other around the central axis of both waves. Both fields travel in the same direction at the same time. The structure somewhat resembles a double helix. There is a picture of an electromagnetic wave in Universe in the chapter on light, optics and telescopes. There are also a number of pictures of the electromagnetic waves online.

Longitudinal waves, sometimes called compression waves, are a pulse of compressed material. In these waves, the crests and troughs of the wave are parallel to the direction of this motion of the wave. Sound waves are a good example. It is easy to demonstrate a longitudinal wave in a classroom. Have the students hold a hand up about an inch from their mouths and speak. The compressed air emanating when the students speak are an obvious examples of a longitudinal wave. Alternatively, a slinky or a fairly loose spring can be used to create a longitudinal wave. Either way, the wave form may be seen in figure 1. As you can see from figure 1, the crest of a longitudinal wave is a denser region and the trough is a less dense region. These concepts may be a bit more difficult for lower level students to understand, but a diagram like the one above combined with the aforementioned demonstration should help to get the ideas across.

Circular, sometimes called elliptical or surface, waves will be familiar to students from the beach. Students, however, probably will not recognize the waves they see at the beach as circular rather than transverse. In the example of a wave at the beach, any given molecule of water moves in a circle. The series of circles next to each other give the appearance of a longitudinal wave on the surface. However, if it were actually a longitudinal wave, there would be no undertow and the water would not recede back from the shore after each wave. Another way to picture this type of wave is to think of the air valve on a bicycle tire as the tire is rolling down the road. If a time-lapse photograph of the tire were taken, the valve would appear to move in a series of connected circles. A line drawn on the top of the circles would look like a transverse wave, but the valve itself is actually moving in a circular wave.

Twisting or torsion waves tend to be found in structures. If you wring out a wet cloth the twisting action is similar to a twisting wave. These waves are generally caused by natural forces acting on large structures. The example that comes to mind is the video of the Tacoma narrows bridge failing due to sympathetic oscillations. The twisting, rolling waves seen in the classic film footage is a good example of this type of wave.

Photons

Electromagnetic radiation is not simply a wave. Electromagnetic radiation always exists in the form of a wave and a photon. A photon is a very small, discrete packet of energy. To really understand photons and electromagnetic energy, though, you must understand how photons interact with atoms.

Photons and atoms interact in illuminating ways. An atom has a nucleus in the center with electron orbitals surrounding it. Think of the atom as a stadium: the nucleus is the stage, the orbitals are the rows of seats. Clearly, this is a very strange stadium as there are only two seats in each section, but never mind that. As in any concert experience, the seats right down in front, closest to the nucleus, are the most valuable. In a concert, they would be the most expensive. At this concert, though, the only currency is energy. So, the two electrons that are in the orbital closest to the nucleus, the ones with the best seats, have the least energy, because the best seats are the most expensive. If an electron "wants" more energy, it can accept a photon with a certain amount energy, but then it has to move to a specific higher orbital, further away from the nucleus. Similarly, if the electron "wants" to move in closer to the nucleus, it must give up a corresponding amount of its "currency", its energy, in the form of a photon. When an atom absorbs light, it is taking in photons which cause its electrons to move to a higher orbital. When an atom emits light, its electrons release energy in the form of photons, aka light, and the electrons move to a lower energy orbital. In the same way that tickets to different concerts cost different amounts, different atoms will react to different amounts of energy. The amount of energy in a given photon depends on the frequency of the electromagnetic wave. The different sources of astronomical electromagnetic energy are discussed below.

This topic has the potential to be a very interesting lesson. A staged "play" showing how electrons and photons interact might be effective in a normal sized class. I can see a situation where Nerf balls representing photons could be tossed into an "atom" made of students representing electrons in the atom. It has the potential to be a very memorable experience. My physics classes tend to be somewhat smaller with heavily pregnant students (being pregnant is a prerequisite for being a student in my school), so I might have the students do a somewhat less active activity like draw a cartoon comic book sequence instead.

Fields

An energy field is an area where a particular force has an influence on objects. In a way it is analogous to a cold-war sphere of influence. Warsaw Pact countries would be under the influence of the Soviet Union. NATO countries would be under the sphere of influence of the United States. A place like Berlin would be under both spheres of influence. In the same way, a paper clip dangling from a magnet would be in the magnetic field of the magnet, but it would also be in the Earth's gravitational field. Magnetic fields are easy to illustrate using iron filings. However, I will caution you that the iron fillings are very hard to get off the magnet if they come into direct contact with it. In my classroom, I generally use a child's toy for illustration. The toy is a piece of cardboard with a face printed on it. The face is covered by a piece of plastic. Between the plastic and the cardboard is a pile of iron filings. The toy comes with a magnet that is used to drag the iron filing around the face. The iron filings look like dark facial hair. In my classroom I evenly distribute the filing over the cardboard and then put a bar magnet underneath the cardboard. It works quite well. A detailed study of fields is possible, but the mathematics required for it is beyond the ability of most of my students.

Light

Astronomical objects emit all kinds of light. Not all of the light reaches the surface of the Earth. Not all of the light can be detected by the human body. Of the light that can be detected by the human body, most of the information it contains can not be analyzed without tools. As a result, astronomy is full of gadgets and tools that make the information we receive from electromagnetic emission in the universe more accessible and more comprehensible. This section is largely about the tools astronomers use and the information astronomers glean from the electromagnetic energy that reaches Earth. This section also addresses the Earth science standards mentioned in the appendix.

Electromagnetic spectrum

The electromagnetic spectrum is the continuum of the different frequencies of electromagnetic waves that we find in the universe. Most basic science textbooks that cover electricity and magnetism will have a diagram similar to figure 2 showing the different types of electromagnetic energy.

When light interacts with an object several things can happen: it can bounce off, reflection; it can go straight through, transmission, it can go through and change direction, refraction; or it can get stuck, absorption. In astronomy, objects will also emit light. Emission, transmission and refraction, absorption, and reflection are discussed below.

Figure 2: Electromagnetic Spectrum with order of magnitude of wavelengths

(image available in print form)

Emission

As described above, when an electron moves from a high state of energy to a lower state of energy, a photon, with energy equal to that which the electron lost, is released. Neon signs are an example of this type of emission. Astronomically, emission by this mechanism is seen from tenuous, hot, gas clouds that surround massive stars.

Blackbody radiation

While some of the light in the universe comes from emissions as described above, most of the light we see in the universe comes from heated matter in the form of blackbody radiation. When matter is heated to a specific temperature, it glows. The red of iron in a blacksmith's forge is an example of this phenomenon. Different types of matter emit different wavelengths of light at different temperatures. This characteristic glow is used by astronomers to gain information about distance objects.

In a star, when an atomic nucleus is shattered, sometimes a photon with gamma ray intensity is released. Sometimes the photon finds its way out of the star intact. However, most of the time, the photon is absorbed by matter in the star and another photon of lower intensity is released. Eventually, the energy is released from the outer layers of the star. The journey of the energy from the interior of the star to the surface is described in detail in chapter 6 of Death by Black Hole and other cosmic quandaries. As a result, the star emits light at various characteristic wavelengths depending on the type of matter that the energy moved through. The set of wavelengths at which a star emits light is called its emission spectrum.

Transmission and Refraction

The human eye can detect electromagnetic energy only in the visible light range of the electromagnetic spectrum. Even in that range, the human eye is not equipped to make precise judgments about the exact frequency of a particular light wave. Furthermore, the human brain tends to reinterpret what the eye reports, so what we recognize as seeing is not always what is actually there. All of this is to say that humans need to use tools to interpret the electromagnetic energy that comes from astronomical observations.

When light encounters matter at an angle perpendicular to the matter's surface, the light will bounce off, be absorbed or go through. When the light goes through the matter without bending or distorting, the object is said to transmit light. Transmission is somewhat rare; more often light is refracted when it passes through matter.

One of the simplest tools used in the science classroom is the prism. When electromagnetic energy is transmitted at an angle through matter, it slows down. When the energy enters the matter at an angle it bends. In my classroom I use a toy car to demonstrate this phenomenon. The car is one of the ones that you roll a few times to prime the spring inside so that when you let it go, the car rolls at a constant speed under the influence of the spring. I point the car in the direction of a pile of sand so that the car hits the sand at a fairly acute angle. The car turns in toward the pile of sand when the tires start to get bogged down in the sand. In the case of the car, the car turns because the sand side wheels are moving more slowly than the table side wheels. In the same way that a car turns a corner more easily when it is traveling slowly than it does when it is traveling faster, the lower energy waves hitting a prism are slowed more and bend more than the higher energy waves. The prism causes the light to separate into its component parts according to the amount of energy each part contains.

A very detail description of refraction and Snell's law may be found on the physic's classroom website.

Laboratory Activity: Snell's Law

When light bends as it passes through matter, the phenomenon is called refraction. The amount that the light bends depends on the type of matter through which it is passing. The amount the light bends is called the index of refraction and is a fundamental property of the type of matter. Calculating the index of refraction of various substances to determine their composition is an easy lab for students to do.

For this experiment students will need paper, several different translucent substances of similar shape and thickness, a light source which emits a beam of light, a ruler and a protractor. I use a flashlight with two pieces of masking tape forming a slight through which light can pass. Something like electrical tape might work better because it is more opaque. When I have done this experiment, I used rectangles of different types of glass and plastic. In my case, the experiment and the materials came with the classroom, so I don't have any good advice as to where to find them. I suspect that the experiment and the materials are available online someplace, though.

In the experiment, the student traces the block of glass on a piece of paper. This line becomes the boundary line between the air and the glass. The student then shines the light towards the glass at a fairly acute angle. The student traces the path of the light from the flashlight to the edge of the glass, the incident ray. The ruler may be useful for this part. When the light hits the glass, it should change directions. The student should lay the ruler on the block of glass so that the edge of the ruler follows the edge of the light. The student should continue this line on to the paper beyond the glass. The glass is then removed. The line that followed the light's path through the glass should be connected to the inside of the boundary line. This line tracing the light's path inside the glass is the refraction line.

This is where the calculation part of the lab begins. A normal line is drawn through the point where the incident ray and the refracted ray meet at the boundary line. The angle of incidence is measured from the normal line to the incident line. The angle of refraction is measured from the normal line to the refraction line.

Snell's law relates the amount of refraction to the type of substance and is written as follows. $n_1 \sin(O_{incident}) = n_2 \sin(O_{refraction})$ Where n_1 is the index or refraction for the substance where the light originates; in our case this substance is air. In the equation, n_2 is the index of refraction for the substance into which the light passes, in our case this substance is the glass. The thetas in the equation are the angles of incidence, measured as described above.

Using Snell's law, students will be able to come up with an index of refraction for their substance and determine the type of substance used. Because this lab is performed in air, whose index of refraction is 1, a variation on this experiment may be used as follows. The student should measure the angle of refraction for multiple angles of incidence. The sine of the angle of incidence may be plotted against the sine of the angle of refraction, forming a straight line. The slope of this line will yield the index of refraction for the substance.

Spectrophotometry

Spectrophotometry is the study of the electromagnetic spectrum. If you are very fortunate and have an electronic spectrophotometer at your disposal, this section of the unit will be fairly straight forward. If, like me, you do not have an electronic spectrophotometer, you will have to improvise a bit. A spectrophotometer uses refraction to separate light into its component parts.

Once light has been separated into its parts, it can be studied to see which pieces are present and which are missing. This task is made easier by the use of a spectrophotometer. A spectrophotometer, at least at the high school level, is used to study electromagnetic waves in the visible light range. Light from a particular source is passed through or reflected off a substance which refracts the light. The light is split into its component parts. The parts of the visible light spectrum that are visible from a particular light source create a sort of fingerprint which can be used to identify the substance that is emitting the light. So, for example, a neon light will not emit the same spectrum of light that a sodium vapor lamp or a tungsten filament lamp will emit. This is obvious from a simple observation of the color of the light emitted by each of the sources, even without a spectrophotometer; however, a spectrophotometer allows a scientist to observe the precise differences in the wavelengths of light that are emitted by each of the sources.

Building a Spectrophotometer Activity

When this unit is taught, the students will make their own spectrophotometers. There are very good directions for making a spectrophotometer on the sci-toys website. When I tried this demonstration with my fellow seminar participants, I made a few modifications to the directions on the sci-toys website. We used shoe boxes and cut a slit to allow the excess CD to protrude. We used electrical tape rather than foil tape. Finally, we used heavy card stock to make the light slit rather than razor blades. These modifications make the spectrophotometer less expensive and somewhat safer to manufacture. In fact the tape is the only thing that has to be purchased. In my classroom, I intend to have each of my students each make her own spectrophotometer. It is an inexpensive project and the spectrophotometers will be used in an experiment described later in this unit.

The spectroscope as I made it requires a shoebox with a lid, the inner tube from a toilet paper or paper towel roll, a dead CD, electrical tape, heavy card stock (a manila folder would work), and a box cutter (for construction). Before you build your spectrophotometer, I recommend that you check the sci-toys website, because they have good explanatory pictures on their site.

Start with the lid on the box. Hold the box so that the lid is on the top and you are looking at one of the long sides of the box. Slide the CD up between the lid and the side of the box so that one edge of the CD lines up with the top of the box and another edge lines up with the left edge of the side you are looking at. Make sure that the top of the box isn't lifted off as you do this. Trace the small hole in the center of the CD on to the side of the box. Remove the CD. Place the hole of the tube over the circle you have just drawn. Trace the outside of the tube. Move the tube a few centimeters to the right and trace the outside of the tube again. You should have something that looks like a Venn diagram drawn on the side of the box. Put the tube down and turn the box so that the short end of the box closest to the Venn diagram is facing you. Use the CD again and line it up so that one edge is lined up with the top of the box and one edge is lined up with the left edge of the short side. Trace the circle in the center of the CD onto the box. Remove the CD and draw a square about one centimeter on a side so that the right side of the square lines up with the left edge of the circle. Turn the box so that you are looking at the short end opposite the end with the square drawn on it. Line up the CD so that one edge lines up with the top of the box and one edge lines up with the *right* side of the short end. On the bottom of the box, where the CD sticks out beyond the short end of the box, draw a line tracing the width of the CD that extends beyond the box. Remove the CD. Using the box cutter, or an exacto knife, cut an oval that encompasses the two circles of the "Venn diagram". Cut out the square on the short side. Cut a slit along the line that was traced on the bottom of the box. Take the top off the box. Insert the CD into the slit and make sure that the box lid still fits. If it doesn't, make the slit longer until the CD fits. However, be sure that the CD still lines up with the side of the box. Once the CD fits, put a piece of tape across the top of the CD to attach the CD to the box. Make sure that the reflective side of the CD is pointing to the inside of the box. Tape the lid down to the box. Cut a piece of card stock that is large enough to cover the square you cut into the short end of the box opposite the CD. Cut your piece of card stock in half and tape the two halves to the box so that you have a vertical slit up the center of the square. Be sure to tape the card stock to the box above and below the square but not covering the square. Finally, position the tube in the oval so that the CD is visible. Tape the tube into place and cover up any places that light leaks in. When you look through the tube you should be able to see the spectrum of light that is emitted by the light source behind you.

If you have questions about these directions, I recommend that you visit the sci-toys website, http://scitoys.com/, because they have pictures to go along with their directions. Their directions are very similar to the ones I have discussed above.

Absorption

Sometimes electromagnetic energy does not make it through a particular substance. Two phenomena can cause this, absorption and reflection. When the wavelength of electromagnetic energy is just right, an atom or a molecule will catch and retain the photon that hit it. The energy contained in the photon inevitably causes some change in the molecule. Sometimes the molecule breaks apart. This frequently happens to gas molecules like ozone in the upper atmosphere when they are hit with ultraviolet light from the sun. In a plant cell, electromagnetic energy from blue and red light is absorbed by the chloroplast and is used to create sugars and starches. In the case of food in a solar cooker or a microwave oven, the electromagnetic energy causes the molecules, particularly the water molecules, in the food to move more rapidly and cook.

In astronomy absorption is often like the microwave oven example above. Electromagnetic energy is absorbed in one wavelength and is emitted by the same substance at a different wavelength. In the example of the solar cooker, visible light is absorbed by the food and infrared light is emitted; we know this because the food becomes hot after sitting in the sunlight. In the universe objects like dust clouds absorb electromagnetic energy at high frequencies and emit electromagnetic energy at different frequencies.

Reflection

Sometime light is neither absorbed nor transmitted by a substance. In this case it "bounces" off the substance. This is called reflection. My students are familiar with the concept of reflection from looking at things in mirrors and typically do an experiment with mirrors when we cover optics. Reflection is used in astronomy primarily in the construction of telescopes. However, reflection is also important in the study of reasonably close objects as it allows us to see objects like planets and moons. As telescopes, planets and moons are not the major focus of this curriculum unit, we will not spend much time on this topic.

Sources of electromagnetic energy in the universe

There are many sources of electromagnetic energy in the universe. The different sources emit light essentially for the same reason; they are very hot and glow. The information in this section comes from Universe; although, it can be found in many other places as well.

Hot gases clouds

Hot gases do not start out that way. Hot gases begin as a collection of cool gas molecules or atoms. In one form of heating as the collection of gas gets larger, the atoms and molecules that make up the gas cloud begin to exert stronger gravitational pull on each other. As the gas cloud begins to collapse under the force of gravity, the gas pressure increases and the gas gets hot. As the gas heats, it glows with greater luminosity. Alternatively, some cold gas clouds are heated by trapping escaped radiation from nearby stars.

Stars

If a gas cloud has enough mass, it will continue to collapse until there is so much pressure in the center of the star that a thermonuclear reaction begins. The gas cloud begins to "burn" hydrogen. In fact, the hydrogen nuclei are being fused into helium nuclei in a nuclear reaction, rather than being combusted with oxygen in a chemical reaction. When the gas cloud begins to fuse hydrogen nuclei into helium nuclei, the gas cloud is relabeled as a star.

Pulsars

Pulsars are a form of dead star. When a very massive star dies, it becomes a supernova, which basically means that it explodes. However, at the site of many supernovas, a core of material remains. This rotating body has a strong magnetic field and is surrounded by electrons and protons in a plasma. The electrons and protons orbit the star following the star's magnetic field. When the subatomic particles come near the magnetic poles, they speed up and emit light. When the magnetic field does not align with the rotational axis, in a situation similar to that on Earth, the poles of the magnetic field on the star rotate around the star. If the star's rotational axis is conveniently arranged, we see the light emitted by the subatomic particles speeding up as they travel near the magnetic poles. Because we only see the light when the magnetic pole is turned towards us, the light appears to pulse. The phenomenon is similar to watching the valve on a rotating bicycle tire from the perspective of an ant riding on the bottom of the bicycle seat. The ant only sees the valve once every rotation.

Quasars

Quasar stands for quasistelar radio source. They are immensely luminous and are very distant from us. They tend to be very small for the amount of energy they release. They consist of a massive black hole with an accretion disc around it. As long as the matter in the accretion disc falls into the black hole, large amounts of energy are emitted. The energy emission mechanism is described below.

Accretion disks (around black holes)

When a star is extremely massive, it will collapse into a black hole. A black hole is called a black hole because it contains so much mass that it is able to exert enough gravity that nothing, not even light, can escape it. As a result of no light being emitted from the object, the object appears black. This begs the question: "If we can't see it, how do we know that it is there?" Black holes are visible because matter falling into them emits light. Near a black hole, stars and other matter are being accelerated by the gravitational pull of the black hole. As the gravitation potential is increasing with proximity to the black hole and the total energy of the matter falling into the black hole must remain constant, the matter must emit as much energy as it gains from the gravitational pull of the black hole. The newly acquired additional gravitational potential energy of the matter is converted into kinetic energy and causes the matter to glow. The matter emits light until it falls beyond the event horizon, where gravity is so strong that the light is unable to escape. The luminous disc of matter surrounding a black hole is called the accretion disc.

Learning from Starlight

Because stars and most other objects in the universe are so far away, it is impossible to visit them. So, we must use the information we have available to study astronomical objects. Most of the information about distant object that we receive comes in the form of electromagnetic energy. As a result most of what we know about distant object is derived from light emitted by stars and other bodies.

Light can be used to determine three basic facts about electromagnetic energy emitting objects. First, the light can be used to determine the composition of the object. Second, in many cases, the light can be used to determine the temperature of the object. Finally, the electromagnetic energy can be used to determine the object's approximate position and motion.

Before I begin the discussion about using starlight, I need to explain about blackbodies. We see colors because various colors of light are reflected from pigments in whatever object we are observing. For example, a plant leaf looks green because it is reflecting green light. An object that reflects no light looks black. If you look at a plant leaf in the absence of green light, it would look black. Light that is not reflected by an opaque object is absorbed by it. As I mentioned earlier, the plant uses the blue and red light it absorbs to make various carbohydrates; it reflects the green light back towards the viewer. The idea of a blackbody extends the idea of blackness to the whole electromagnetic spectrum. So, a blackbody absorbs all electromagnetic energy and reflects none of it. However, when heated, it does emit electromagnetic energy. It emits electromagnetic energy at all wavelengths; although not all of the wavelengths are emitted at equal intensity. The amount of energy emitted by the blackbody, and the frequency at which it is emitted most intensely, depends on the temperature of the blackbody. Stars can generally be described as blackbodies. The concept of blackbodies is discussed in both Universe and Stars, galaxies, and cosmology.

Using starlight to determine material composition

Electromagnetic energy emissions from a substance are used to determine its composition. Different types of matter absorb light at different characteristic wavelengths. In the laboratory, this property of matter can be used to identify unknown substances using a spectrophotometer. In the lab an unknown substance is placed in a glass tube and light is passed through it. The light that comes through the tube is collected and analyzed. The difference between the light that was sent into the tube and the light that comes out is the absorption spectrum of the substance. These photons get absorbed and re-emitted with lower energies (i.e., lower frequencies) by the outer layers. The atoms in the relatively cold gas in the outermost layers of the Sun completely absorb some of the photons. Because stars emit light at all wavelengths the material composition of the star can be determined by the light that does not pass through the outer layers of the star.

Laboratory Activity: Electromagnetic spectrum

When I teach this unit, the students will do an experiment using their spectrophotometers at this point in the unit. The students will use their spectrophotometers to observe various light sources. If I have the resources available, I will purchase specially made tubes containing different gases. The tubes fit into a florescent light socket stand and when energized, the gases glow with their characteristic spectra. I would like to have the students observe the different gases and attempt to identify the gases by their spectra. The characteristic spectra for gasses are available in many places. I have found two interactive webpages contain emission spectra for most of the elements in the periodic table. The links to those pages are listed below in the resources section of the unit.

If the fluorescing tubes are beyond my budget, I plan to go shopping at a local hardware store and buy several different bulbs. A tungsten filament bulb acts as a blackbody, but it has a different emission curve from that of the sun. There are colored bulbs available that are basically a tungsten filament bulb that is painted to allow only certain wave lengths through. They should provide an interesting contrast to the ordinary tungsten filament bulbs. A halogen bulb has a different spectrum than those of the florescent tubes we have in our ceiling lights; and both have different spectra from the incandescent bulb and sunlight. Having investigated this possibility, I am assured that there are many other lighting choices beyond those just mentioned. I urge you to be creative.

In either case, my students will be expected to record the approximate wavelengths of light that they see, or at least the colors of light that they are able to see. The students will then be asked to try to figure out: first, if the light source is a blackbody; and second, if it is not a blackbody, what substance is emitting or absorbing the light.

Using starlight to determine temperature

As I stated earlier, blackbodies emit electromagnetic energy in all wavelengths, but not all wavelengths of light are emitted at the same intensity. A blackbody curve shows the intensity of electromagnetic energy at all the wave lengths. Illustrations of blackbody radiation curves are found by the thousands on the Internet. A blackbody curve will show a peak at the highest intensity wavelength, called Λ_{max}. Using a relationship discovered by Wilhelm Wien, found below in the equations section of the Appendix, the temperature of the blackbody can be determined from Λ_{max}.

Using starlight to determine position and movement

The universe appears to be expanding. The degree and direction of the expansion are still debated, but most scientists agree that the universe is expanding. This means that objects in the cosmos are moving apart. The movement causes the apparent wavelength of light emanating from objects to change. These changes in wavelength yield information about the movement of the object and the observer.

Motion

Figure 3: The Doppler Effect

(image available in print form)

The Doppler effect causes apparent changes in frequency of light emanating from moving light sources. As seen in figure 3, an object that is moving towards the observer continues to emit light. As the object moves, the newly emanated light waves pile on top of the previously emitted light waves. The two sets of waves are seen by the observer at the same time, causing the apparent frequency of the light to increase. In astronomy this shift causes visible light to look more like colors toward the blue end of the spectrum. When the object retreats, the waves spread apart, causing the apparent frequency to decrease. This shift causes visible light to look more like colors towards the red end of the spectrum. Although light in the non-visible portions of the spectrum are not red or blue, the same terminology is applied to similar shifts.

Distance from us

There are two methods that are commonly used to determine the position of stars. The first method is parallax. Parallax is a form of triangulation. This method is useful for objects that are reasonable close to us. Two observations of an object are made from two different positions. The object will appear to have moved against the background by a certain angle. The angle of movement of the object is determined by the distance of the object from the observer. Parallax is a fascinating subject for discussion, but it is only tangentially related to the topic in question in this unit. The other method of measuring distance is more applicable to this unit.

The second method of measuring distance to object is to use Hubble's law. This method is useful for objects that are far away from us. As stated earlier, the universe is expanding. This means that observed objects are moving apart from the observer. Strictly speaking, some objects, like orbiting pairs of binary stars, are sometimes moving towards the observer, but as a whole, objects in the universe are moving apart. This movement of objects, particularly in aggregate, like galaxies, causes the light to shift red. This red shift is used with Hubble's law to determine the distance between the observer and the moving object.

Light makes life better

This final section will likely be used if this unit is taught at the end of the school year and there is some time left. In this section, student will explore how light makes life easier. The students in my physics class tend to be juniors and seniors, who will go on to some college and expect to be working in a few years. As a result, I will frequently discuss career options with them as it comes up in class. This project is one such opportunity. The students will research how light is used in their ideal prospective job. Light is used in some form in nearly every profession, so it should not be too difficult a task for my students to find connections to their prospective careers. After about a week of research, the students will give a presentation on their findings explaining what type of light is used, how it is used, how it makes our lives better.

Reading List

Books

Bennett, J., Donahue, M., Schneider, N., & Voit, M. (2007). *The cosmic perspective: Stars, galaxies and cosmology 4 edition* . San Francisco: Pearson Education.

Useful general reference

Kaufmann, William J. (1985). *Universe* . New York, NY: W.H. Freeman and Company

Useful general reference

Tyson, Neil DeGrasse (2007). *Death by black hole and other cosmic quandaries* . New York, NY: W. W. Norton and Company.

Interesting reading. I bought it long before I took this seminar and was glad of the excuse to read it.

Waller, W. H., & Hodge, P. W. (2003). *Galaxies and the cosmic frontier* . Cambridge, MA: Harvard University Press.

Also interesting reading.

Leonard, W, Dufresne, R, Gerace, W, & Mestre, J (2001). *Minds on physics: Complex systems, activities and reader* . Dubuque, IA: Kendall/Hunt.

Basic set of physics books that are designed for a physics first approach to science. Physics is taught primarily through activities with very little math beyond basic algebra.

Websites

Henderson, Tom (1998). The Physics Classroom. Retrieved April 7, 2007, from The Physics Classroom Web site: http://www.physicsclassroom.com/Default2.html

The physics classroom is an excellent resource for both teachers and students. The website is structured as an online study guide and covers most of the basic concepts in physics. It has wonderful animations which help explain difficult questions. It also has questions at the end of most sections with answers that have been carefully explained.

White, Nicholas (2004). Dark Energy - Introduction. Retrieved April 7, 2007, from NASA's Imagine the universe Web site: http://imagine.gsfc.nasa.gov/docs/science/mysteries_l1/dark_energy.html

Boen, Brooke (2007). Exploring the invisible universe: Chandra X-Ray Observatory. Retrieved April 7, 2007, from NASA Web site: http://www.nasa.gov/mission_pages/chandra/main/index.html

Russell, Randy (2004). Fundamental Physics. Retrieved April 7, 2007, from Windows to the Universe Web site: http://www.windows.ucar.edu/tour/link=/physical_science/physics/physics.html&edu=high

Canright, Shelley (2007). Stars. Retrieved April 7, 2007, from NASA Web site: http://www.nasa.gov/audience/foreducators/topnav/subjects/spacescience/Stars.html

This is general collection of Star resources for Educators on NASA's website.

http://www.bbc.co.uk/science/space/

Easily accessible for students; couldn't find specific credits, though

Payne, W. E. (2001). Exploring the electromagnetic spectrum. Retrieved July 19, 2007, from Altair Web site: http://www.altair.org/index.html

Great web resource. It is also available in Spanish and Italian.

Thaller, M (2007). Cool Cosmos. Retrieved July 19, 2007, from Cool Cosmos Web site: http://coolcosmos.ipac.caltech.edu/

Great website from NASA's JPL. Also comes in Spanish.

Smith, DeLee (2007, January 26). In a Different Light. Retrieved July 19, 2007, from Star Gazers - Educators Web site: http://stargazers.gsfc.nasa.gov/educators/in_different_light/iadl_table_contents.htm

This site from NASA contains a number of lessons using the electromagnetic spectrum

Bothun, G (2007). Elements. Retrieved July 19, 2007, from Atomic spectrum by element Web site: http://jersey.uoregon.edu/elements/Elements.html

This University or Oregon site is an interactive Java applet that lets you click on a element and it will display either the absorption spectrum or the emission spectrum.

Jircitano, A. J. (2007, May 7). Periodic Table of Elements. Retrieved July 19, 2007, from Periodic Table Web site: http://chemistry.bd.psu.edu/jircitano/periodic4.html

This Penn State website allows the user to click on an element and its emission spectrum.

Appendix

Connecticut State Standards

The Connecticut physics standards are actually based on the California state science standards, so I have given the standard and the corresponding California standard number. The City of New Haven does not yet have standards for physics, so I have use the Connecticut and California state standards as a basis for this curriculum unit.

Physics Standards (California chapter 5, standard 4)

> "Waves have characteristic properties that do not depend on the type of wave."
> "Radio waves, light and X-rays are different wavelength bands in the spectrum of electromagnetic waves, the speed of which in a vacuum is approximately 3 x 10^8 m/s, and less when passing through other media." (California chapter 5, standard 4e)
> "Electrical current can be transformed into light through the excitation of electrons." (CT standard 9.2)

Earth Science Standard (California chapter 5, standard 2)

> "Earth-based and space-based astronomy reveal the structure, scale and changes in stars, galaxies and the universe over time."
> "Visual, radio and X-ray telescopes may be used to collect data that reveal those differences in the life cycles of stars." (California chapter 5, standard 2d)

Variables and Equations

(table available in print form)

(table available in print form)