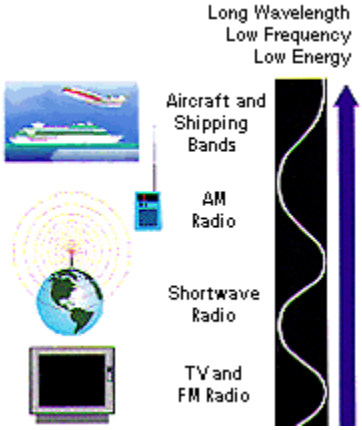
The Electromagnetic Spectrum

DISCUSSION:

Measuring the electromagnetic spectrum

Hello, my name is *insert name here.* Today's mission will be to understand the electromagnetic spectrum. You actually know more about the electromagnetic spectrum than you may think! The electromagnetic spectrum is just a name that scientists give a bunch of types of radiation when they want to talk about them as a group. Radiation is energy that travels and spreads out as it goes-- visible light that comes from a lamp in your house or radio waves that come from a radio station are two types of electromagnetic radiation. Other examples of radiation are microwaves, infrared and ultraviolet light, X-rays and gamma rays. Hotter, more energetic objects and events create higher energy radiation than cool objects. Only extremely hot objects and particles moving at very high velocities can create high-energy radiation like x-rays and gamma-rays.



Radio... yes, this is the same kind of energy that radio stations emit into the air for your boom box to capture and turn into your favorite Mozart, Madonna, or Coolio tunes. But other things such as stars and gases in space also emit radio waves. You may not be able to dance to what these objects emit, but you can use it to learn about what they are made of and how much of the stuff they have.

Microwaves... they will cook your popcorn in just a few minutes! In space, microwaves are used by astronomers to learn about the structure of our own Galaxy.

Infrared... we often think of this as being the same thing as 'heat', because it makes our skin feel warm. In space, IR emission maps the dust between stars.

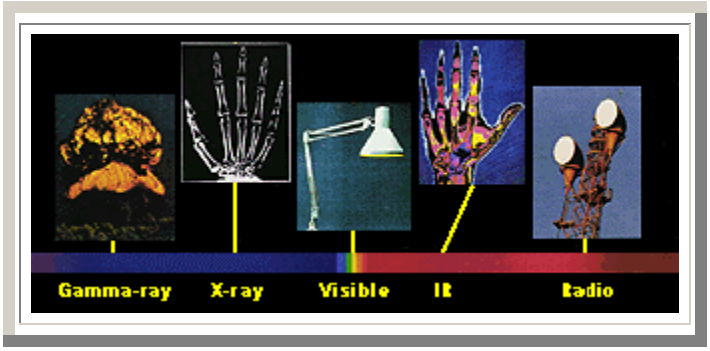
Visible... yes, this is the part that our eyes see. Visible radiation is emitted by everything from fireflies to light bulbs to stars... also by fast-moving particles hitting other particles.

Ultraviolet... we know that the Sun is a source of ultraviolet (or UV) radiation, because it is the UV rays that cause our skin to burn!

X-rays... your doctor uses them to look at your bones and your dentist to look at your teeth. Hot gases in the Universe also emit X-rays .

Gamma-rays... radioactive materials (some natural and others made by man in things like nuclear power plants) can emit gamma-rays. Big particle accelerators that scientists use to help them understand what matter is made of can sometimes generate gamma-rays. But the biggest gamma-ray generator of all is the Universe! It makes gamma radiation in all kinds of ways.

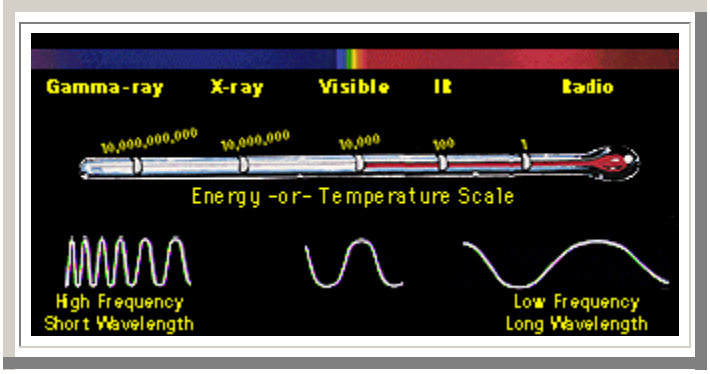
A Radio Wave is not a Gamma-Ray, a Microwave is not an X-ray... or is it?



We may think that radio waves are completely different physical objects or events than gamma-rays. They are produced in very different ways, and we detect them in different ways. But are they really different things? The answer is 'no'. Radio waves, visible radiation, X-rays, and all the other parts of the electromagnetic spectrum are fundamentally the same thing. They are all electromagnetic radiation.

Electromagnetic radiation can be described in terms of a stream of massless particles, each traveling in a wave-like pattern and moving at the speed of light. Each massless particle contains a certain amount (or bundle) of energy. Each bundle of energy is called a photon, and all electromagnetic radiation consists of these photons. The only difference between the various

types of electromagnetic radiation is the amount of energy found in the photons. Radio waves have photons with low energies, microwaves have a little more energy than radio waves, infrared has still more, then visible, ultraviolet, X-rays, and…the most energetic of all... the gamma-rays.

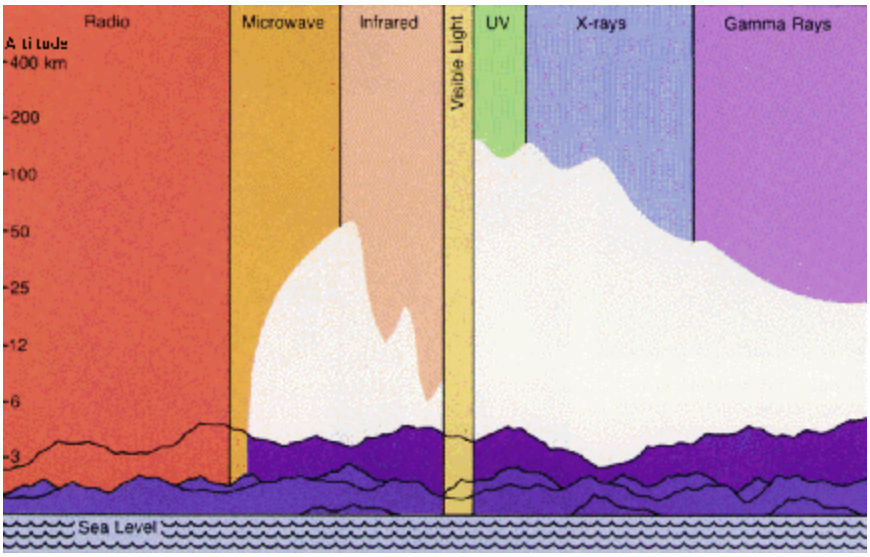


Actually, the electromagnetic spectrum can be expressed in terms of energy, wavelength, or frequency. Each way of thinking about the EM spectrum is related to the others in a precise mathematical way. So why have three ways of describing things arisen, each with a different sets of physical units? After all, frequency is measured in cycles per second (which is called a Hertz), wavelength is measured in meters, and energy is measured in electron volts.

The answer is that scientists don't like to use big numbers when they don't have to. It is much easier to say or write "two kilometers or 2 km" than "two thousand meters or 2,000 m". So generally, scientists use whatever units are easiest for whatever they are working with. In radio astronomy, astronomers tend to use wavelengths or frequencies. This is because most of the radio part of the EM spectrum falls in the range from a about 1 cm to 1 km, and 1 kilohertz (kHz) to 1 megahertz (MHz). The radio is a very broad part of the EM spectrum. Infrared astronomers also use wavelength to describe their part of the EM spectrum. They tend to use microns (or millionths of meters) for wavelengths, so that they can say their part of the EM spectrum falls in the range 1 to 100 microns. Optical astronomers use wavelengths as well. In the older "CGS" version of the metric system, the units used were angstroms. An Angstrom is equal to 0.0000000001 meters (10^{-10} m in scientific notation)!

In the newer "SI" version of the metric system, we think of visible light in units of nanometers or 0.000000001 meters (10^{-9} m). Then we have the violet, blue, green, yellow, orange, and red light we know so well having wavelengths between 400 and 700 nanometers. This is a very tiny part of the EM spectrum. By the time you get to the ultraviolet, X-ray, and gamma-ray regions of the EM spectrum, lengths have become too tiny to think about any more. So scientists usually refer to these photons by their energies, which are measured in the tiny unit of electron volts. Ultraviolet radiation falls in the range from a few electron volts (eV) to a about 100 eV. X-ray photons have energies in the range 100 eV to 100,000 eV (or 100 keV). Gamma-rays then are all the photons with energies greater than 100 keV.

Why Do We Have to Go to Space to See All of the Electromagnetic Spectrum?



Electromagnetic radiation from space is unable to reach the surface of the Earth except at a very few wavelengths, such as the visible spectrum and radio frequencies. Astronomers can get above enough of the Earth's atmosphere to observe at some infrared wavelengths from mountaintops or by flying their telescopes in an aircraft. Experiments can also be taken up to altitudes as high as 35 km by balloons that can operate for months. Rocket flights can take instruments all the way above the Earth's atmosphere for just a few minutes before they fall back to Earth, but a great many important first results in astronomy and astrophysics came from just those few minutes of observations. For long-term observations, however, it is best to have your detector on an orbiting satellite...and get above it all!

ACTIVITY

Several fun activities can be used in support of this activity, depending on available materials. Most are extremely to construct and do. Each activity is designed to illustrate the electromagnetic spectrum.

Activity 1. Water Prism

Materials

- Large clear drinking glass
- Water
- Sunlight or flashlight
- White wall
- Spoon
- One tablespoon of milk (per glass of water)

Procedure:

1. Have Mission Team members fill a glass with water, leaving one inch at the top.

2. If a white wall is available near a sunlit window place the glass in position to receive the sunlight's exposure. If not, a flashlight can also be used. Sunlight will enter the prism and be dispersed into its rainbow colors. Observe the colors that appear on the floor or wall. Red, Orange, Yellow, Green, Blue, Indigo, Violet

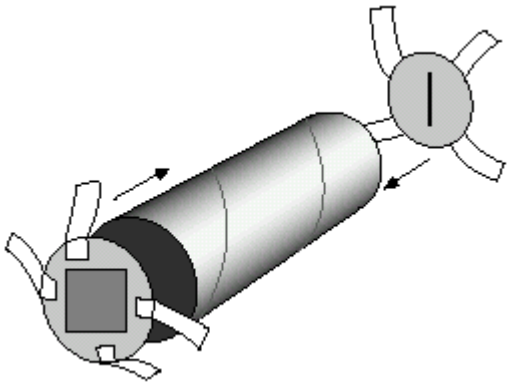
Now let's ask the question of why the sky looks orange or red towards the evening. The reason is the atmosphere filters out some of the light wave colors. Only the orange and red can make it through the atmosphere. Let's illustrate this process and filter out a few light waves. Put a tablespoon of milk into each glass and look at the colors. The red and orange remain while the others have been filtered out. Just like the atmosphere.

Mission Team Leader's notes:
The water in the water prism bends sunlight the same way glass does in a glass prism. Sunlight, entering the prism, is bent (refracted). Visible light rays (like sunlight) bend according to their wavelengths. Shorter wavelengths are bent more than longer wavelengths. This variable bending of the light causes its dispersion into the colors of red, orange, yellow, green, blue, and violet.

The water prism is a good starting point for capturing Mission Team members' interest in the electromagnetic spectrum. Not only will it disperse a broad swath of color across a classroom when sunlight enters it at the proper angle, it is also interesting to look through. The water prism disperses narrow bands of color along the edges of dark objects.

Activity 2. **Simple Spectroscope**

Materials:
- Diffraction grating 2 cm square (See Team Leader's note.)*
- Paper tube (tube from toilet paper roll)
- Poster board square (5x10cm)
- Masking tape
- Scissors
- Razor blade knife
- 2 single edge razor blades
- 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 night time street lighting. Use extreme caution when examining sunlight; **do not look directly into the Sun.**

Mission Team Leader's notes

Most science supply houses sell diffraction grating material in sheets or rolls. One sheet is usually enough for every Mission Team member to have a piece of grating to build his or her own spectroscope. Holographic diffraction gratings work best for this activity.

Many 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 to run them are expensive. The advantage of spectrum tubes is that they provide spectra from different gases such as hydrogen and helium. Using colored pencils or crayons; make sketches of the spectrum emitted by different light sources. Try incandescent and fluorescent lamps, bug lights, street lights (mercury, low-pressure sodium, and high-pressure sodium), neon signs, and candle flames. How do these spectra differ?