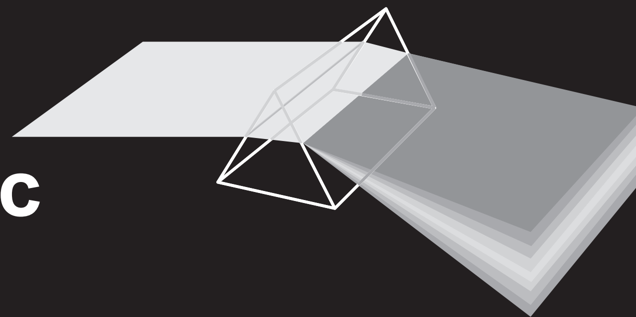
Unit 2

The Electromagnetic Spectrum



Introduction

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

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

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

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

The wavelengths of x-rays and gamma rays

Ångstroms and Nanometers

Astronomers still use an old unit of measurement for the wavelengths of electromagnetic radiation. The unit is the angstrom, or Å, named after the Swedish astronomer who first named these wavelengths. One nanometer is equal to 10 angstroms. Therefore, green light has a wavelength of about 5000 Å, 500 nanometers, or 5 $X10^{-7}$ meters.

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

Using The Electromagnetic Spectrum

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

Virtually everything astronomers have learned about the universe beyond Earth depends on the information contained in the electromagnetic radiation that has traveled to Earth. For example, when a star explodes as in a supernova, it emits energy in all wavelengths of the electromagnetic spectrum. The most famous supernova is the stellar explosion that became visible in 1054 and produced the Crab Nebula. Electromagnetic radiation from radio to gamma rays has been detected from this object, and each section of the spectrum tells a different piece of the story.

For most of history, humans used only visible light to explore the skies. With basic tools and the human eye, we developed sophisticated methods of time keeping and

Figure 1. Electromagnetic Spectrum

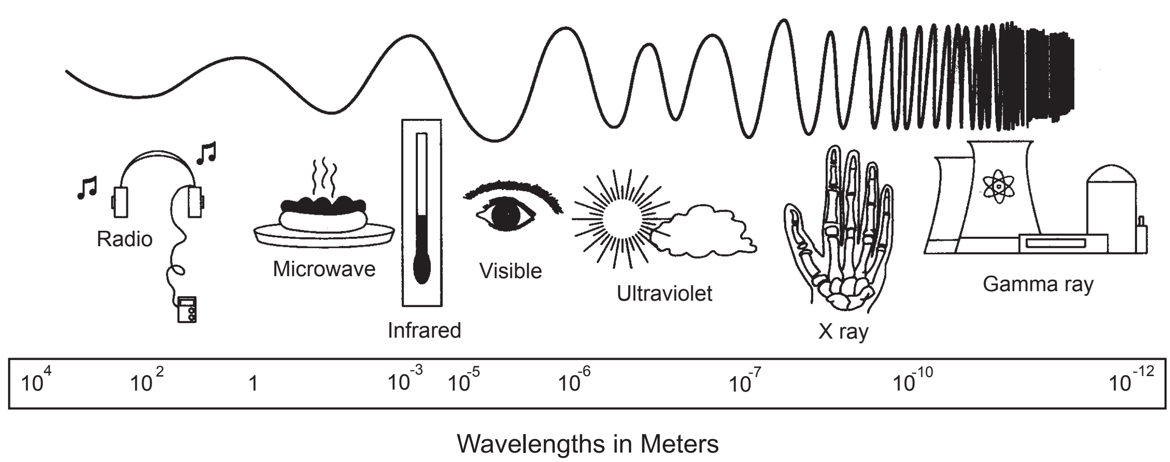
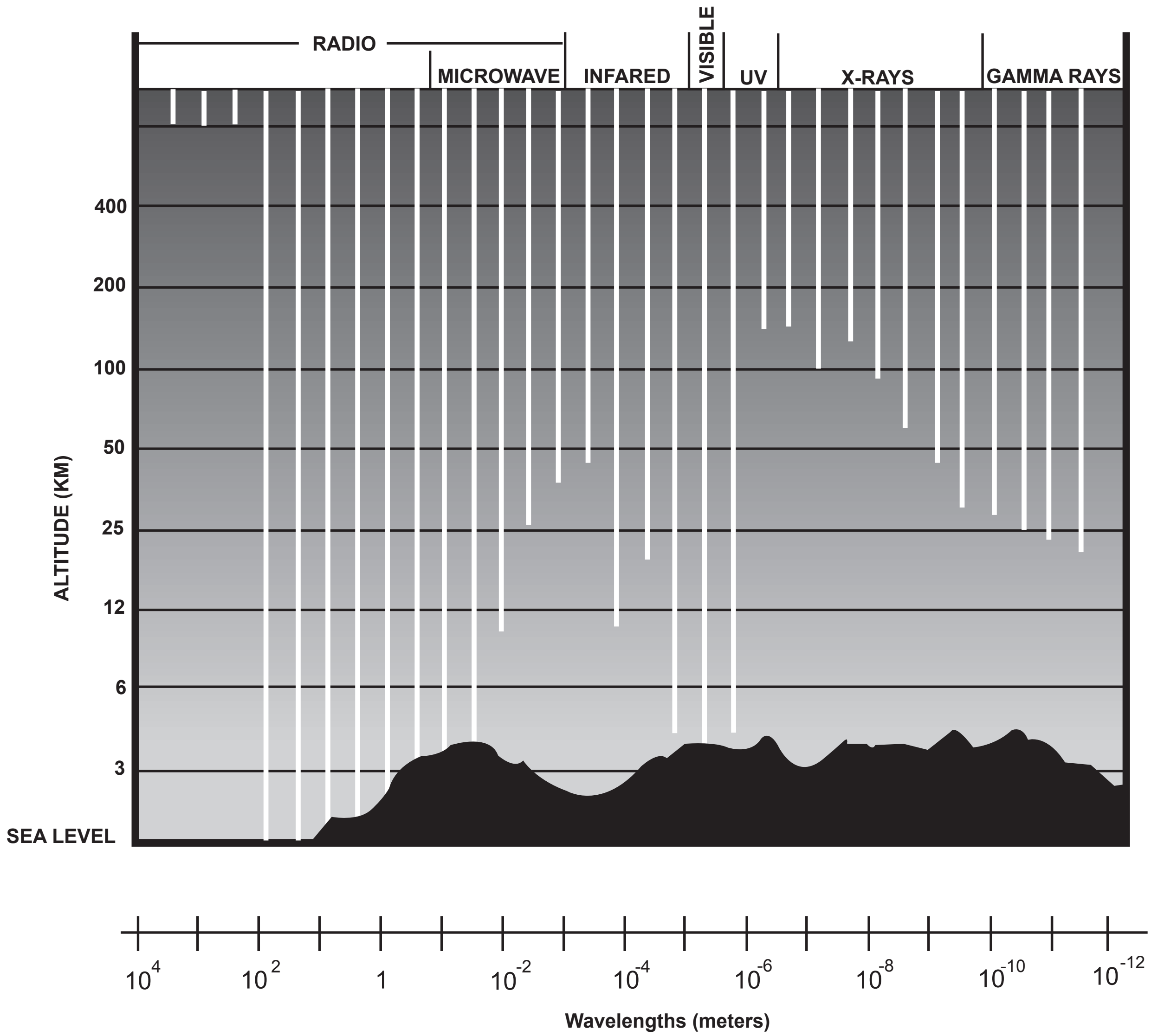


Figure 2. Transparency of Earth's Atmosphere



calendars. Telescopes were invented in the 17th century. Astronomers then mapped the sky in greater detail—still with visible light. They learned about the temperature, constituents, distribution, and the motions of stars.

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

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

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

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

There are two main techniques for analyzing starlight. One is called *spectroscopy* and the other *photometry*. Spectroscopy spreads out the light into a spectrum for study. Photometry measures the quantity of light in specific wavelengths or by combining all wavelengths. Astronomers use many filters in their work. Filters help astronomers analyze particular components of the spectrum. For example, a red filter blocks out all visible light wavelengths except those that fall around 600 nanometers.

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

Unit Goals

- To investigate the visible light spectrum and the near infrared and ultraviolet spectral regions.
- To demonstrate the relationship between energy and wavelength in the electromagnetic spectrum.

Teaching Strategy

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