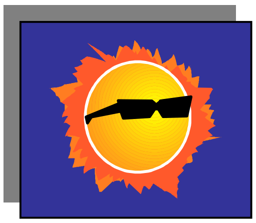
The Sun and Solar Wind: A Search for the Beginning

Electromagnetic Radiation

STUDENT TEXT



The powerhouse in the sky that we call the sun distributes most of its energy into its surroundings in the form of **electromagnetic radiation**. It is the effect of this radiation that makes us visually aware of the sun and, at the same time, makes it extremely dangerous to look at the sun directly, since the electromagnetic energy delivered to the retinal cells in your eye can be extremely damaging. Since we are visually responsive to the sun's electromagnetic radiation, it is not surprising that investigations of these emissions have been instrumental in solar studies for many, many years. Some of the earliest reliable data regarding the composition of the sun came from analysis of its electromagnetic radiation, and it is interesting to note that the element helium was identified on the sun before it was discovered on Earth. This discovery is directly connected to the sun's electromagnetic radiation.

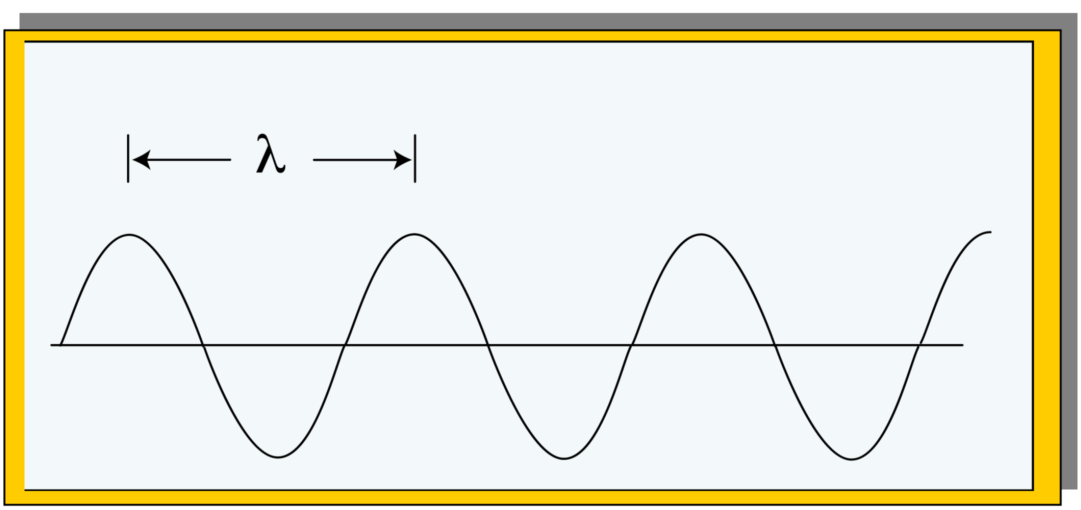
What is Electromagnetic Radiation?

So, what is electromagnetic radiation? The first and perhaps most important thing to know about electromagnetic radiation is that it carries energy through a medium, including empty space, where it travels at the speed of light—because it is light! And energy cannot be transported faster than this. Nor is the transport hindered in the slightest as long as the radiation is travelling in empty space.

As is often the case in science, electromagnetic radiation is modeled since we cannot see it directly. We envision it as propagating through space as a dance of oscillating electric and magnetic fields and there exist beautiful equations that describe the oscillations in great detail. These equations are not needed here. For our purposes, it will be sufficient to define only three characteristics of the radiation—its wavelength, frequency, and energy.

As electromagnetic radiation moves from place to place it can be envisioned as being much like ripples on a pond. With this model in mind we can define the wavelength as the distance between adjacent wave crests and this distance is usually given the symbol λ. See Figure 1 below.

Figure 1



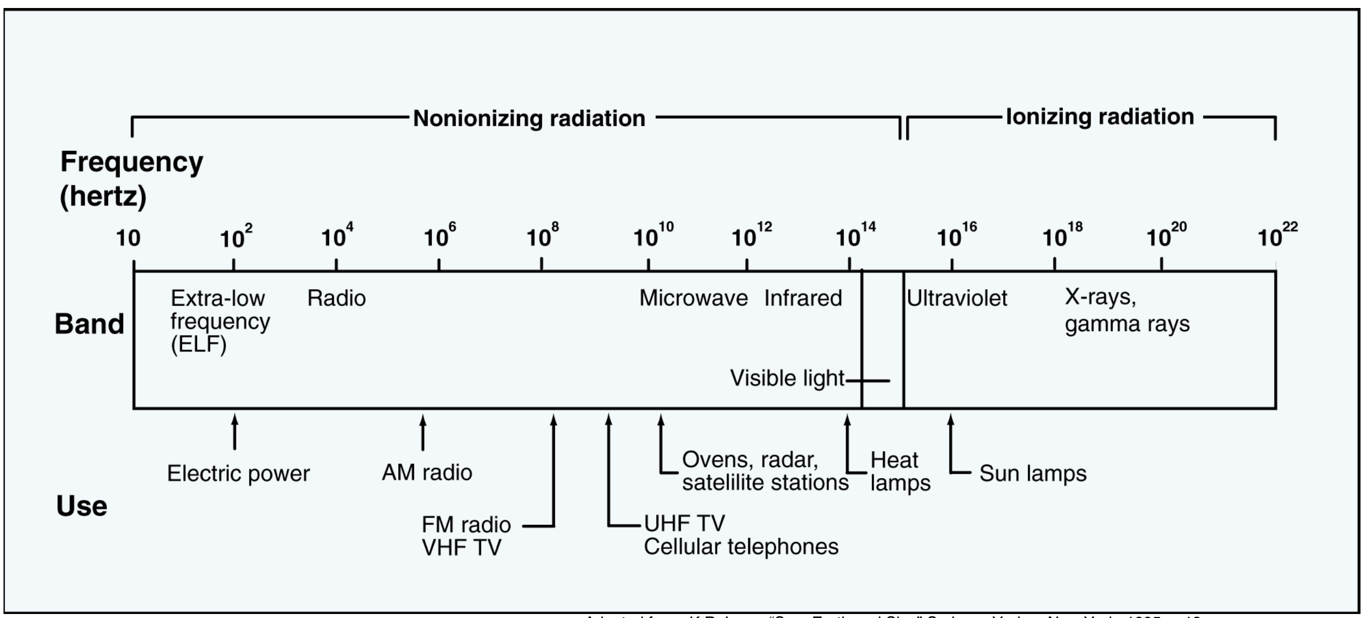
The wavelengths of electromagnetic radiation vary enormously depending on the source. Very short wavelengths, like those around 300 nm, provide what is called ultraviolet light. Intermediate wavelengths provide visible light (500 nm = green light), and very long wavelengths (say 80 m) provide such things as radio waves.

The human optical apparatus is designed to receive only the visible wavelengths from about 400 nm to around 700 nm. Radio waves are too long to affect the sensors inside the eye, which perhaps is a good thing. Can you imagine what it would be like to "see" music by Aerosmith or Garth Brooks?

Sometimes it is convenient to describe electromagnetic radiation in terms of its frequency, ν, instead of its wavelength, although the two are related. The frequency is the number of wave crests that cycle by a stationary observer in one second. The frequency therefore tells us how fast the radiation oscillates in its up and down motion. The product of the frequency and the wavelength equals the velocity of light c, i.e., $c = \lambda\nu$. The velocity of light is a constant (3×10^8 ms-1), so it is obvious that when the wavelength increases the frequency must decrease and vice versa. The electromagnetic radiation emitted by radio stations usually is characterized by its frequency instead of its wavelength, although it should be clear that if the frequency is known, the wavelength can be calculated. Frequencies are often expressed in units of hertz, where a hertz is one cycle per second.

Finally, we must make note of the energy of electromagnetic radiation, which is proportional to the frequency, as expressed through the equation $E = h\nu$, where h is a constant. Radiation, having a high frequency (or short wavelength), is very energetic and vice versa. Electromagnetic radiation in various regions of the spectrum finds application in many areas of human activity. Note that ultraviolet, x-rays, and gamma rays are called ionizing radiations**.** This is because these radiations possess sufficient energy to ionize atoms and molecules when they strike them. Some of these relations are summarized in Figure 2 below.

Figure 2



Adapted from: K.R. Lang, “Sun, Earth and Sky,” Springer-Verlag, New York, 1995, p 13.

We know that light has a split personality. Sometimes it behaves like a wave, as described above, but on other occasions it is best regarded as particle-like. When it behaves like a particle we refer to it as a package of energy called a **photon**. When an object such as the sun emits electromagnetic radiation, it is implied that photons are created. Conversely, when radiation is absorbed by matter, photons are consumed.

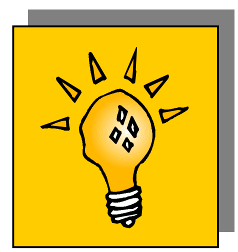
How Atoms Absorb and Emit Light

Now it is necessary to inquire briefly into the process through which atoms absorb and emit light. To begin with, it may be useful to refer to the Student Text on "Atoms, Elements, and Isotopes" in the Genesis module on Cosmic Chemistry. Our model of the atom places the nucleus at the center, with orbitals around the nucleus where electrons are found. Orbitals may or may not contain electrons. When an electron is located in one of these orbitals its energy is fixed. However, there are many such orbitals in a given atom, and electron energies vary depending on the orbital in which the electron finds itself. Generally the energy increases the farther the electron is from the nucleus.

If an atom is exposed to photons possessing the proper energy, it is possible for the packet of photonic energy to be absorbed, resulting in the promotion of one or more electrons to higher energy levels. That is, electromagnetic radiation is absorbed by the atom, which is converted from its ground to one of many possible excited states. Electrons also can be promoted to excited states by other energy sources such as the heat of a flame. Since the energy of electrons in orbitals is fixed, it should be clear that when an electron is promoted, a very specific amount of energy is required—corresponding to the energy difference between the initial orbital and the final orbital. To put it another way, electrons move between the ground and the specific excited state. Note that, if the photonic energy is very high, such as might be the case with x-rays, the electron may be totally removed from the atom, leaving an ion in its place. Orbital energies are characteristic of the atom to which they belong. For example, although sodium and potassium have similar electronic arrangements (structures), their electrons do not have identical orbital energies. Different, but again atom-specific, amounts of photonic energy are required to promote electrons in these atoms to the various excited states. This means that it is possible to distinguish between these two atoms through a study of the characteristic photonic energies required to excite their electrons.

Atoms generally do not stay in an excited state and they tend to relax to their ground states as quickly as possible. In doing so they must emit their excess energy as the electron falls to a lower orbital. There are various processes that are involved in the relaxation, but often the end result is that the atoms emit their excess energy once again as light. And the light they radiate will correspond to a very specific set of photon energies.

Atomic Spectroscopy



The study of the absorption and emission of light by atoms is called atomic spectroscopy, and this field has been of enormous importance to developing an understanding of the sun. For example, if we regard the sun as a light bulb that emits a broad spectrum of electromagnetic radiation, then this radiation must pass through the sun's atmosphere on its way to Earth. If there are atoms or ions of iron in the atmosphere, they will absorb certain characteristic wavelengths from the light passing through from below. Therefore, some specific wavelengths will be missing from the light reaching Earth, and through the analysis of these "lost" wavelengths it is possible to identify the iron in the atmosphere.

Doppler Effect

Finally, one last property of electromagnetic radiation must be mentioned, again because it has had enormous importance in solar and space science. This is the Doppler effect. As is the case with sound waves, the wavelength of electromagnetic radiation shifts when the object emitting the radiation moves with respect to the observer. If the motion is toward the observer, the radiation shifts to shorter wavelengths (called a blue shift), but when the motion is away from the observer the radiation wavelength becomes longer (called a red shift). Therefore if light is emitted from a certain region of the sun that happens to be moving toward us at that particular time, the light will have a slightly shorter wavelength than it would have otherwise. It thus becomes possible to study very small undulatory motions of the photosphere by observing Doppler-shifted light. Such studies fall under the umbrella of the new field of helioseismology.