Solar Radiation and how the Atmosphere is Heated

As the temperature profile of the Earth shows, several factors contribute to the heating of the Earth's atmosphere. To understand how the atmosphere is heated, we must first understand the nature of **radiation**. In today's world, the word radiation tends to have negative connotations, often associated with nuclear fallout or nuclear plant mishaps. The term radiation is much more general than that, and refers to any form of energy which can travel through a vacuum. (Sound, for instance, cannot travel through a vacuum and requires a medium (like air or water) through which it propagates, hence sound is not a form of radiation.)

All forms of radiation share certain properties, including traveling through a vacuum at the same speed (the so-called speed of light) and being able to be characterized as waves. The following diagram shows the various types of radiation and some of their properties:

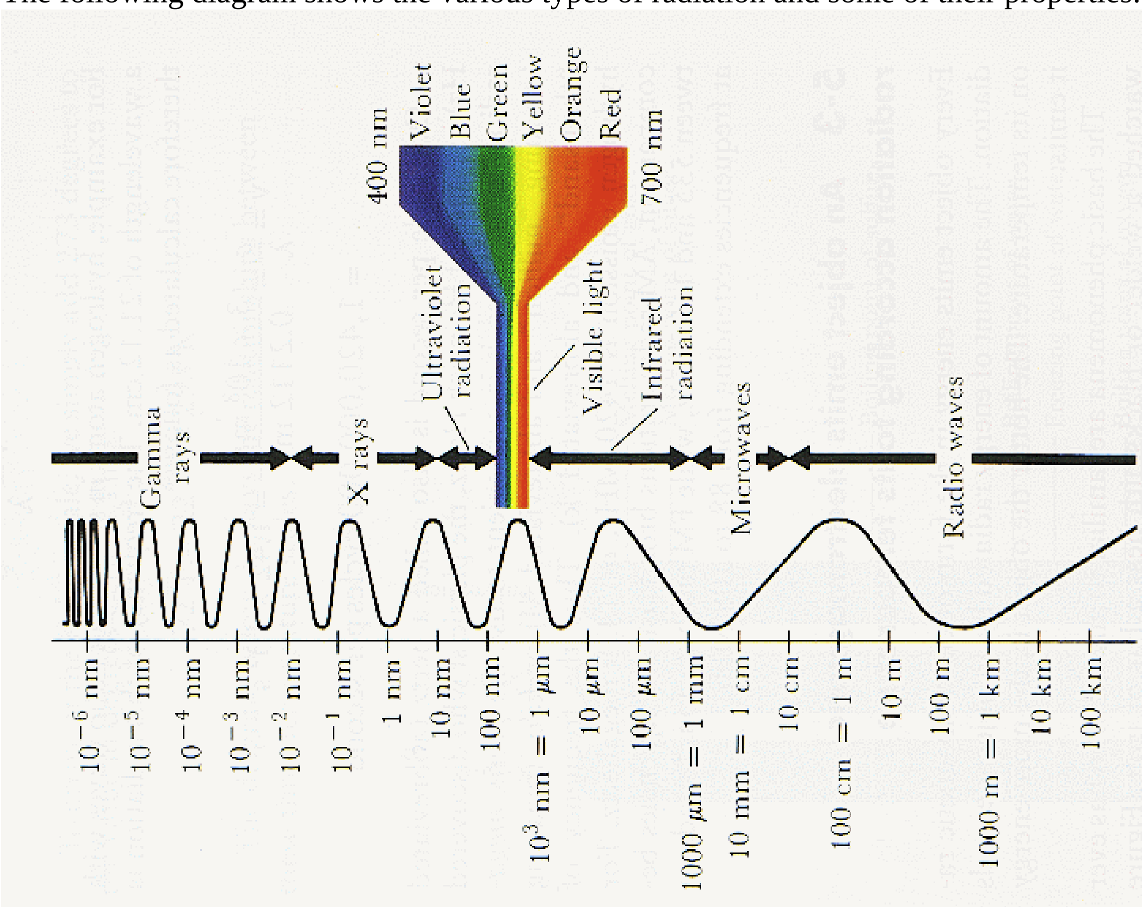

image courtesy Johns Hopkins Univ

This diagram shows that the array of radiation, often called the electromagnetic spectrum, varies from the shortest wavelength gamma rays to the longest radio waves. Each one of these types of radiation travels through a vacuum at the same speed of light, however, each type of radiation has its own wavelength and frequency. Moreover, and this is very important, each packet of radiation carries a certain amount of energy. Specifically, the higher the frequency of the radiation (similarly, the shorter the wavelength), the greater the energy contained in the packet of radiation. The diagram below shows how we measure the wavelength of a wave:

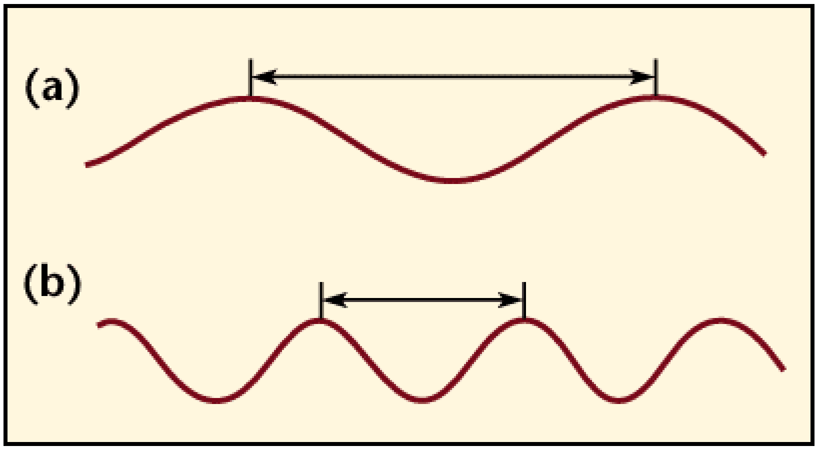

image courtesy Lawrence National Lab

And this site has a very nice interactive graphic to show how wavelengths of different waves compare. You can use the slide bar here.

The sun emits all types of electromagnetic radiation, from the highest energy gamma rays to the lowest energy radio waves. However, it is important to note explicity that the sun does not emit equal amounts of all different types of energy. The black line in the diagram:

image courtesy the College of New Jersey

shows how the sun's emitted energy is distributed. Very little energy is emitted at the very highest and lowest wavelengths, with most of the solar energy emission occuring in the infrared and visible portions of the spectrum.

This is the spectrum of energy that travels from the sun and reaches the upper atmosphere of the Earth. When this radiation reaches the Earth's atmosphere, the radiation begins to interact with the atoms and molecules that make up the atmosphere.

Each type of gas in the Earth's atmosphere will interact with incoming solar radiation, however, it is important to know that each type of gas interacts differently. In particular, different gases are effective at absorbing different wavelengths of solar radiation. For intance, atomic nitrogen and oxygen are extremely efficient absorbers of gamma and x-rays, so solar gamma and x-rays are absorbed in the Earth's thermosphere. The heating that takes place in the thermosphere is the direct result of this absorption of solar gamma and x radiation.

As we discussed yesterday, solar ultraviolet light is absorbed by ozone in the stratosphere, and the heating of the stratosphere is the result of this direct absorption of solar energy in that region.

The sunlight that does penetrate as far as the troposphere travels through the troposphere essentially unabsorbed, and reaches the surface of the Earth. This means that this sunlight warms the Earth, but also means that the sun is not directly heating the troposphere. Rather, this solar energy warms the Earth, and the Earth emits its own energy to space. Because the surface of the Earth is much cooler than the surface of the Sun, the Earth emits most of its energy at longer wavelengths (i.e., lower energy radiation). Almost all of the Earth's energy is emitted in the infrared portion of the spectrum.

The troposphere lacks gases which efficiently absorb sunlight, however, there are gases in the troposphere that are efficient absorbers of the Earth's emitted infrared energy. The two most effective of these IR absorbers are water vapor and carbon dioxide. Thus, the troposphere of the Earth is warmed by the surface of the Earth, not by the Sun directly. Molecules of water vapor and carbon dioxide absorb the IR emitted by the Earth, and share this energy with other molecules in the troposphere via successive collisions. The name **greenhouse effect** is often used to describe this process, in which solar energy warms the Earth, and Earth emitted IR is absorbed to warm the troposphere. (This is sometimes called the atmospheric effect.)

The greenhouse effect is one of the most hotly debated environmental issues of our day. But some background and history are in order. First, it is important to realize that the Earth's troposphere was warmed by the greenhouse effect long before there were any human industrial activities to impact global climate. In fact, without the atmosphere producing any greenhouse effect, the Earth's surface would be at a temperature of approximately $-15^{o}C$, rather than the global average of $+15^{o}C$. The concern held by many scientists and environmentalists is not that there is a greenhouse effect, indeed without one the planet would be much more inhospitable. Rather, the concern is over an enhanced greenhouse effect, where CO_2 produced by human industrial activities increases the magnitude of the greenhouse effect and contributes to a global warming.