

Radiant Energy

You can tell that light carries energy, because it takes energy to produce light, and also because sufficiently intense light striking an object will warm it noticeably. Although there is no well-known term for the type of energy carried by light, some scientists call it **radiant energy**, because of the way that light radiates outward from a source like a lightbulb or the sun.

What is light? We call it an “electromagnetic wave,” made of electric and magnetic “fields” that propagate along very quickly, even through empty space. This is hardly an explanation of what light actually *is*, but the key point for our purposes is that light behaves like a wave. This behavior can be demonstrated by aiming a beam of light at a narrow hole and watching it spread out on the other side, just as water waves passing through a gap in a barrier will spread out on the other side. From the amount of spreading you can determine the **wavelength** of light, that is, the distance from one wave crest to the next as you move along the beam. This wavelength turns out to be extremely tiny: about half a millionth of a meter ($0.5 \mu\text{m}$, where μ , the Greek letter mu, stands for *micro*). The wavelength of red light is somewhat longer than this (0.6 to $0.7 \mu\text{m}$), violet light somewhat shorter ($0.4 \mu\text{m}$), and other colors in between, in the order of the rainbow. A reasonably uniform mixture of all the the colors of the rainbow appears white to our eyes.

It’s also possible to create “light” with wavelengths longer than that of red, or shorter than that of violet. The longer wavelengths are called **infrared**, while the shorter ones are called **ultraviolet**. Our eyes are unable to see these “colors,” but they’re perfectly real: they can be detected by certain types of film or electronic cameras, and they most definitely carry energy. Beyond the infrared, at wavelengths above a millimeter, are what we call **microwaves** and **radio waves**, while at very short wavelengths are **x-rays** and **gamma rays**. The whole range of wavelengths from radio waves down to gamma rays is called the **electromagnetic spectrum**. It’s somewhat similar to the continuum of possible musical pitches, like the notes on a piano but including every possible intermediate pitch as well as pitches that extend far above and far below the audible range. Figure 6.1 shows all these portions of the electromagnetic spectrum, in order by wavelength.

Some sources of electromagnetic waves emit only a very narrow range of wavelengths, while others emit a broad range of wavelengths. In the first category are radio broadcasting antennas, magnetrons in microwave ovens, light-emitting diodes (LED’s), lasers, and sodium-vapor street lights. In the second category are incandescent lights, the sun, and objects at room temperature (which emit mostly infrared wavelengths). To visualize the mixture of wavelengths emitted by a particular source, we often draw a graph of brightness vs. wavelength.

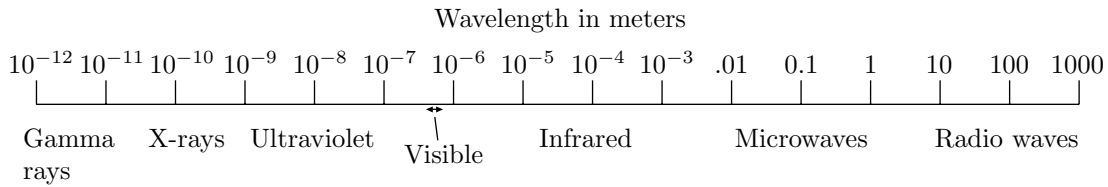


Figure 6.1. The most important portions of the electromagnetic spectrum. On this graph, each horizontal unit represents a range of wavelengths that is ten times the size of the previous horizontal unit. Note that the visible-light portion of the spectrum covers only a tiny range, from about $0.4 \mu\text{m}$ (violet) to $0.7 \mu\text{m}$ (red).

Figure 6.2 shows graphs (somewhat simplified) of brightness vs. wavelength for two familiar light sources: the sun, and a typical incandescent light bulb. Notice that the sun's light is brightest in the visible range, but also contains a great deal of infrared as well as some ultraviolet. The incandescent bulb, on the other hand, is brightest in the infrared, with only a relatively small fraction of its light in the visible range and almost no ultraviolet. Furthermore, whereas sunlight contains a relatively uniform mixture of the colors of the visible rainbow, incandescent light contains much more red than blue or violet. This is why incandescent light has that familiar "warm," orangish color, and why photographs taken under incandescent light often appear to have an orange tint to them.

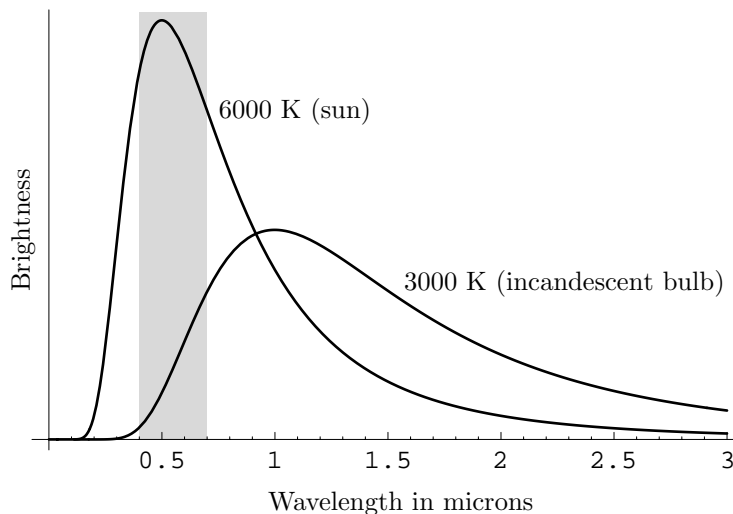


Figure 6.2. Graphs of the spectra from two "thermal" sources, one at 6000 K (such as the sun) and the other at 3000 K (such as an incandescent lightbulb). The horizontal axis is calibrated in units of one micron (μm), which is 10^{-6} meter. The vertical axis indicates relative brightness, with the two sources assumed to have the same total brightness. The visible colors lie in the approximate range $0.4 \mu\text{m}$ to $0.7 \mu\text{m}$, indicated by the gray shading.

Ironically, the reason why incandescent light has this mix of colors skewed toward the red is because its source, the filament of the bulb, is *cooler* than the sun. The

temperature of an incandescent filament is normally around 2700 degrees Celsius, or 3000 kelvin, where the **kelvin temperature scale** is similar to Celsius but is measured with respect to absolute zero (-273°C) instead of the freezing point of water. Thus, kelvin temperatures are always 273 degrees higher than Celsius temperatures, and for sufficiently hot objects we can just round this number to 300. The nice thing about using the kelvin temperature scale is that it gives meaning to the concept of one object being twice as hot as another, or ten times as hot, and so on. The sun's surface, at about 6000 K, is roughly twice as hot as the filament of a light bulb, whereas room temperature, 300 K, is ten times colder than the filament.

Now look again at the graphs in Figure 6.2. Both of these spectra have basically the same shape, with an abrupt rise at shorter wavelengths and a gradual decline at longer wavelengths. This is because any object at a well-defined temperature emits light with a spectrum of this shape. (There is a mathematical formula for the shape of the graph, but it's not important for our purposes.) The light emitted by any object at a well-defined temperature is called **thermal radiation**, and in some sense can be considered a type of thermal energy. As far as the light is concerned, the only difference between one source of thermal radiation and another is the temperature of the source: hotter objects tend to emit more of the shorter wavelengths, while cooler objects tend to emit more of the longer wavelengths. More precisely, the wavelength at which the spectrum peaks is inversely proportional to the temperature of the source (measured on the kelvin scale). For example, the spectrum of the light bulb peaks at a wavelength twice as large as that of the sun, because the filament is only half as hot as the sun. The spectrum of an object at room temperature (300 K) peaks at a wavelength ten times higher still, because room temperature is only 1/10 as hot as the filament. This is why objects at room temperature emit essentially no visible light—just infrared.

The spectrum graph for a laser or some other **monochromatic** (“one-color”) light source (such as an LED or a laser) would look very different: zero at almost all wavelengths, with a high, sharp spike at the wavelength of the source. A fluorescent light bulb is like a mixture of a small number of monochromatic sources, with the precise mixture depending on the type of coating used on the fluorescent tube. Because the human eye has only three types of color sensors, it is possible to use three (or more) different monochromatic sources to produce light that the human eye perceives as “white,” as if it were a mixture of all of the infinite colors of the rainbow.

Exercise 6.1. Given that light carries energy, and energy cannot be destroyed, why doesn't a room continue to become brighter and brighter and brighter, the longer you leave on the light? Explain carefully.

Exercise 6.2. Looking at the spectrum of an incandescent light bulb in Figure 6.2, explain why incandescent lights are considered to be very “inefficient.”

Exercise 6.3. True or false: In a building that is being heated by electricity, there is no point in turning out lights to save electricity. (Please explain your answer.)