BASIC LAWS OF RADIATION

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Abstract

In this article, opinions were expressed about the basic laws of radiation.

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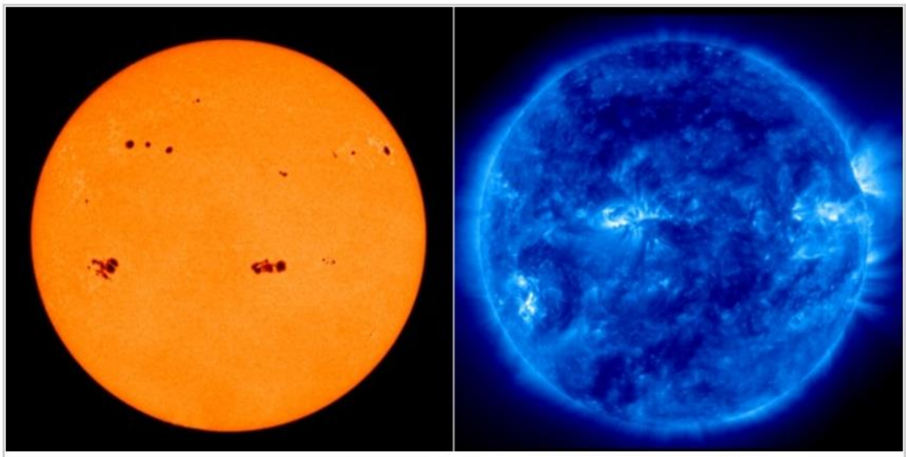
In order to best make use of the of information that comes to us via the electromagnetic spectrum, we need to understand some basic properties of radiation. A complete treatment on the subject of radiation theory would take an entire course at least (indeed, folks pursuing a BS in meteorology are usually required to take a Radiative Transfer course). Instead, you just need to know the fundamental principles describing the electromagnetic radiation that originates from an object, and how that radiation travels through space (discussed in the next section).

For electromagnetic radiation, there are four "laws" that describe the type and amount of energy being emitted by an object. In science, a law is used to describe a body of observations. At the time the law is established, no exceptions have been found that contradict it. The difference between a law and a theory is that a law simply describes something, while a theory tries to explain "why" something occurs. As you read through the laws below, think about observations from everyday life that you have made that might support the existence of each law.

Planck's Law can be generalized as such: Every object emits radiation at all times and at all wavelengths. If you think about it, this law is pretty hard to wrap your brain around. We know that the sun emits visible light (below left), infrared waves, and ultraviolet waves (below right), but did you know that the sun also emits microwaves, radio waves, and X-rays? OK... you are probably saying, the sun is a big nuclear furnace, so it makes sense that it emits all sorts of electromagnetic radiation. However, Plank's Law states that every object emits over the entire electromagnetic spectrum. That means that you emit radiation at all wavelengths -- so does everything around you!



Two images of the sun taken at different wavelengths of the electromagnetic spectrum. The left image shows the sun's emission at a wavelength in the visible range. The right image is the ultraviolet emission of the sun. Note: colors in these images and the ones above are deceptive. There is no sense of "color" in spectral regions other than visible light. The use of color in these "false-color" images is only used as an aid to show radiation intensity at one particular wavelength. Credit: NASA/JPL

Now before you dismiss this statement out-of-hand, let me say that you are not emitting X-rays in any measurable amount (thank goodness!). The mathematics behind Plank's Law hinge on the fact that there is a wide distribution of vibration speeds for the molecules in a substance. This means that it is possible for matter to emit radiation at any wavelength, and in fact it does.

Another common misconception that Plank's Law dispels is that matter selectively emits radiation. Consider what happens when you turn off a light bulb. Is it still emitting radiation? You might be tempted to say "No" because the light is off. However, Plank's Law tells us that while the light bulb may no longer be emitting radiation that we can see, it is still emitting at all wavelengths (most likely, it is emitting copious amounts of infrared radiation). Another example that you hear occasionally on TV weathercasts goes something like this. "When the sun sets, the ground begins to emit infrared radiation..." This is certainly not true by nature of Planck's Law (and besides, how does the ground know when the sun sets anyway). We'll talk more about radiation emission from the ground in a future lesson. For now, please dismiss such statements as hogwash. The surface of the earth emits radiation all the time and at all wavelengths.

So, now that we've established Wein's Law, how do we apply it to the emission sources that effect the atmosphere. Consider the chart below showing the emission curves (called Planck functions) for both the sun and the earth.

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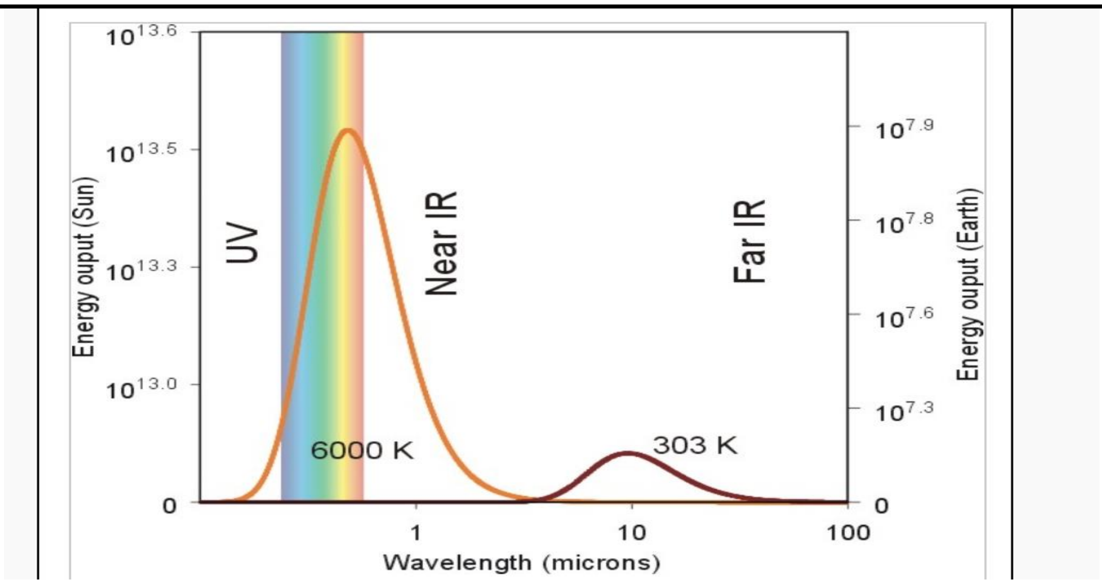

The emission spectrum of the sun (orange curve) compared to the earth's emission (dark red curve). The x-axis shows wavelength in factors of 10 (called a "log scale"). The y-axis is the amount of energy per unit area per unit time per unit wavelength. I have kept the units arbitrary because as you can see, they are messy. Credit: David Babb. Note the idealized spectrum for the earth's emission (dark red line) of electromagnetic radiation compared to the sun's electromagnetic spectrum (orange line). The radiating temperature of the sun is 6000 degrees Celsius compared to the earth's measly 15 degrees Celsius. This means that given its high radiating temperature, the sun's peak emission occurs near 0.5 microns, on the short-wave end of the visible spectrum. Meanwhile the Earth's peak emission is located in the infrared portion of the electromagnetic spectrum.

Kirchhoff's Law

In the preceding radiation laws, we have been taking about the ideal amount of radiation than can be emitted by an object. This theoretical limit is called "black body radiation". However, the actual radiation emitted by an object can be much less than the ideal, especially at certain wavelengths. Kirchhoff's Law describes the linkage between an object's ability to emit at a particular wavelength with its ability to absorb radiation at that same wavelength. In plain language, Kirchhoff's Law states that for an object whose temperature is not changing, an object that absorbs radiation well at a particular wavelength will also emit radiation well at that wavelength. One implication of Kirchhoff's law is as follows: If we want to measure a particular constituent in the atmosphere (water vapor for example), we need to choose a wavelength that is emitted well by water vapor (otherwise we wouldn't detect it). However, since water vapor readily emits at our chosen wavelength, it also readily absorbs radiation at this wavelength -- which is going to cause some problems measurement-wise.

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Well look at the implications of Kirchhoff's Law in a later section. For now, we need to complete our discuss of radiation by looking at the possible things that can happen to a beam of radiation as it passes through a medium.

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