Module 5 - Lecture 13

Here are some rules governing the emission of electromagnetic radiation. Wavelength is defined in micrometers, which is one millionth (10^{-6}) of a meter.

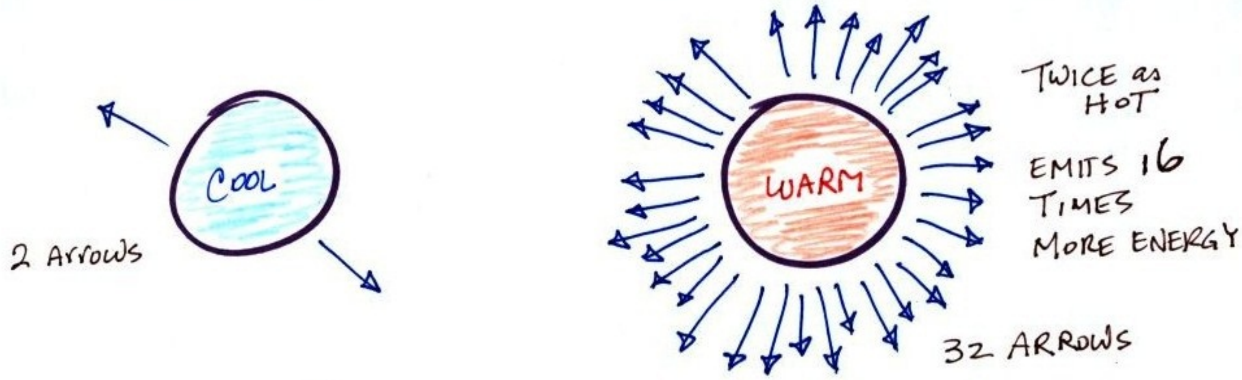
1. ***All objects emit EM radiation unless the object has a temperature of 0^0Kelvin (absolute zero).*** Every object in a classroom is emitting radiation: the people, the furniture, the walls, the floor, and even the air. Objects at room temperature and also people emit infrared radiation that is invisible to the human eye. Night vision goggles detect infrared radiation and enable the wearer to see people in the dark. Both the amount and kind (wavelength) of the emitted radiation depend on the object's temperature.

2. ***Hot objects emit more energy than cold objects.*** The second rule allows you to determine the amount of EM radiation (radiant energy) an object will emit. The amount depends on temperature to the fourth power. If the temperature of an object doubles, the amount of energy emitted will increase by a factor of 2 to the 4th power (that's 2 x 2 x 2 x 2 = 16). This means that a hot object emits a lot more energy than a cold object.

The equation used to calculate the amount of energy emitted by an object is called the ***Stefan-Boltzmann Law***. You can think of EM radiation as an amount, or rate, or intensity. You do not need to worry about the units, (energy per unit area per unit of time, calories per square centimeter per minute for example). In the equation, σ is a constant.

Amount rule

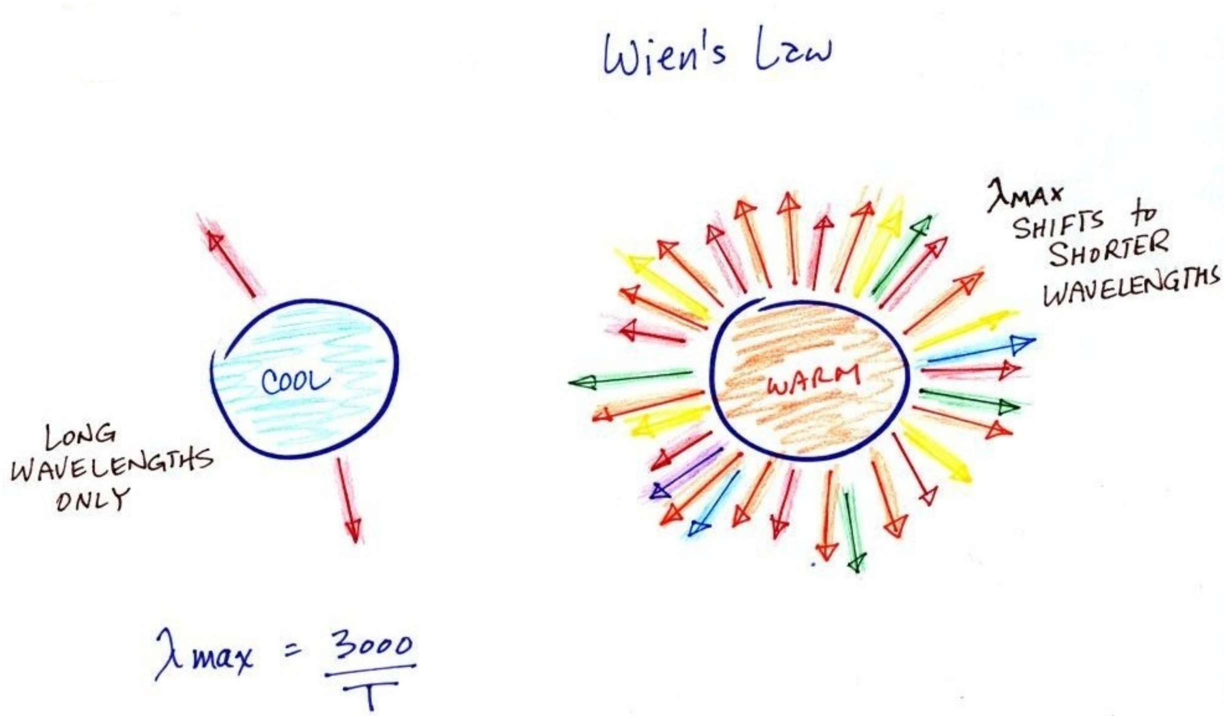
Stefan-Boltzmann Law



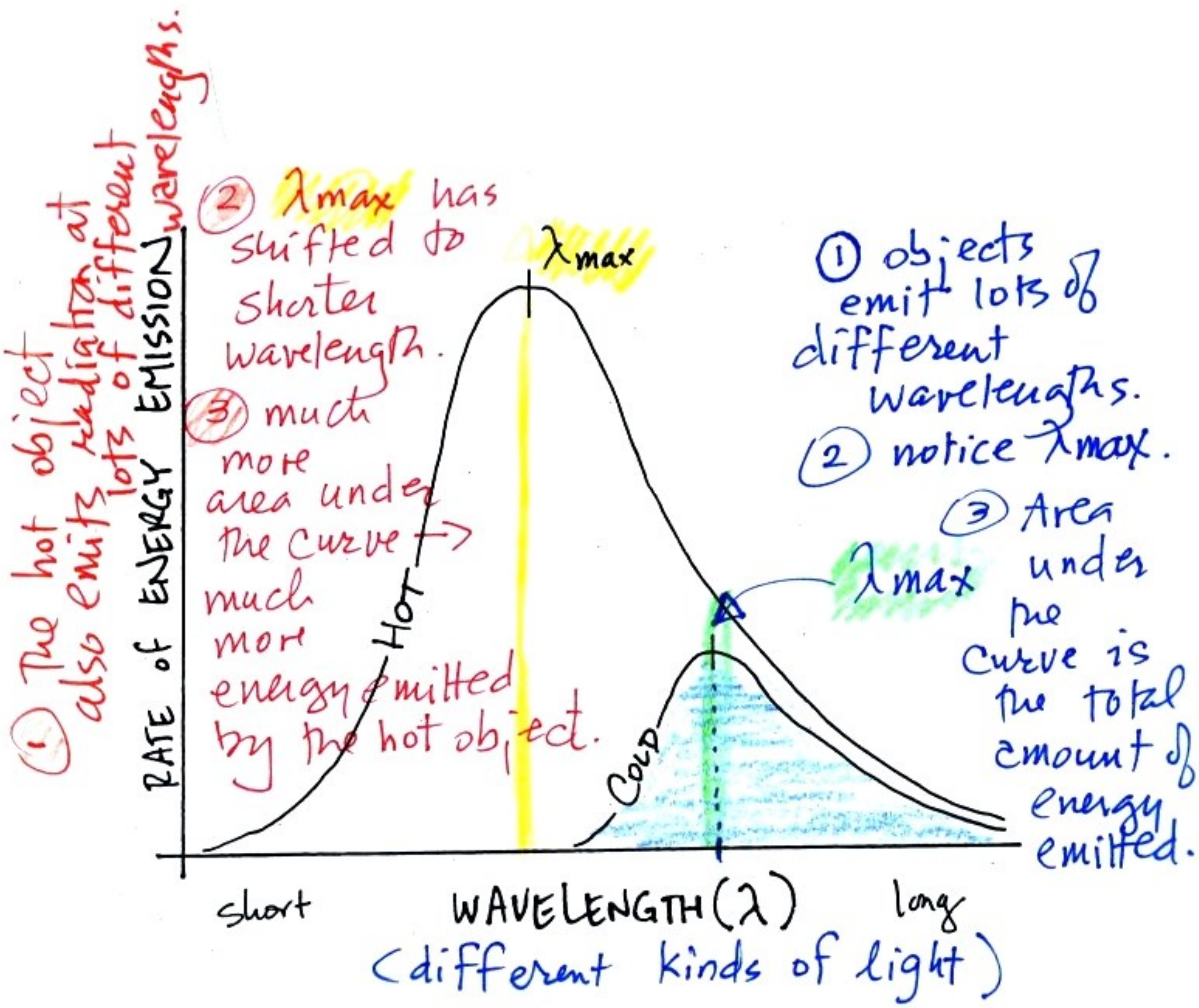
$$E = \sigma T^4$$

$$\frac{\text{Energy}}{\text{area} \cdot \text{time}}$$

3. ***The wavelength of maximum energy depends upon the temperature of an object.*** We will see that objects usually emit radiation at many different wavelengths. There is one wavelength at which the object emits more energy than at any other wavelength. This is called λ_{max} (lambda is the Greek character used to represent wavelength) and is called the wavelength of maximum emission. ***Wien's Law*** allows you to calculate λ_{max}.



The following graphs also help to illustrate Stefan-Boltzmann's law and Wien's law.

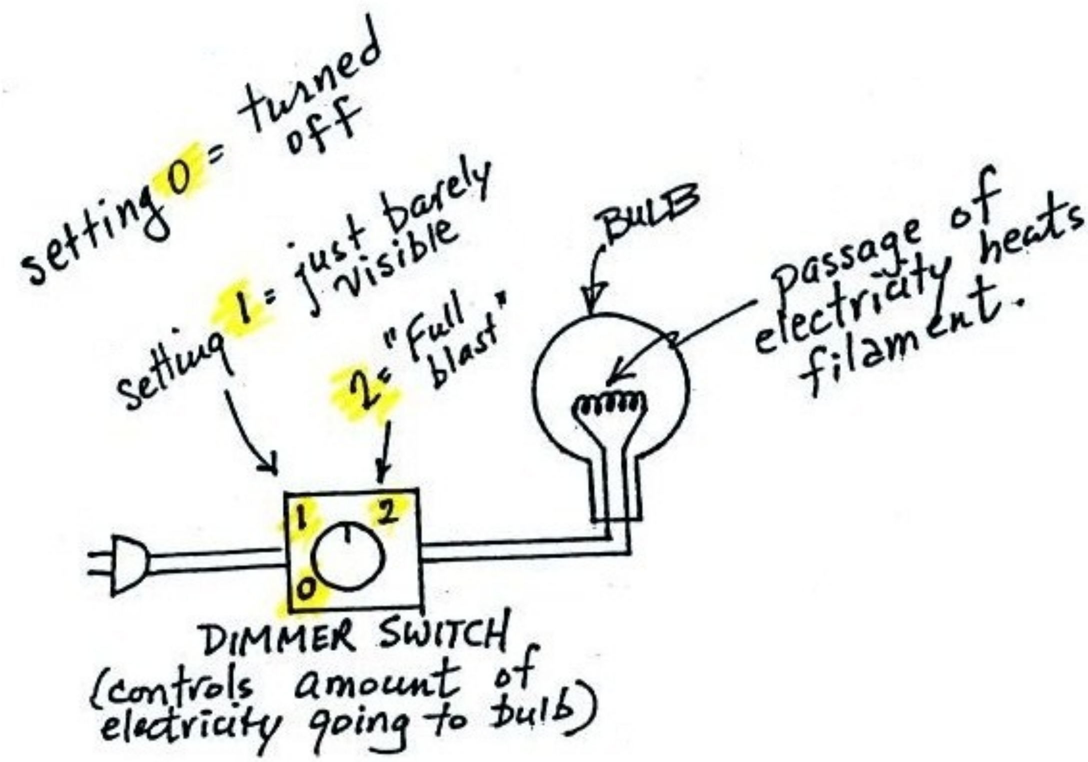


1. Note first that both the warm and the cold objects both emit radiation over a range of wavelengths. The energy emission curves above are like quiz scores in which there is a distribution of scores because not everyone gets the same score.

2. λ_{max} has shifted toward shorter wavelengths for the warmer object (red). This is Wien's law in action. The warmer object is emitting a lot of short wavelength radiation that the colder object (blue) does not emit.

3. The area under the curve is a measure of the total radiant energy emitted by the object. The area under the warm object curve is ***much*** bigger than the area under the cold object curve. This illustrates the fact that the warmer object emits a lot more radiant energy than the colder object, as indicated by the Stefan-Boltzmann Law.

In the classroom version of this course, a 200 W tungsten bulb connected to a dimmer switch is used to demonstrate these rules.



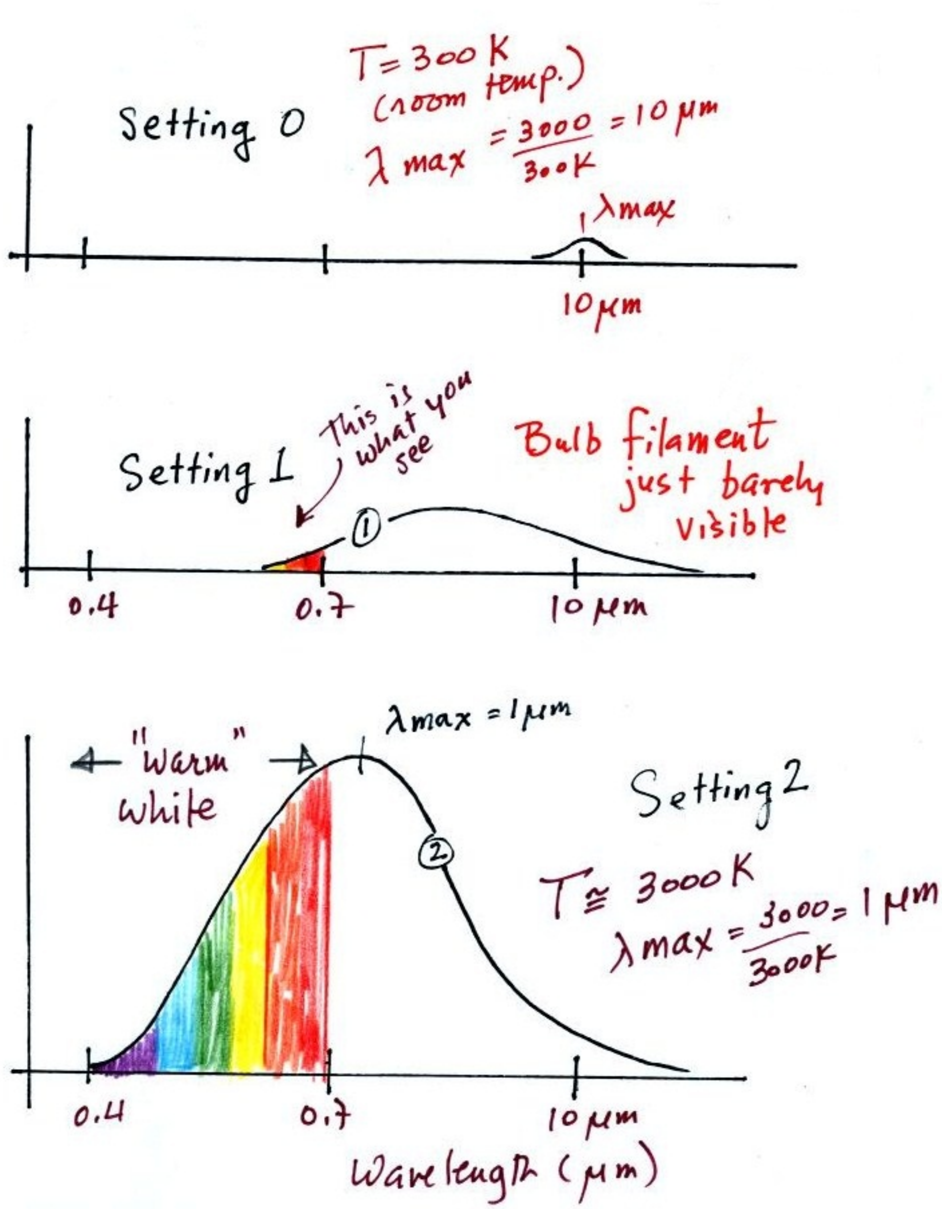
We now look at the EM radiation emitted by the bulb filament. The three graphs below show the EM radiation emitted (both wavelength and intensity) for the 3 switch settings in the figure above.

We will start with the bulb turned off (Setting 0). The filament will be at room temperature which we will assume is around 300^0K. (Remember that this is the average temperature of the earth's surface). At this setting, the bulb emits invisible infrared radiation. The intensity of the infrared radiation is too weak for us to feel it. The wavelength of peak emission is 10 micrometers.

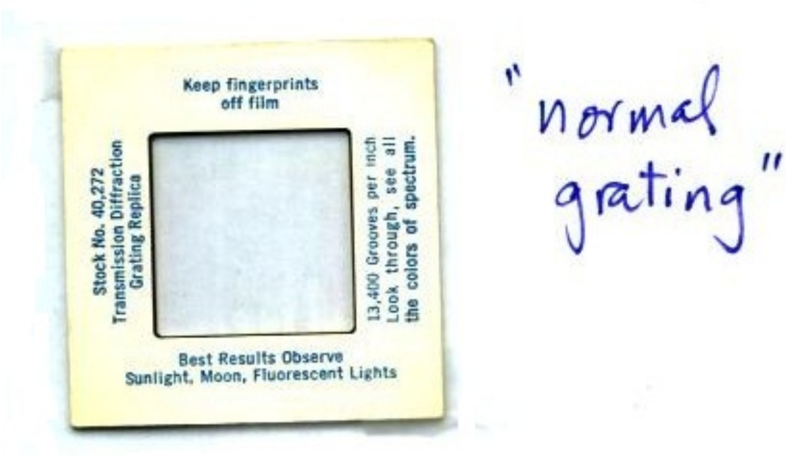
Next we turn the dimmer switch to Setting 1 and the bulb's filament just begins to glow. The temperature of the filament is now about 900^0K. The bulb is dim and has an orange color. The far left end of the emission curve has moved left of the 0.7 micrometer mark, which is the boundary that marks the visible range of the spectrum. We are only able to see the small fraction of radiation that is in the orange, visible part of the spectrum. Most of the radiation emitted by the bulb is still in the infrared region. The bulb feels warm to the touch because the infrared energy is sufficient intensity for us to feel it.

Finally we turn on the bulb all the way on to Setting 2. The filament temperature is now about 3000^0K. The 200 watt bulb is now very bright because it is emitting a lot of visible light in all colors, although not all colors are emitted in equal amounts. The mixture of colors produces a "warm white" light. The light appears warm because the bulb emits a lot more red, orange, and yellow light than blue, green, and violet light. λ_{max} is 1 micrometer, which means that most of the radiation emitted by the bulb is still in the infrared portion of the spectrum.

The Energy Independence and Security Act of 2007 requires the manufacture of more efficient light bulbs. The efficiency standards will start with 100-watt bulbs in January 2012 and end with 40-watt bulbs in January 2014.



Diffraction gratings are handed out for this demonstration. A diffraction grating is made by making many fine, parallel scratches on the surface of a flat piece of transparent material so that the grating may contain 6,000 lines per cm. The scratches are opaque but the areas between the scratches can transmit light. When you look at the bright white bulb filament through a diffraction grating, the colors are separated to the right and left of the bulb as shown below.

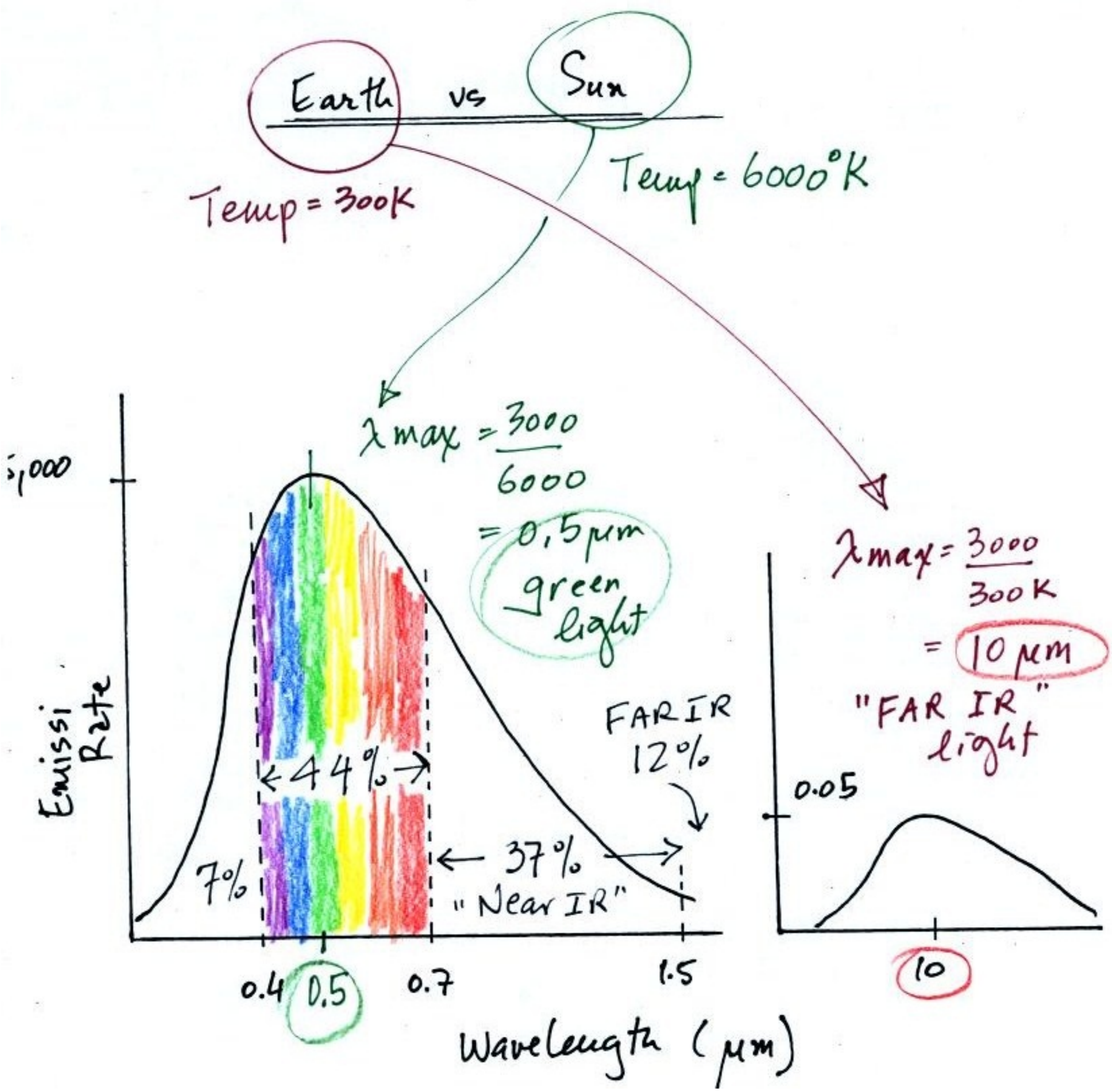


This section compares the EM radiation emitted by the sun and the earth. The kind and amount of EM radiation emitted depends upon their respective temperatures.

The curve on the left is for the sun. We used Wien's Law to calculate λ_{max}, assuming a temperature of 6000^0K, and obtained a value of 0.5 micrometers. This value is for green light, which means that the sun emits more green light than any other kind of light. The sun does not appear green because it is also emitting lesser amounts of violet, blue, yellow, orange, and red. The combination of all these colors appears white. 44% of the radiation emitted by the sun is visible light, 49% is infrared light (37% near infrared and 12% far infrared), and 7% is ultraviolet light. More than half of the light emitted by the sun is invisible.

The curve on the right is for the earth. λ_{max} was also calculated for the earth, assuming a temperature of 300^0K, and a value of 10 micrometers was obtained. All of the radiation emitted by the earth is in the infrared region of the spectrum.

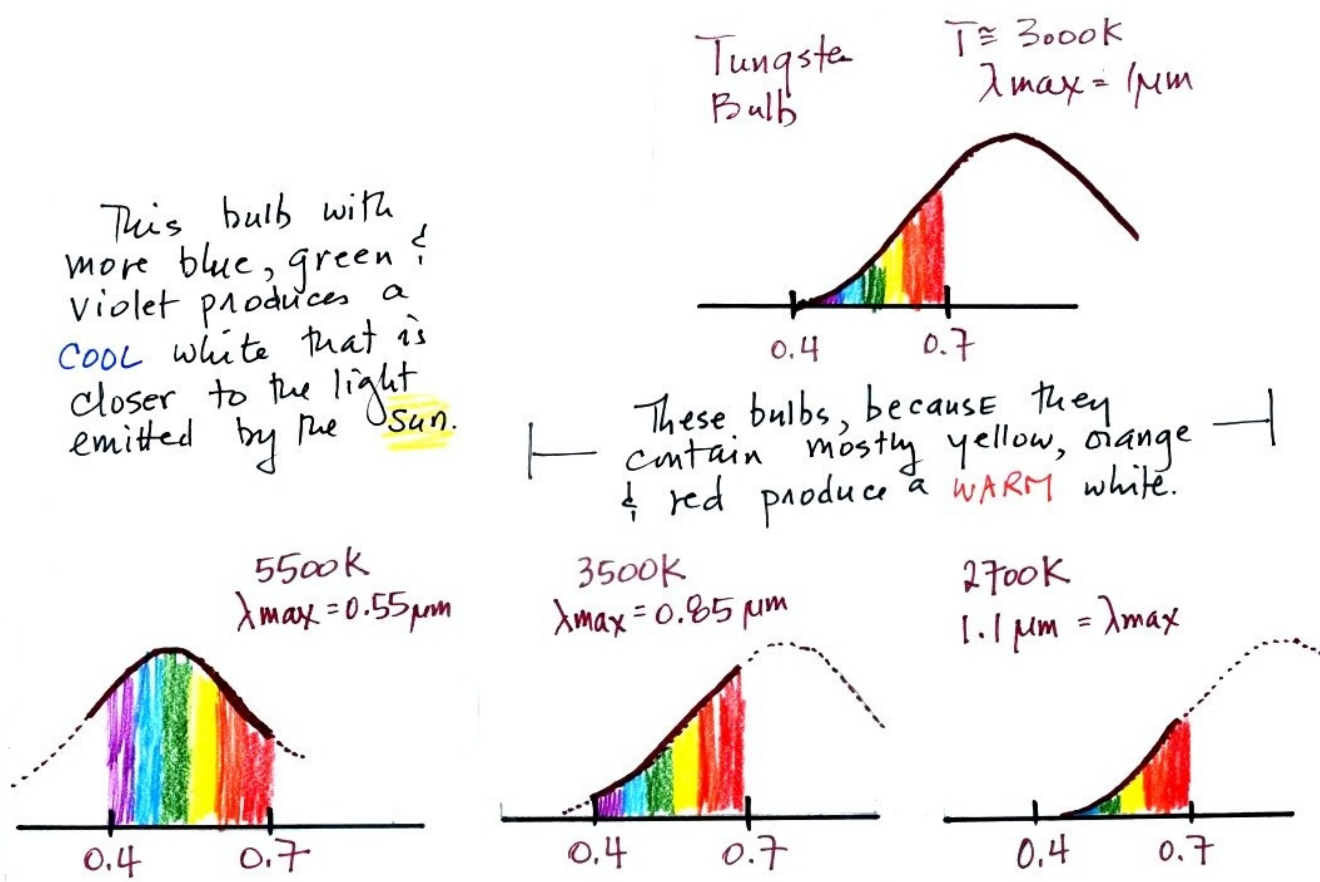
Because the surface of the sun is 20 times hotter than the surface of the earth, the sun emits energy at a rate that is 160,000 times higher (20^4) than the earth. Note the different vertical scales on the graph. If both the earth and sun were plotted with the same vertical scale, the earth curve would be too small to be seen.



This demonstration from the classroom version of the course shows how you can save money by using efficient light bulbs. Ordinary tungsten bulbs (incandescent bulbs) waste energy because they emit a lot of infrared energy that does not light up a room. An incandescent bulb produces a warm, white color because it emits more orange, red, and yellow light than blue, green and violet light. More efficient compact fluorescent lamps (CFLs) are being touted as an ecological alternative to tungsten bulbs because they use substantially less electricity, emit less wasted infrared light, and also last longer. CFLs come with different color temperature ratings.

The bulb with the hottest temperature rating, 5500^0K in the figure below, is meant to simulate sunlight. The temperature of the sun is 6000^0K and its λ_{max} is 0.5 micrometers. The spectrum of the 5500^0K bulb is similar to the spectrum of the sun. The tungsten bulb (3000^0K) and the CFLs with temperature ratings of 3500^0K and 2700^0K produce a warmer white light.

Three CFLs with the temperature ratings above are set up in class so that you could see the difference between warm and cool white light. Many people find the 2700^0K bulb "too warm" and think it makes a room seem gloomy and depressing. The 5500^0K bulb is "too cool" and creates a stark sterile atmosphere that you often see in a hospital. The 3500^0K bulb is a good compromise.



This figure below is from http://en.wikipedia.org/wiki/Compact_fluorescent_lamp on compact fluorescent lamps in Wikipedia. You can see a distinct difference between the cool white bulb on the left and the warm white light produced by a tungsten bulb (2nd from the left) and 2 CFCs with low temperature ratings (3rd and 4th from the left).

There is one major disadvantage to the energy efficient CFLs. The bulbs contain mercury and should not just be discarded in your ordinary household trash. They should be disposed of properly at a hazardous materials collection site or perhaps at the store where they were purchased. The city of Tucson has free drop-off sites for the disposal of household hazardous waste that are open the first Saturday of every month.