1. The brightness, $B$, is the power emitted per unit area, per unit solid angle. According to the Planck Law,

$$B_f(f, T) = \frac{2hf^3/c^2}{\exp(hf/kT) - 1}$$

where: $B_f(f, T)$ is the spectral brightness (units of W m$^{-2}$ sr$^{-1}$ Hz$^{-1}$); $h$ the Planck constant ($= 6.63 \times 10^{-34}$ J s); $f$ the frequency; $c$ the phase velocity of electromagnetic waves in a vacuum ($= 1/\sqrt{\mu_o \epsilon_o}$); $k$ the Boltzmann constant ($= 1.38 \times 10^{-23}$ J K$^{-1}$); and $T$ the temperature in kelvin. Make a log–log graph of spectral brightness versus frequency from $f = 10^5$ Hz to $f = 10^{17}$ Hz for three temperatures $T = 5$ (sky), 300 (Earth), and 5900 K (Sun). If using MATLAB, I suggest using the logspace function.

2. When written in terms of wavelength, $\lambda$, the Planck law takes the form,

$$B_\lambda(\lambda, T) = \frac{2hc^2/\lambda^5}{\exp(hc/\lambda kT) - 1}$$

where $B_\lambda(\lambda, T)$ is also the spectral brightness. Make a log–log graph of spectral brightness versus wavelength from $\lambda = 10^{-14}$ m to $\lambda = 10^4$ m for the three temperatures in Problem 1 using MATLAB or python.

3. Use “Blackbody Spectrum” at http://phet.colorado.edu to visualize the Planck law. This is a Shockwave Flash Object: open with a web browser that has the Adobe Flash Player installed. Play and experiment. Then answer the following questions.

(a) If you saw two hot, glowing objects, one glowing red and the other white, which object is hotter? Why?

(b) Set the temperature to that of an incandescent light bulb, about 3000 K. Assuming that the thermal emission of such a light bulb is close to that of a blackbody over much of the spectrum, comment on the energy efficiency of such a light bulb. How do fluorescent light bulbs differ from incandescent light bulbs?
(c) Zoom out so that longer wavelengths are shown on the abssisca. What can you say about the level of power emitted in the microwave region of the spectrum as compared to the power in the visible and infrared region of the spectrum?

(d) What is the Stefan–Boltzmann law, and how can you illustrate the Stefan–Boltzmann law with the “Blackbody Spectrum” simulation?

4. Show that if $hf/kT \ll 1$, then $\exp(hf/kT) - 1 \approx hf/kT$ and (1) simplifies to

$$B = \frac{2k}{\lambda^2} T \quad (3)$$

where $\lambda$ is the free–space wavelength and a small but finite range of frequencies sampled has been assumed. This is the Rayleigh–Jeans law. Hint: use a Taylor series.

5. Show how the Wien law and Rayleigh–Jeans law approximate the Planck law by producing a MATLAB figure. Plot a curve for each (Wien, Rayleigh–Jeans, and Planck) at $T = 300$ K in the same figure. Have the log–log plot show frequencies from $f = 10^7$ to $10^{15}$ Hz.

6. For temperatures of 5 and 350 K (the approximate range of Earth surface and atmosphere temperatures), estimate the frequency and wavelength at which the difference between the Rayleigh–Jeans law and the Planck law is larger than 0.5% and larger than 1%.

7. Play with the simulation “Molecules and Light” at http://phet.colorado.edu. Then answer the following questions.

(a) Find one frequency (microwave, infrared, visible, and ultraviolet) and molecule pair that illustrates the following absorption/emission mechanisms:

i. an electronic transition;

ii. a vibrational transition;

iii. a rotational transition;

(b) According to the simulation, which molecules are greenhouse gases?

(c) Use the simulation to explain how a microwave oven heats food.

(d) Pick one molecule, do a little research, and write a few sentences on why the simulation behaves the way it does for that molecule.


(a) I thought the units of $h$ (Planck’s constant) are J s! Explain how to get the units of $h$ mentioned in the article.

(b) Explain in your own words why it is important to know the value of physical constants as precisely as possible.