3.6 Thermal Radiation

PRE-LECTURE READING 3.6

- *Astronomy Today*, 8^{th} Edition (Chaisson & McMillan)
- *Astronomy Today*, 7^{th} Edition (Chaisson & McMillan)
- *Astronomy Today*, 6^{th} Edition (Chaisson & McMillan)

VIDEO LECTURE

- Thermal Radiation[1] (27:10)

SUPPLEMENTARY NOTES

Thermal Radiation

- See Thermal Radiation[2].
- Temperature measures the average motion of a collection of particles.
- Absolute zero corresponds to no motion.
- Moving particles bounce off of one another.
- These bounces create ripples in the electromagnetic fields emanating from these particles.
- These ripples are light (see Light and the Electromagnetic Field).
- Consequently, a distribution of particle speeds results in a distribution of bounce speeds, and consequently in a distribution of ripple frequencies, and consequently in a distribution of light frequencies.
- This distribution of light frequencies is called a Planck, or blackbody, or thermal distribution.

[1] http://youtu.be/RiD8Rmx14U0
[2] http://en.wikipedia.org/wiki/Thermal_radiation

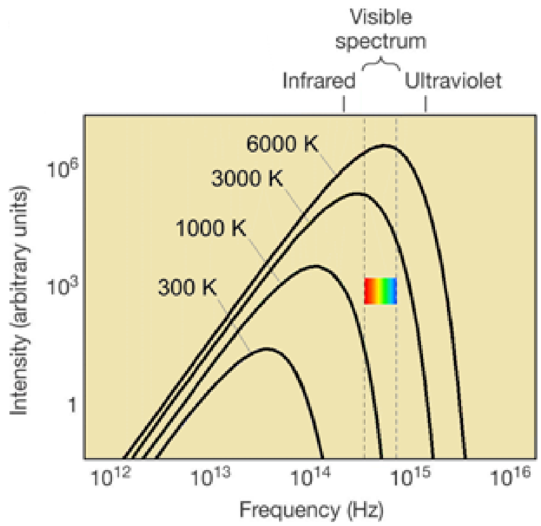

Figure 1

- Higher temperatures correspond to faster particle speeds, and consequently faster bounce speeds, and consequently higher-frequency ripples, and consequently higher-frequency light: The distribution of light shifts to higher frequencies. This is called Wien's Law.
- Higher temperatures correspond to faster particle motions, and consequently more particle bounces, and consequently more ripples in the electromagnetic field, and consequently more light: The distribution of light becomes more intense at all frequencies. This is called Stefan's Law.

Wien's Law

- See Wien's Law[3].

$$\lambda_{\text{peak}} = \frac{2.9 \text{ mm}}{(T/1 \text{ K})} \tag{10}$$

- λ_{peak} = wavelength at which a blackbody emits the most light
- T = temperature of the blackbody
- For stars, λ_{peak} is usually measured in nm and T in 1,000s of K. Hence, you might find this equivalent form of Wien's law more convenient to use:

$$\lambda_{\text{peak}} = \frac{2{,}900 \text{ nm}}{(T/1{,}000 \text{ K})} \tag{11}$$

[3] http://en.wikipedia.org/wiki/Wien%27s_displacement_law

EXAMPLE:

The sun's surface temperature is 5,800 K. Hence, it emits most of its light at

$$\lambda_{\text{peak}} = \frac{2{,}900 \text{ nm}}{(5{,}800 \text{ K}/1{,}000 \text{ K})} = 500 \text{ nm},$$

which is in the visible part of the electromagnetic spectrum.

- Reminder: The visible part of the electromagnetic spectrum spans wavelengths of ≈700 nm (red) to ≈400 nm (violet).

- **If λ_{peak} is in the ultraviolet, X-ray, or gamma-ray parts of the electromagnetic spectrum, its thermal distribution will still cross the visible part of the spectrum, and will be blue in color.**
- If λ_{peak} is in the near-infrared (infrared, but almost visible) part of the electromagnetic spectrum, its thermal distribution will still cross the red side of the visible part of the spectrum, and will consequently be red in color (e.g., the $T = 1{,}000$ distribution in Figure 1).
- If λ_{peak} is in the far-infrared or radio parts of the electromagnetic spectrum, its distribution will not cross the visible part of the spectrum, and will consequently be invisible (although detectable in the far-infrared and radio; e.g., the $T = 300$ distribution in Figure 1).

Stefan's Law

- See Stefan's Law[4].

$$F = \sigma T^4 \tag{12}$$

- F = energy flux (energy emitted per unit area and per unit time) of a blackbody
- σ (Greek letter "sigma") = Stefan–Boltzmann constant
- T = temperature of the blackbody

[4] http://en.wikipedia.org/wiki/Stefan%E2%80%93Boltzmann_law

In this course, you will never need to use the Stefan–Boltzmann constant to solve a problem.

EXAMPLE:

Person A has a fever and is 1.01 times hotter than Person B. The energy flux coming off of Person A is how many times greater than the energy flux coming off of Person B?

Solution: Let $T_{\rm A}$ and $F_{\rm A}$ be the temperature and energy flux of Person A. Let $T_{\rm B}$ and $F_{\rm B}$ be the temperature and energy flux of Person B. Then, $F_{\rm A} = \sigma {T_{\rm A}}^4$ and $F_{\rm B} = \sigma {T_{\rm B}}^4$. Dividing the latter equation into the former equation yields:

$$\begin{aligned} \frac{F_{\rm A}}{F_{\rm B}} &= \frac{\sigma T_{\rm A}^4}{\sigma T_{\rm B}^4} \\ &= \left(\frac{T_{\rm A}}{T_{\rm B}}\right)^4 \\ &= 1.01^4 \approx 1.04. \end{aligned}$$

- Notice that we did not need to know the constant of proportionality, in this case σ, to solve this problem. This is what is called a ratio problem.

Most of the math problems in this course are ratio problems.

- If the constant of proportionality is not needed, we can more simply write:

$$F \propto T^4$$

EXAMPLE:

Person A has a fever and is 1.01 times hotter than Person B. The energy flux coming off of Person A is $1.01^4 = 1.04$ times greater than the energy flux coming off of Person B.

ASSIGNMENT 3

- Do Questions 4 and 5.