INST 2403 Activity

Spectra & Blackbody Radiation

Everything radiates! Literally every body sends out electromagnetic waves of many different wavelengths.
There are several laws of physics connected to this phenomenon of blackbody radiation, since there are several interesting questions we can ask. The truly amazing thing is that the amount and exact distribution of waves sent out just depends on two things: the temperature T of the body and its surface area A. Nothing else matters, and so objects as different as a hot star, the human body, and an ultra-cold gas cloud in outer space send out blackbody radiation obeying the same laws. Kirchhoff's laws tells us that every solid or liquid body sends out a continuous spectrum, i.e. waves of all kinds of wavelengths. The Stefan-Boltzmann law tells us how much power or energy per time the object radiates. Wien's law tells us at which wavelength the object shines brightest. Let's look at these laws in detail.

Part I: Kirchhoff's Laws

These three laws describe the different spectra encountered in Nature.

1. Describe what we mean be the term "spectrum".

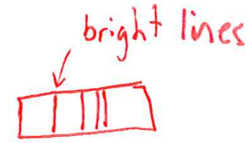
A compilation or list or plot, detailing how bright an object is at different wavelengths

2. What does the spectrum of a hot, solid object look like? How do we call such a spectrum?

Hot, solid objects radiate at many wavelengths → Continuous spectrum

3. What does the spectrum of a hot dilute gas look like?

Only a discrete set of colors or wavelengths show up → Emission spectrum



4. What does the spectrum of a hot solid object look like when it is viewed though a cold, dilute gas cloud?

Continuous spectrum interrupted by a few dark lines → Absorption spectrum

Part II: Stefan-Boltzmann law

The law states that $\boldsymbol{P = \sigma A T^4}$, where σ is the Stefan-Boltzmann constant. Its value is of no interest to us since we need to understand relative luminosities only.

4. Compare two stars of same size, star A being three times hotter than star B. Which star is more luminous and by which factor?

$T_A = 3T_B \Rightarrow P_A = 3^4 P_B = 81 P_B \Rightarrow$ A is more luminous by a factor 81

5. Compare two stars of same temperature, and star C being half the size of star D. Which star is more luminous and by which factor?

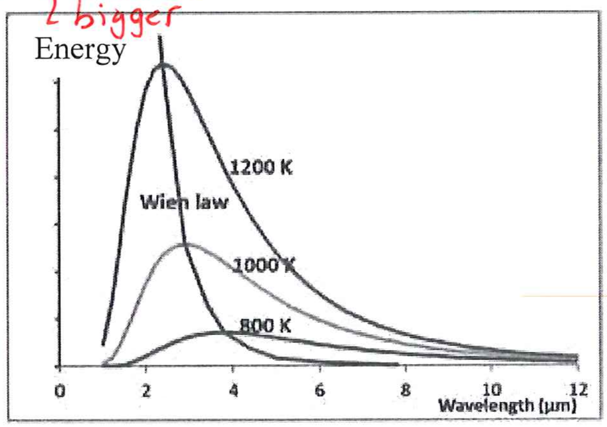
$P = A\sigma T^4 = 4\pi R^2 T^4 \Rightarrow R \to \frac{1}{2}R \Rightarrow P \Rightarrow (\frac{1}{2})^2 P = \frac{1}{4} P$

6. Can two stars of different temperature have the same luminosity? How or why not?

Yes, the {hotter / cooler} star has to be {smaller / bigger}

Hot & small "=" Cool & big

Part III: Wien's law



The distribution of wavelengths an object sends out has a universal shape which is called the Planck curve, see figure. The special features of the curve are not important to us, but the general features are rather obvious. Indeed, Kirchhoff figured them out in 1859 by pure speculation, without any specific data. An object will not send out very short nor very long wavelengths, so the curve must start and end at zero. This means it must rise up to a maximum, and then decrease. That's all we need. There is a peak, and since wavelengths can be arbitrarily long, the peak cannot be in the middle; it sits off center.
Wien's law tells us where it is. It states that the peak wavelength λ_{peak} (the wavelength at which the object sends out most light) multiplied by the object's temperature T is the same for any object. This product is equal to Wien's constant k_{Wien} = 0.0029 m K (meter times Kelvin): $T \times \lambda_{peak} = 0.0029\ m\ K$.

7. Figure out **your** peak wavelength.

Say $T_{you} = 300K$ and $0.0029 \approx 3 \cdot 10^{-3} \Rightarrow \lambda_{peak\,you} = \frac{3 \cdot 10^{-3}\ m \cdot K}{300K} = 1 \cdot 10^{-5}\ m = 10\ \mu m$

8. What do we call electromagnetic waves with this wavelength?

Infrared radiation

9. The sun is 20 times hotter than you. What is its peak wavelength?

$\lambda_{sun} = \frac{1}{20}\lambda_{you} = \frac{10\ \mu m}{20} = 0.5\ \mu m = 500\ nm$

10. What do we call electromagnetic waves with this wavelength?

Visible light, actually green light.