Lecture 18 (2-2), Oct 24, 2022

Blackbody Radiation

- Total radiation from a body is the sum of reflection and absorption
- A *blackbody* is some object that absorbs all incoming light at all wavelengths, i.e. no reflection
  - In order to satisfy energy balance, this blackbody must radiate out power
  - Kirchhoff's Law: Emissive power is proportional to absorption coefficient
    * Therefore emissive power of a blackbody is a universal property determined only by temperature
- Intuitively we know that things glow when they're hot
  - The spectral function of a hot object has more low wavelength emissions
  - Total radiative energy is proportional to T^4 (Stefan-Boltzmann Law)
  - Peak wavelength is inversely proportional to temperature, i.e. $\lambda_{max}T$ is constant (Wien's Displacement Law)
- To approximate a blackbody experimentally, Wien + Lummer used a box with a tiny hole; when light goes in, it reflects around inside and has a negligible chance of coming back out

Blackbody Radiation Theory

- Spectral distribution function ρ is given by $\rho(\lambda, T) = \lambda^{-5} f(\lambda T)$, since $\lambda_{max}T$ is constant
- Wien guessed $\rho(\lambda, T) = \frac{c_1}{\lambda^5} e^{-\frac{c_2}{\lambda T}}$, which fits experimental results
  - Planck aimed to come up with a theory that explained this
- Discrepancy between Wien's model and experimental data is observed for longer wavelengths

Planck's Law

- Planck assumed the energy of blackbody radiation is quantized in the calculation of average energy
  - In the classical picture $\langle E \rangle = \displaystyle\int_0^\infty E f(E)\,\mathrm{d}E$ where $f(E) = ce^{-\frac{E}{kT}}$ (Boltzmann)
    * This works out to kT, which does not match experimental data
  - Planck calculated $\langle E \rangle = \displaystyle\sum_0^\infty E f(E)$
    * Assume $E = n(hf)$, i.e. energy is in quantized in units of some value proportional to frequency
    * This works out to $\dfrac{hf}{e^{-hf} kT - 1}$
- This matches Wien's model at lower wavelengths and explains the discrepancy at higher wavelengths due to the -1
- $\rho(\lambda, T) = \dfrac{8\pi hc}{\lambda^5} \dfrac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$
- h is *Planck's constant*, $h = 6.626\,070\,15 \times 10^{-34}\,\mathrm{m^2\,kg/s}$
- Even though this quantization of energy was used to solve the blackbody radiation problem, no one really thought it was physically meaningful at the time – except for Einstein

Specific Heat of Solids

- Specific heat: amount of heat required to raise the temperature of matter by a unit amount
- Dulong-Petit Law: all solids have the same molar specific heat
- Diamond's specific heat is way lower than what the D-P law predicts
- Einstein solved this by assuming each oscillator in a solid has quantized energy levels, similar to the blackbody radiation problem