Chapter 7A

The Origins of Quantum Mechanics

Classical Mechanics

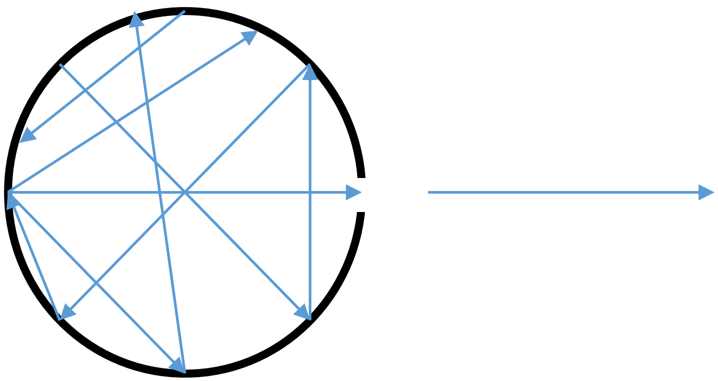
- Predicts a precise trajectory (locations and momenta at each moment) for particles
- Energies of all values are allowed and possible.
- Light is a wave.

Punchline

- To become familiar with the experiments that showed contradictions with Classical Mechanics for very small molecules and light.
- Learn why quantum mechanics is necessary.

Energy is Quantized

- Black-Body Radiation



Black-body Emitter:
A spherical container held at constant temperature with a pinhole.

Light emitted from the pinhole is representative of the radiation inside the container.

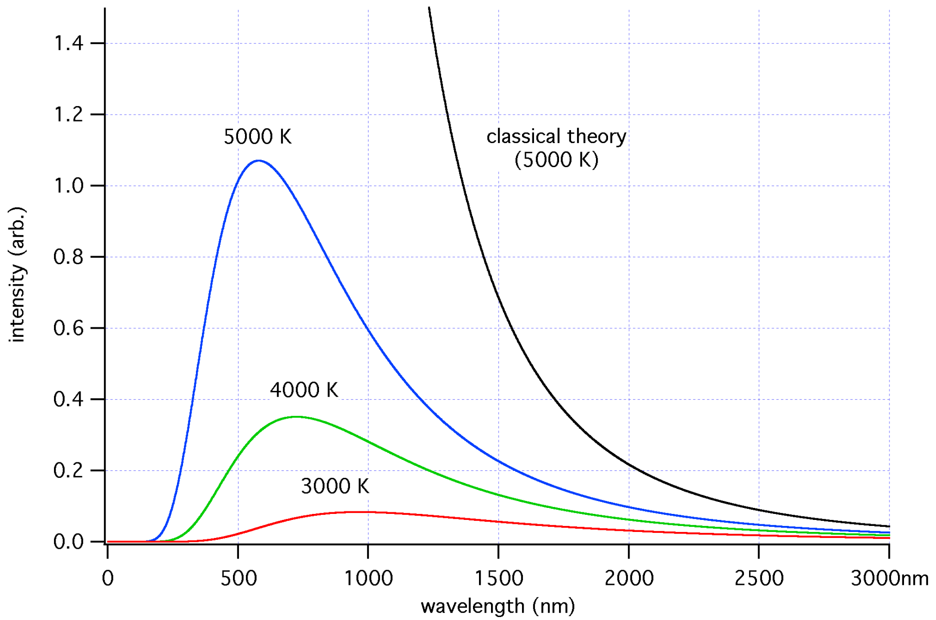
$$d\mathcal{E} = \rho(\lambda, T)d\lambda$$

$$\mathcal{E}(T) = \int_0^\infty \rho(\lambda, T)d\lambda$$

$$\mathcal{E}(T) = \int_0^{\infty} \rho(\lambda, T)\, d\lambda$$

$$\mathrm{E}(T) = V * \mathcal{E}(T)$$

Ultra-Violet Catastrophe



$$\rho(\lambda, T) = \frac{8\pi k T}{\lambda^4}$$

Rayleigh-Jeans Law

Max Planck to the Rescue!

What if…
The energy of each oscillator is bound to specific quantities?

$$E = nh\nu$$

$$\rho(\lambda, T) = \frac{8\pi hc}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)}$$

Energy is Quantized

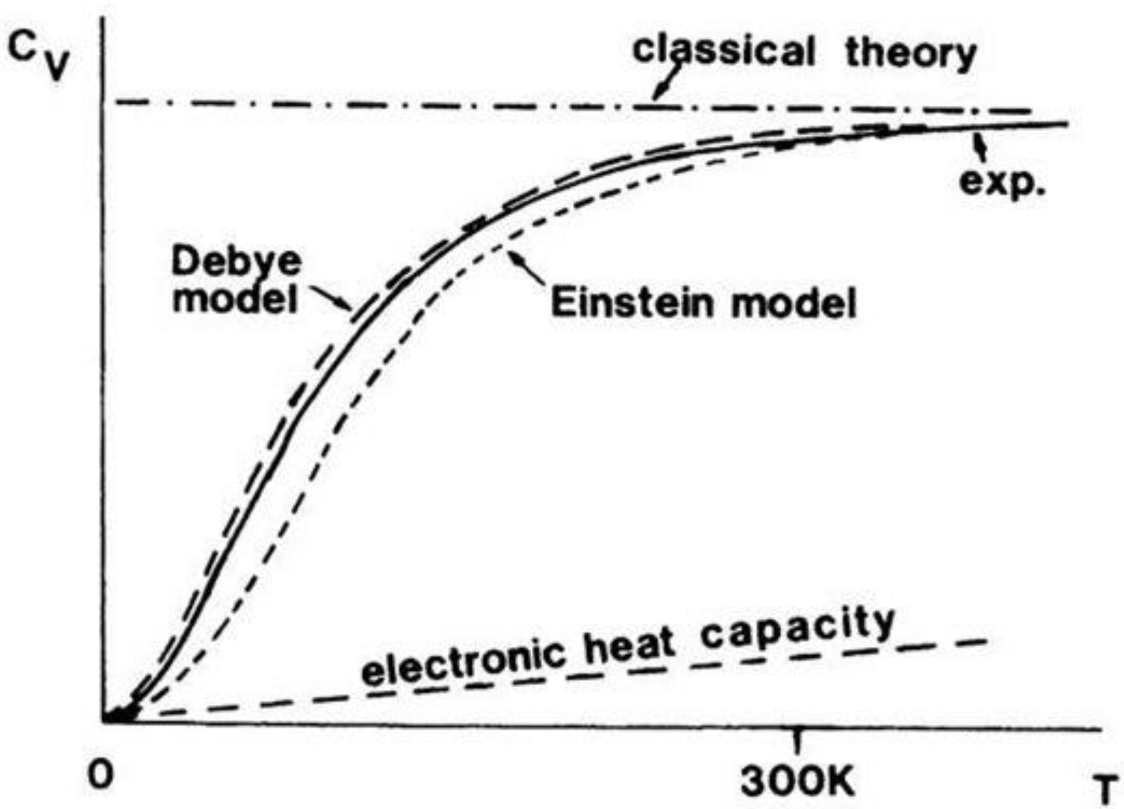
- Dulong and Petit determined the heat capacities C_v for numerous solids.
  - They propose that all are the same and C_v=25 J/K*mol

$$U_m = Molar\ Internal\ Energy = 3RT$$

$$C_v \left(\frac{\partial U}{\partial T}\right)_V = 3R = 24.9\,\frac{J}{K * mol}$$

NOT TRUE AT LOW TEMPERATURES!

- Einstein corrected this by using Plank's hypothesis that oscillation is confined to discrete values.

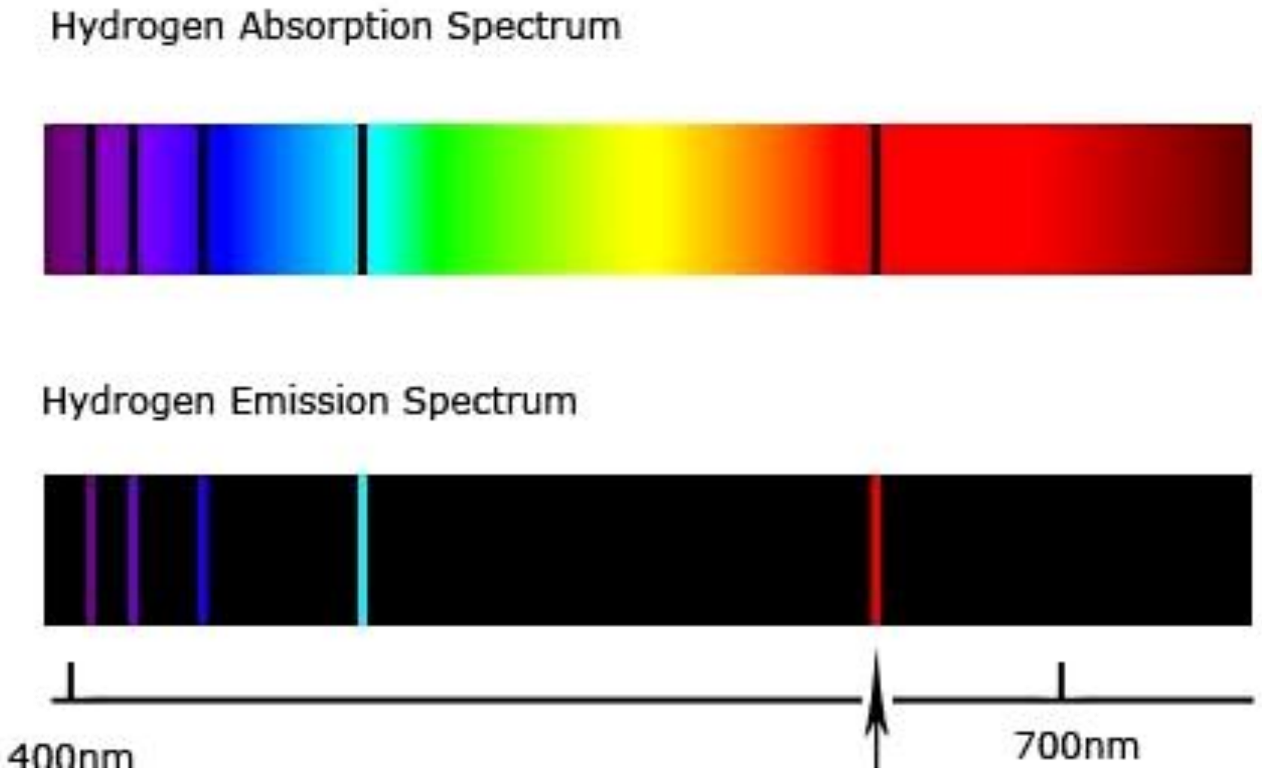


$$C_{v,m}(T) = 3Rf_E(T)$$

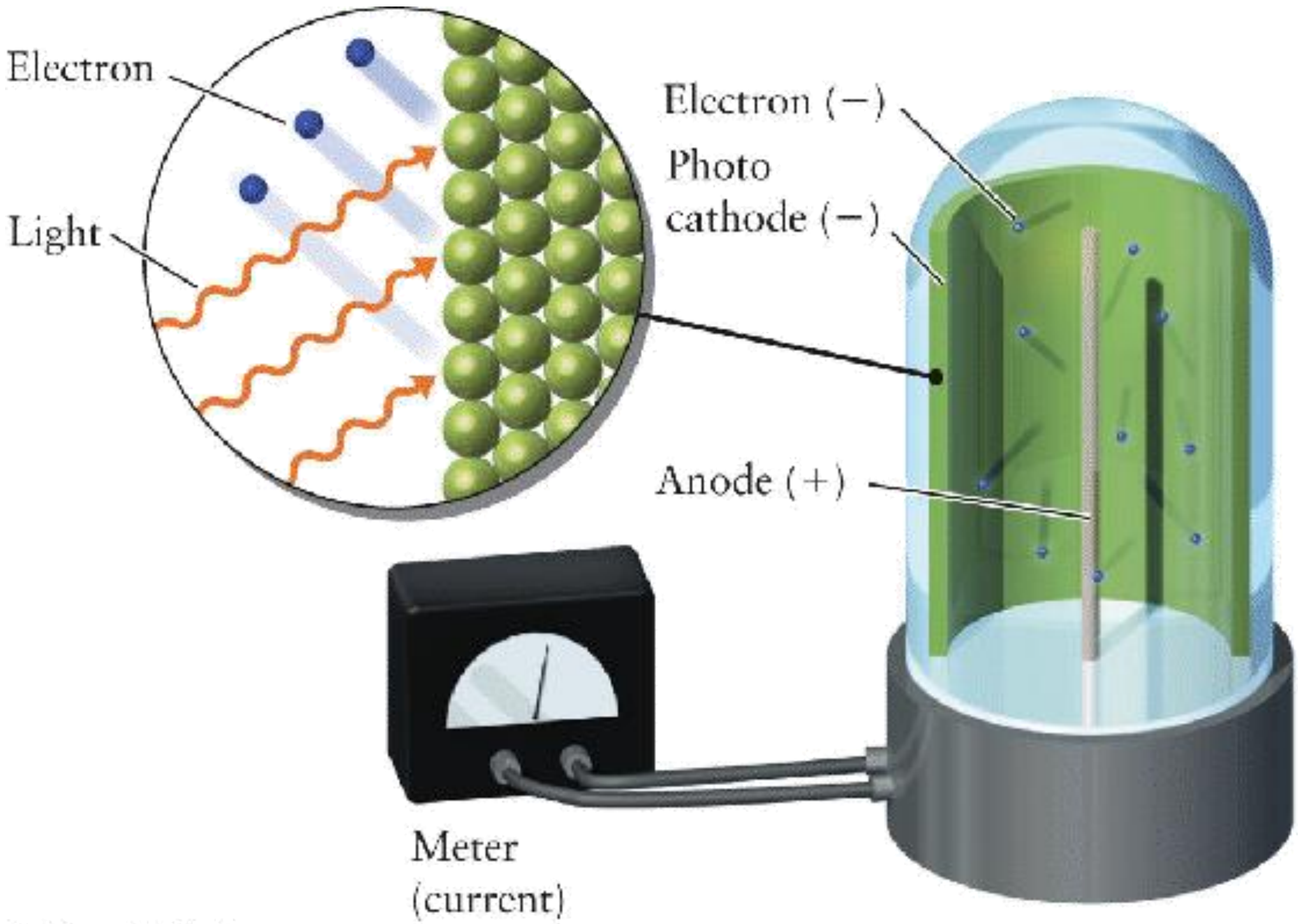
$$f_E(T) = \left(\frac{\theta_E}{T}\right)^2 \left(\frac{\exp(\theta_E/2T}{(exp\,\theta_E/T) - 1}\right)^2$$

Energy is Quantized

- The lines seen in absorption or emission spectroscopy are DISCRETE



Wave-Particle Duality



Wave-Particle Duality

- Einstein's Results:
  1. No e- are ejected (regardless of Intensity of light) if the light frequency is below threshold.
  2. e- are ejected (even at very low Intensities) when frequency is just above the threshold.
  3. The Kinetic Energy of the electron is proportional to the frequency of the light, and is independent of the intensity.

Note that with waves, higher intensity means higher energy!

Photons explain:

1. Why if $h\nu < \Phi$, no electrons are ejected.
2. Why after you reach Φ, the rest of the energy is given to the electron as KE.
3. Why you see one electron ejected per photon.

Wave-Particle Duality

- Diffraction of electrons by a crystal
  - Davisson-Germer Experiment
    - They hit a crystal with a beam of electrons and observed diffraction pattern. This showed that electrons behaved as waves..
- Double-Slit Experiment
- deBroglie Wavelength

$$\lambda = \frac{h}{mv}$$