Last Time
- Matter-Energy interactions are problematic
  - Matter = collection of oscillating dipoles
  - High $\nu$ oscillators “missing in action” at low $T$

Quantized Energy
- Classical energy exchange
  \[ KE = \frac{1}{2} m \nu^2 = \frac{p^2}{2m} \]
  \[ PE = \frac{q_1 q_2}{R} \]
  \[ \Delta E \rightarrow 0 \]
- Quantized energy exchange
  \[ \Delta E = h \nu \quad (QM \text{ if } h\nu/kT \text{ not } << 1) \]

Photoelectric Effect
- Monochromatic light ejects electrons from metal surface
- Measure #electrons (current)
- Measure electron KE by adjusting voltage

Classical physics says
- $E_{\text{light}}$ proportional to intensity (not frequency)

Predicts
- If electrons bound to atoms,
  - Intensity threshold for current
  - Intensity and electron KE rise together
  - Current & KE do not depend on frequency
- Observe the opposite!
Photoelectric Effect

- Observations
  - Current rises with intensity
    - no threshold
  - $KE = h\nu - \phi$
    - Indep’t of intensity
- Einstein (1879-1955)
  - 1905
  - light energy = photons

Atomic Spectra

- Magic numbers predict H atom $\lambda$

  \[
  \frac{1}{\lambda} = R_H \left( \frac{1}{n_1^2} - \frac{1}{n^2} \right) \text{ where } n > n_1 \text{ and are integers}
  \]

- Why?

Bohr (1885 – 1962)

- 1913, H atom model
  - electron in stable circular orbit
  - Light emitted if electron jumps orbits
    - $h\nu$ orbit $\rightarrow$ lo E orbit
    - $E$ change = $h\nu$
  - Angular momentum quantized = $nh/2\pi$
    - $n$ is (magic) quantum number
  - Rydberg

  \[
  R_H = \frac{2 \pi^2 m_e q_e^4}{h^3 c}
  \]
Sporadic Progress

- Heat capacity
- Blackbody, 1900 → E quantized
- Photoelectric, 1905 → E localized
- Atomic spectra, 1913 → Connects quantum theory to huge volume of data
- What about matter?
  - Why do atoms exist?

de Broglie’s Proposal

- de Broglie (1892-1987)
  - 1923
    - photons \( E = h \nu = mc^2 \)
    - \( h / \lambda = mc = \text{momentum} \)
    - matter \( h / \lambda = m \nu = p \)
    - de Broglie \( \lambda = h / p \)

de Broglie’s wavelength

- “quick” electron
  - \( m_e = 9.1 \times 10^{-31} \text{ kg} \)
  - \( v = 3 \times 10^7 \text{ m/s} \)
  - \( \lambda = 24 \text{ pm} \)
- ave Ar atom at 298 K
  - \( m = 6.63 \times 10^{-26} \text{ kg} \)
  - \( v = (3 \text{ kT} / m)^{1/2} = 430 \text{ m/s} \)
  - \( \lambda = 23 \text{ pm} \)
- Alan walking
  - (88 kg)(1 m/s)
  - \( \lambda = 7.6 \times 10^{-24} \text{ pm} \)

Measure \( \lambda \) by Diffraction
Interference

Young's Experiment

Sunlight

Narrow slit

Observing screen

Pattern observed on screen

Right slit open

observed

Left slit open

observed

Both slits open

wave theory

particle theory

observed