

Chapter 1

Late 1800's – Several failures of classical (Newtonian) physics discovered

1905 – 1925 – Development of QM – resolved discrepancies between expt. and classical theory

QM – Essential for understanding many phenomena in Chemistry, Biology, Physics

- photosynthesis + vision
- magnetic resonance imaging
- radioactivity
- operation of transistors
- lasers (CD + DVD players)
- van der Waals interactions

Examples where classical Physics inadequate

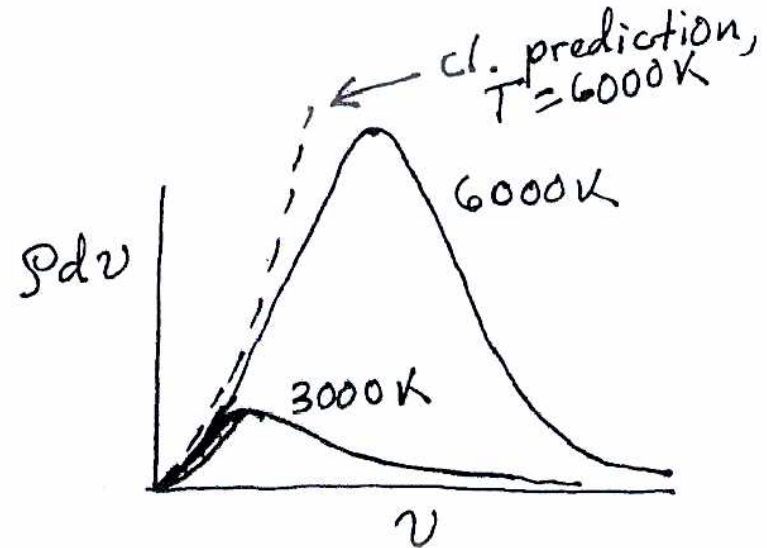
1. Blackbody Radiation

heated objects → light

Classical theory

$$\begin{aligned}\rho d\nu &= \frac{8\pi\nu^2}{c^3} \bar{E}_{osc} d\nu \\ &= \frac{8\pi\nu^2}{c^3} kT d\nu\end{aligned}$$

Emits ∞ energy at all T



ν = frequency
 ρ = density oscillators
 \bar{E}_{osc} = average energy/osc

Planck:
(1900)
$$\rho d\nu = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{h\nu/kT} - 1} d\nu$$

originally by fitting experiment

Planck's constant: $h = 6.626 \times 10^{-34} \text{ J}\cdot\text{S}$

http://en.wikipedia.org/wiki/Planck's_constant

Planck later showed this is consistent with the energies of the oscillators making up the blackbody object taking on discrete values

$$E = nh\nu, \quad n = 0, 1, 2, \dots$$

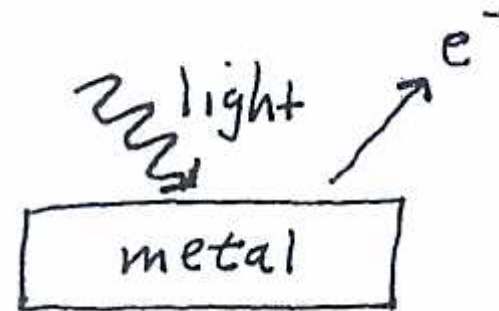
$$\Rightarrow \bar{E} = \frac{h\nu}{e^{h\nu/kt} - 1}$$

$T \rightarrow 0 \rightarrow 0$

$T \rightarrow \infty \rightarrow kT$ Classical result

Taylor series of e^x for small x : $e^x = 1 + x + \dots$

2. Photoelectric effect



expected behavior

- light is a wave, so each e⁻ absorbs small fraction of the energy
- e⁻ emitted at all ν , if intensity (I) great enough
- KE \propto with I

observed

- #e⁻ emitted \propto I
- e⁻ emitted if $\nu > \nu_0$ (critical freq.)
- KE \propto with ν , and independent of I

Explained by Einstein in 1905

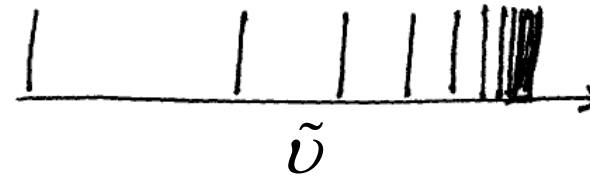
light has energy $h\nu$ and acts particle-like, enabling its energy to be focused on one e⁻

$$E_{e1} = h\nu - \phi, \quad \phi = \text{work function of metal}$$

3. Heat capacity of solids

4. Spectra of atoms + molecules – discrete lines

spectrum H atom



$$\tilde{\nu} = R_H \left(\frac{1}{n_1^2} - \frac{1}{n^2} \right) \leftarrow \text{Rydberg series}$$

n_1, n integers, $n = n_1+1, n_1+2, n_1+3, \dots$

$$R_H = 109,677.581 \text{ cm}^{-1}$$

We will return to this

Wave-particle duality

- photoelectric effect \Rightarrow light can behave as a particle
- diffraction of light \Rightarrow light can behave as a wave

de Broglie (1924): particles have a wavelength:

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

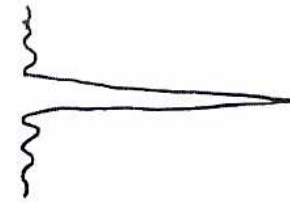
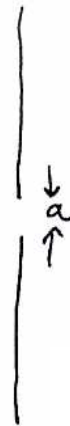
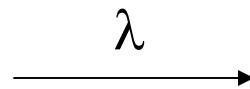
Demonstrated by diffraction of e^- , He, H_2 from crystalline surfaces

e^- with KE = 17 eV has $\lambda = 3 \text{ \AA}$, a typical lattice spacing in a crystal \Rightarrow interference (diffraction)

large objects – baseballs, cars, etc., have de Broglie wavelengths too small to be detected

Diffraction experiments

light incident on a
single slit



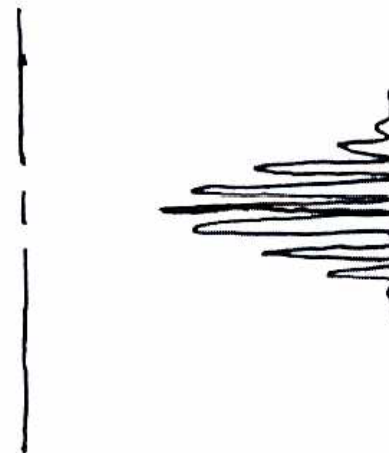
minima: $\sin \theta = \frac{n\lambda}{a}$,
 $n = \pm 1, \pm 2, \pm 3, \dots$

- well separated peaks when $\lambda \approx a$
- $\lambda \gg a$ – can't see diffraction

double-slit expt. with e^-

the e^- goes through both slits!!

In 1977 the expt. was done with
the He atoms \Rightarrow Each atom
goes through both slits!!



Summary:

- energy + oscillators are quantized
- wave-particle duality
- de Broglie relationship
- these ideas paved the way for QM

NOTE: Frequencies of a guitar string are “quantized” (and guitars are clearly Classical)

Quantization comes from boundary conditions

Fourier transforms:
(frequency + time)
(position, momentum)
are conjugate variables

We will come back to these considerations.