Introduction

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

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

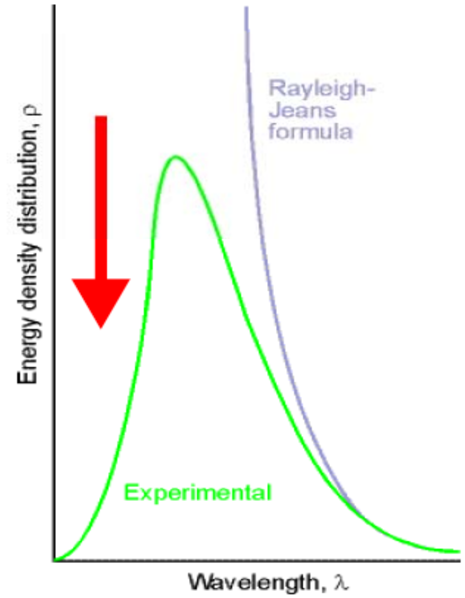
QM – Essential for understanding many phenomena in Chemistry, Biology, Physics

- photosynthesis + vision
- magnetic resonance imaging
- radioactivity
- operation of transistors
- lasers (CD + DVD players)
- van der Waals interactions
- forces between molecules
- interpretation of spectra
- breaking of chemical bonds

Examples where classical Physics inadequate

1. Blackbody Radiation

heated objects → light



Classical theory

$$d\varepsilon = \rho(\lambda) d\lambda$$

$$d\varepsilon = \frac{8\pi kT}{\lambda^4} d\lambda$$ (Raleigh-Jeans)

Emits ∞ energy at all T

λ = wavelength
ρ = density of oscillators
Avg energy per oscillator assumed to be kT

Planck: (1900)

$$\rho = \frac{8\pi hc}{\lambda^5} \frac{e^{-hc/\lambda kT}}{1 - e^{-hc/\lambda kT}} d\lambda$$

originally determined by fitting experiment

Planck's constant: $h = 6.626x10^{-34}\ J \bullet S$

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

$$E = nh\upsilon \ , \ \ n = 0,1,2,...$$

$$\Rightarrow \overline{\mathrm{E}} = \frac{h\upsilon}{e^{h\upsilon/kT} - 1}$$

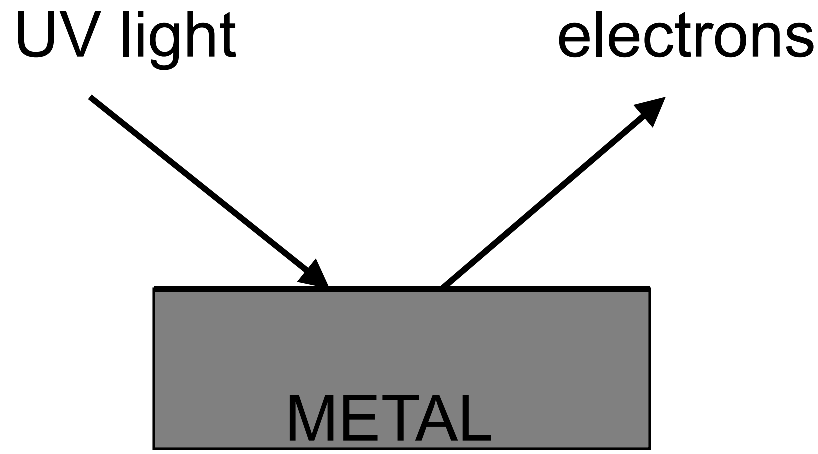
T → 0: 0

T → ∞: kT — Classical result

$$c = \upsilon\lambda$$

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

2. Photoelectric effect



expected behavior	
• light is a wave, so each e^- absorbs small fraction of the energy	• # e^- emitted $\propto I$
• e^- emitted at all υ, if intensity (I) great enough	• e^- emitted if $\upsilon > \upsilon_0$ (critical freq.)
• KE > with I	• KE > with υ, and independent of I

Explained by Einstein in 1905

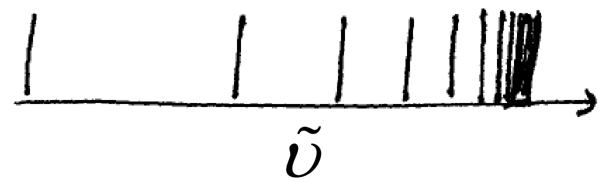
light has energy $h\upsilon$ and acts particle-like (photon), enabling its energy to be focused on one e^-

$E_{kin} = h\upsilon - \phi$, ϕ = work function of metal

3. Heat capacity of solids

4. Spectra of atoms + molecules – discrete lines

spectrum H atom



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

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

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

} 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:

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

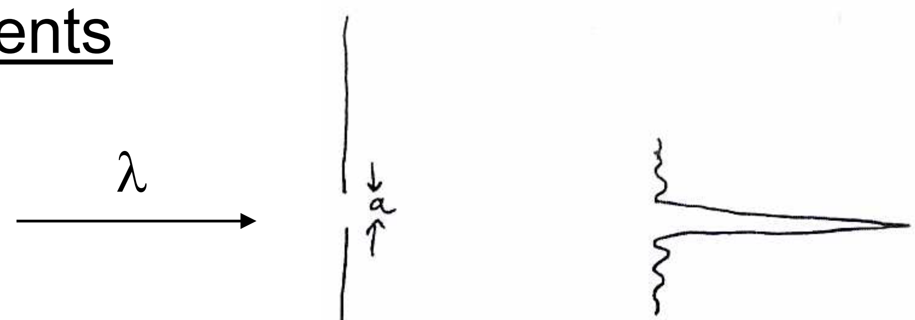
Demonstrated by diffraction of e^-, He, H_2 from crystalline surfaces

e^- with KE = 17 eV has λ = 3 Å, 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



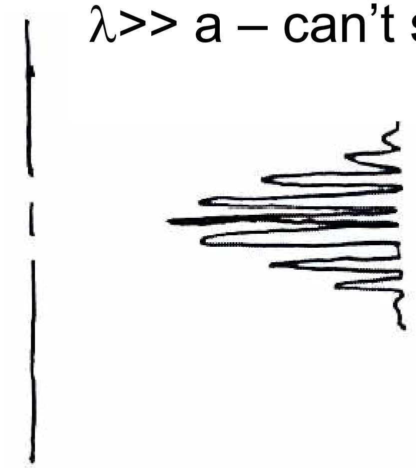
minima: $\sin\theta = \frac{n\lambda}{a}$,
n = ±1, ±2, ±3, …

well separated peaks when
$\lambda \approx a$
$\lambda >> a$ – 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.