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

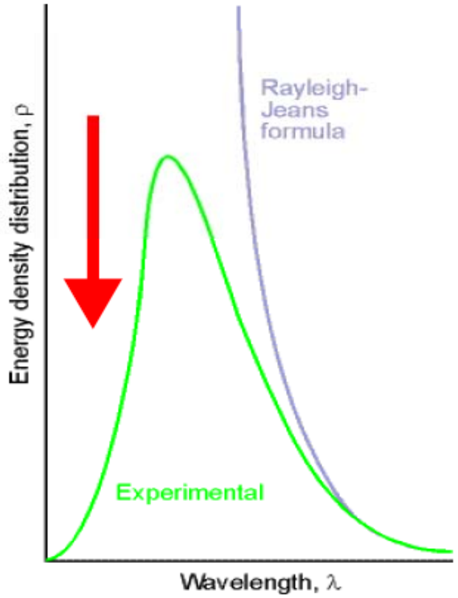
Classical theory

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

$$d\varepsilon = \frac{8\pi kT}{\lambda^4}d\lambda$$

(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

$$E = nh\upsilon \;,\;\; n = 0,1,2,\ldots$$

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

T → 0: 0

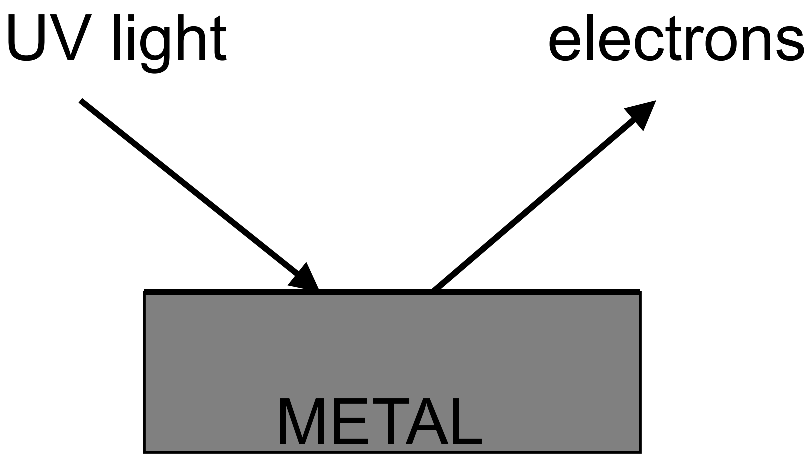
T → ∞: kT

Classical result

$$c = \upsilon\lambda$$

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

2. Photoelectric effect



expected behavior

- light is a wave, so each e^- absorbs small fraction of the energy
- e^- emitted at all υ, if intensity (I) great enough
- KE > with I

- \# e^- emitted $\propto I$
- e^- emitted if $\upsilon > \upsilon_0$ (critical freq.)
- KE > with υ, and independent of I

Explained by Einstein in 1905

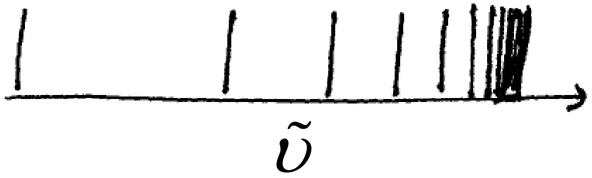
light has energy $h\upsilon$ and acts particle-like (photon), enabling its energy to be focused on one e^-

$E_{kin} = h\upsilon - \phi$, 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, …

R_H = 109,677.581 cm^{-1}

} We will return to this

Wave-particle duality

- •photoelectric effect ⇒ light can behave as a particle
- •diffraction of light ⇒ light can behave as a wave

de Broglie (1924): particles have a wavelength:

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

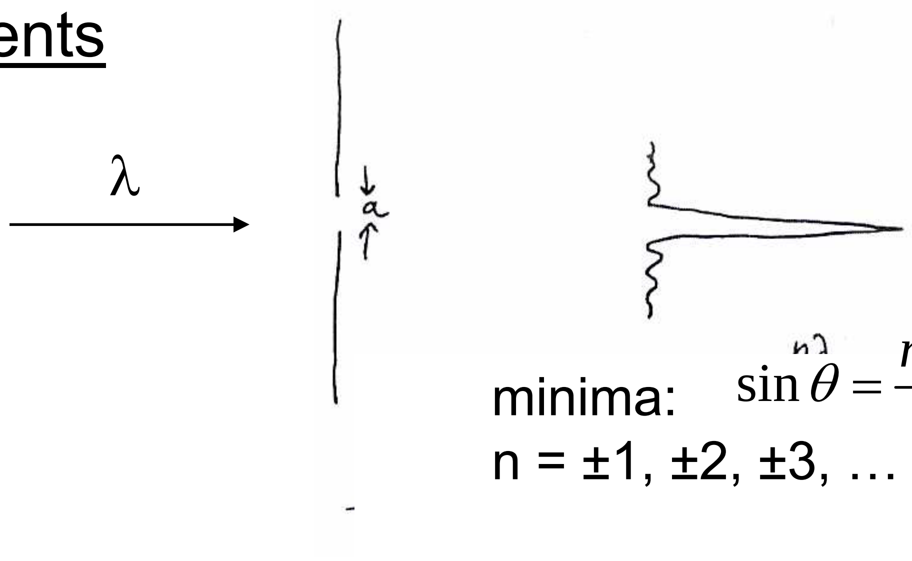
Demonstrated by diffraction of e^-, He, H_2 from crystalline surfaces

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



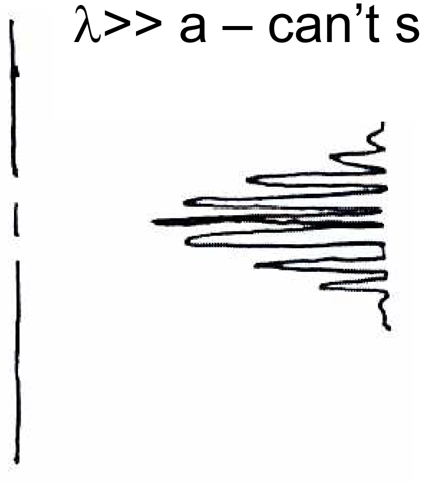
minima: $\sin\overset{n\lambda}{\theta} = \frac{n\lambda}{a}$,
n = ±1, ±2, ±3, …

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