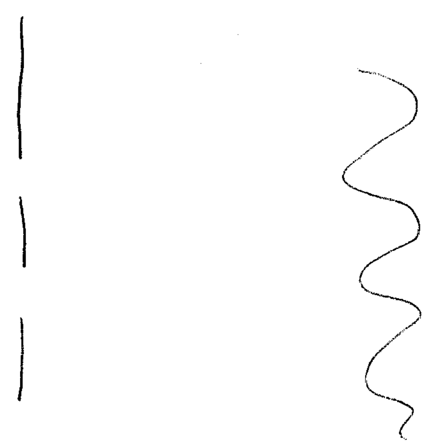
PHYSICS 248 Lecture 12   Gary Shiu   2/23/07

Wave - Particle Duality

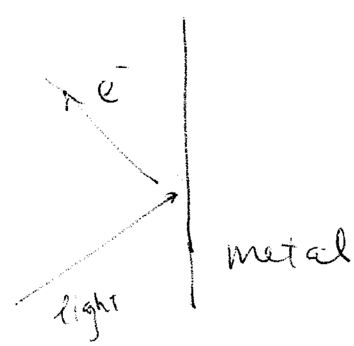
We have seen that light is a wave, e.g.

2-slit interference



But various experiments in the early 1900s suggested that energy of light is quantized

Photoelectric effect



$$K_{electron} = h\nu - \phi$$

h = Planck constant

$= 6.63 \times 10^{-34}$ Js

ν = frequency

Also <u>Blackbody radiation</u>

$$U(\nu) = \text{constant} \frac{\nu^3}{e^{h\nu/kT} - 1}$$

Both experiments suggested strongly that light consists of particles:

$$\boxed{E = h\nu}$$

This suggests that ;

light can be both a wave & a particle. It gives up energy in discrete steps

$$E = h\nu = \hbar\omega \qquad \left(\hbar = \frac{h}{2\pi}\right)$$

Relativity

$$p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$$

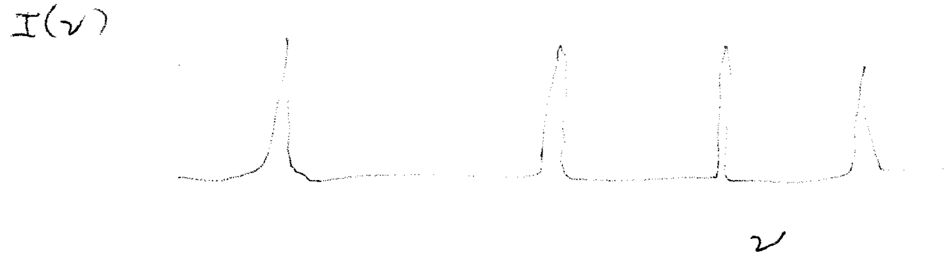
<u>Wave - particle duality</u> (de Broglie)

If light can have both wave - particle properties, why not matter ?

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

de Broglie wave length

Atomic Spectra

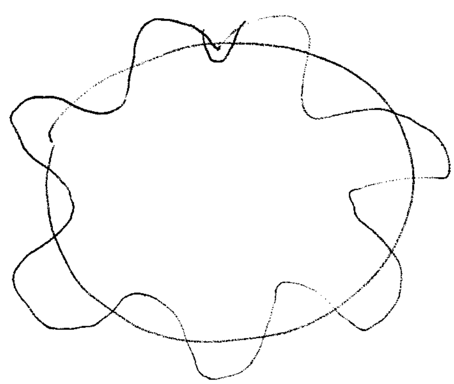


only discrete wavelengths are emitted (lab this week)
as if the electrons in an atom have only
certain resonance frequencies (just like guitar strings)

Idea: old quantum theory (Bohr)

electrons in atoms are represented by standing waves:

e^- orbits around nucleus



Assume $L = n\hbar$

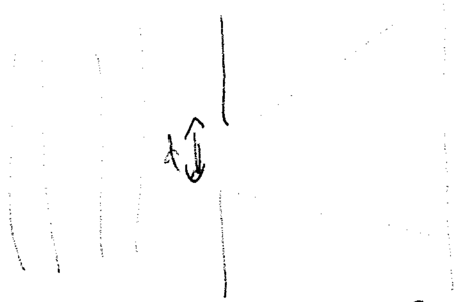
$$mvr = n\hbar$$

$$2\pi r = \frac{n\hbar \cdot 2\pi}{mv}$$

$$= \frac{nh}{p} = n\lambda$$

How come we don't see the wave nature of particles in everyday life?

Recall:



Screen

$$\sin\theta = \frac{\lambda}{d}$$ ← size of slit

if $\frac{\lambda}{d} \ll 1$ no diffraction

$\frac{\lambda}{d} \simeq 1$ diffraction

$$\boxed{\text{Need to compare } \lambda \text{ with typical size of system}}$$

<u>Example</u> Ping Pong ball

$m = 2g \quad v = 5 m/s$

$$\lambda = \frac{6.63 \times 10^{-34} Js}{(2.0 \times 10^{-3} kg)(5 m/s)} = \underbrace{6.6 \times 10^{-23} nm}_{\text{incredibly small!}}$$

Example An electron with kinetic energy $\simeq 10\,eV$

$$E = \frac{1}{2}mv^2 = \frac{p^2}{2m} \simeq 10\,eV$$

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$$

$$= \frac{6.63\times10^{-34}\,Js}{\sqrt{2\times\left(0.511\frac{MeV}{c^2}\right)(10\,eV)}}$$

$c = 3\times10^{8}\,m/s$

$$= \frac{6.63\times10^{-34}\,Js \times c}{\sqrt{2\times5.11\times10^{6}\times(1.6\times10^{-19}\,J)^2}}$$

$$= 3.88\,\mathring{A}$$

$(1\,\mathring{A} = 10^{-10}\,m)$
= atomic scale

More conveniently, we express everything in eV

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{hc}{\sqrt{2mc^2E}}$$

$$= 2\pi\frac{\hbar c}{\sqrt{2mc^2E}}$$

mc^2 & E are expressed in units of eV

$$\hbar c = \frac{6.626\times10^{-34}\,Js}{2\pi}\times 2.9979\times10^{8}\,m/s$$

$$= 1973\,eV\,\mathring{A}$$

eV = typical energy scale
$\mathring{A}$ = typical atomic scale