Learning Objectives

1. Revise- Heisenberg's Uncertainty Principle

2. Particle-Wave duality

3. Wave nature of electron

4. What is quantum mechanics?

References: 1) Quantum Physics by H.C. Verma
2) Concepts of Modern Physics by Arthur Beiser
3) Feynman lectures on Physics, vol1, Chapter 37

$$\Delta x \Delta v \geq \frac{h}{4\pi m}$$

More formulations

Position but not speed   Speed but not position

$$\Delta E \Delta t \geq \frac{h}{4\pi}$$

one cannot measure the precise energy of a system in a finite amount of time

Quantum Physics: Richard Feynman

It is the description of behaviour of material at atomic scale. Things on a very small scale behave like nothing that you have any direct experience about. They do not behave like waves, not like particles, not like clouds, not like billiard balls, not like springs, or anything that you have ever seen.

Because atomic behaviour is so unlike ordinary experience, it is very difficult to get used to and it appears peculiar and mysterious to everyone, both to the beginner and experienced physicist. Even the experts do not understand it the way they would like to, and it is perfectly reasonable that they should not, because all of direct human experience applies to large objects.

Quantum Physics: Dual behaviour of particle

Let's start with some terms

Particle

Ball, person, or point like objects called particles.

They can be located at a space point at a given time.

They can be at rest, moving or accelerating.

Falling Ball
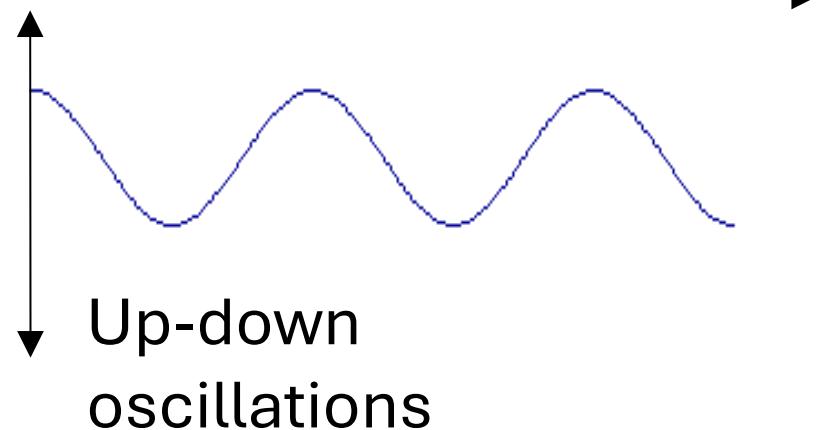
Ground level

Wave

ocean waves, sound waves, radio waves.

Direction of travel, velocity

Up-down oscillations
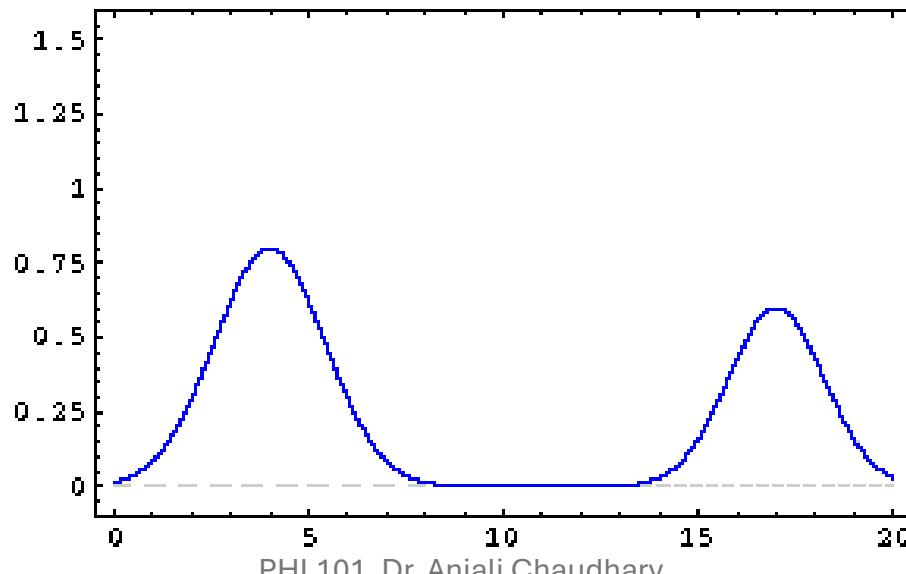
Quantum Physics: Dual behaviour of particle
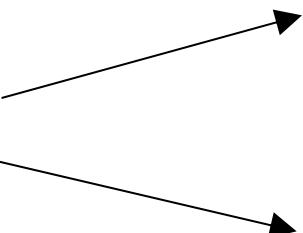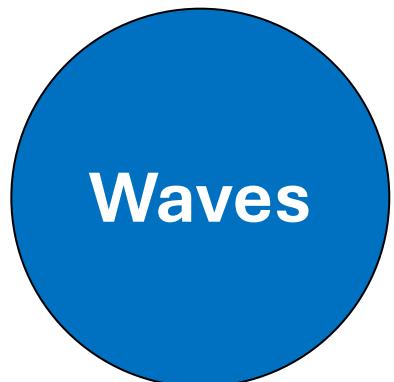
Particle: collision

Wave: collision
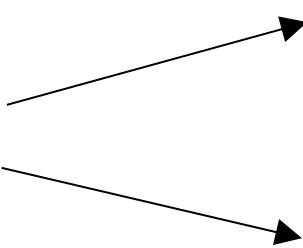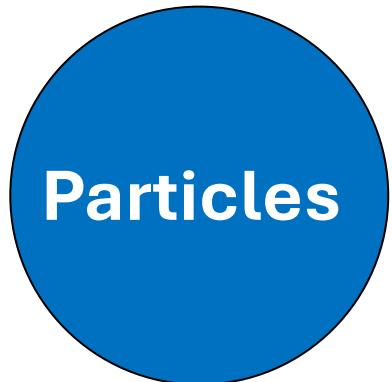
Quantum Physics: Dual behaviour of particle

Wavelength   Frequency

Waves

Spread in space and time

Can be superposed – show interference effects

Pass through each other

Particles

Localized in space and time
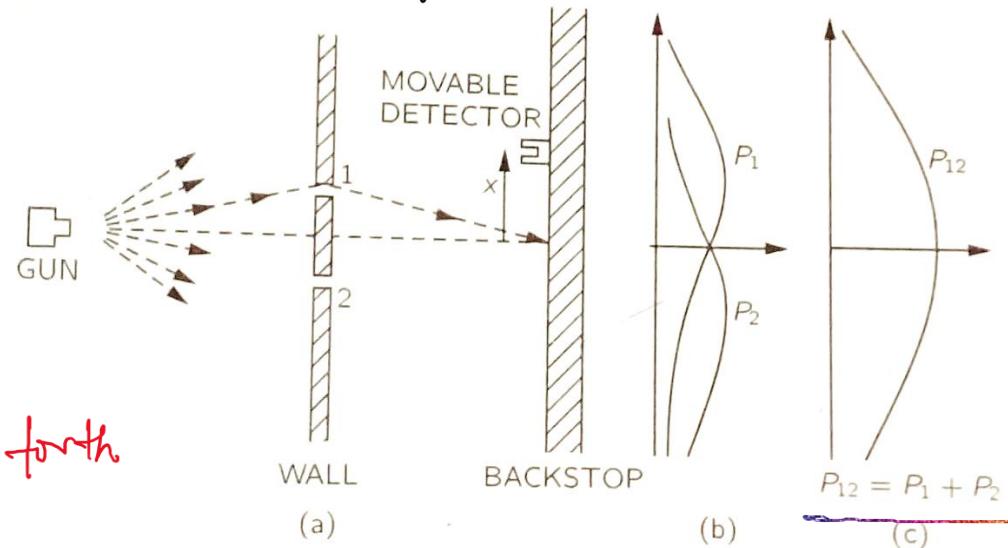
Cannot pass through each other - they bounce or shatter.

Double slit experiment: with bullets (particle)

- Gun sprays bullet randomly
- holes 1 and 2 are big enough to let a bullet through
- backstop - absorb the bullet
- detector - say box of sand any bullet that enters detector will be stopped and accumulated.
- detector can be moved back and forth

interference experiment

MOVABLE DETECTOR

GUN

WALL

BACKSTOP

P_1

P_2

P_{12}

$P_{12} = P_1 + P_2$

(a)

(b)

(c)

What is the probability that a bullet which passes through holes in the wall will arrive at the backstop at a distance "x" from the center?

$P_1 \rightarrow$ probability of passing a bullet through hole 1 when 2 is closed

$P_2 \rightarrow$ probability of passing a bullet through hole 2 when 1 is closed

$$P_{12} = P_1 + P_2$$

Ref. Feynman lectures, Vol. I, Chapter - 37.

Double slit experiment: with wave

interference experiment
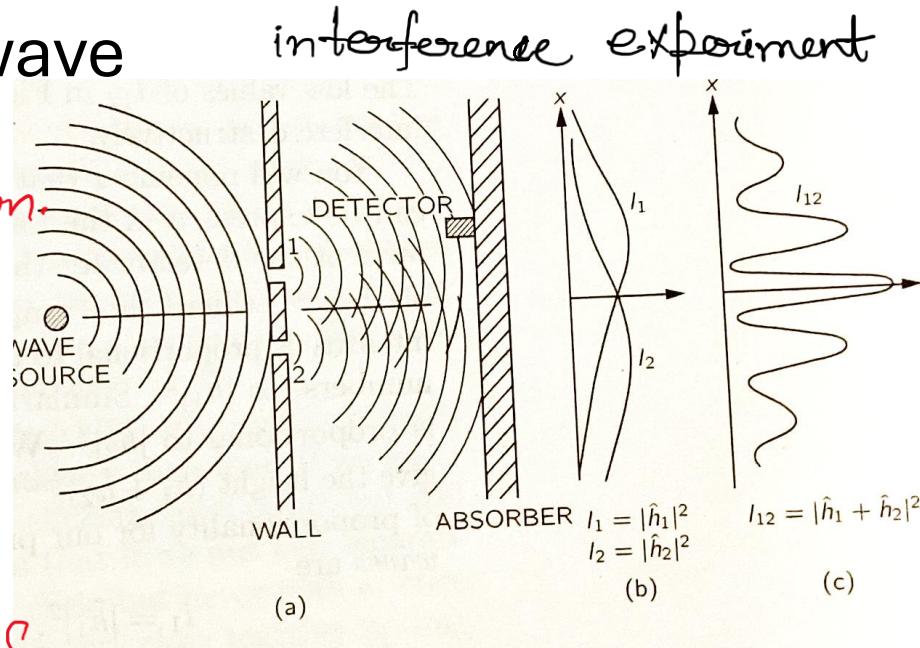
- sand beach
- detector — measure height of wave motion.
- intensity is proportional to square of actual height.

$$I_1 = |\hat{h}_1|^2 \qquad I_2 = |\hat{h}_2|^2$$

$$I_{12} = |\hat{h}_1 + \hat{h}_2|^2$$

$$= |\hat{h}_1|^2 + |\hat{h}_2|^2 + 2|\hat{h}_1||\hat{h}_2|\cos\delta$$

$$= I_1 + I_2 + \boxed{2\sqrt{I_1 I_2}\,\cos\delta} \longrightarrow \text{interference term}$$

of
property of wave

DETECTOR

WAVE SOURCE

WALL   ABSORBER $I_1 = |\hat{h}_1|^2$ $I_{12} = |\hat{h}_1 + \hat{h}_2|^2$
                          $I_2 = |\hat{h}_2|^2$

(a)   (b)   (c)

Ref.: Feynman lectures on Physics, vol1
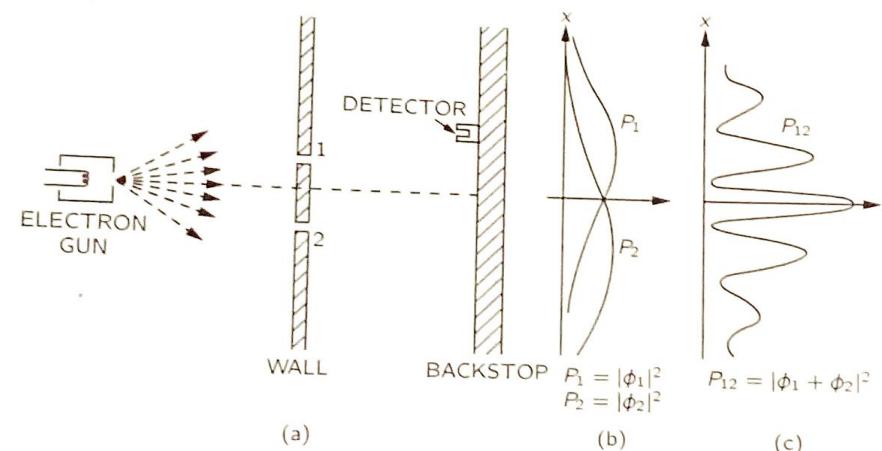
Do you notice any such thing inside the campus?

Quantum Physics: Dual behaviour of particle

Double slit experiment: with electron (Young's thought experiment)

- e^- are particles
- but they show interference pattern similar to waves

Dual behavior of particle

For electron $P_{12} \neq P_1 + P_2$

Particle: particle and wave nature..HOW??

Particle (or matter) wave

$\lambda = \dfrac{h}{p}$, p is momentum

This λ is deBroglie's wavelength.

Photons and footballs both follow the same relation.

1. Wavelength of football

Momentum :mv =(0.4kg)(30 m/s)= 12 kgm/s

$\lambda = \dfrac{h}{p}$**=?**

2. Wavelength of electron

$\lambda = \dfrac{h}{p}$ …. need to know p for electron

Particle: particle and wave nature..HOW??

Particle (or matter) wave

$\lambda = \dfrac{h}{p}$, p is momentum

This λ is deBroglie's wavelength.

Photons and footballs both follow the same relation.

1. Wavelength of football

Momentum :mv =(0.4kg)(30 m/s)= 12 kgm/s

$\lambda = \dfrac{h}{p}$= 5.5X10^{-26} nm.....***wavelength of football too small to be seen***

2. Wavelength of electron

$\lambda = \dfrac{h}{p}$ .... need to know p for electron

Quantum Physics: Dual behaviour of particle

2. Wavelength of electron $\quad\lambda = \dfrac{h}{p}$ …. . need to know p for electron
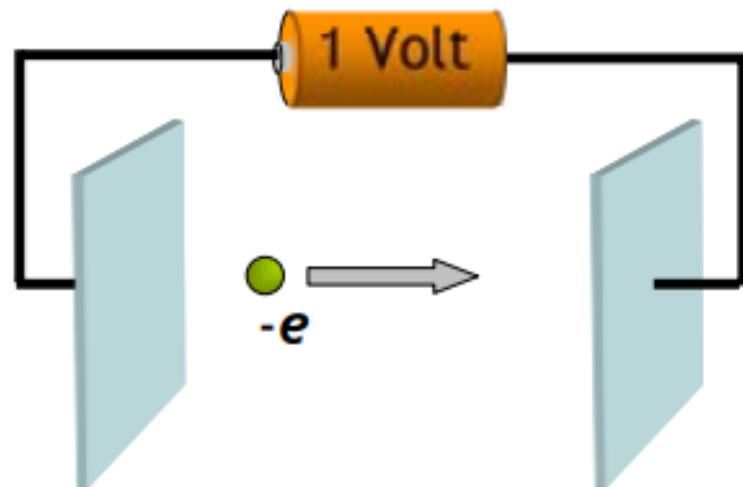
How electrons move???

Electron is a charged particle.
Electric field accelerates electron
Work done on electron is (charge)X(voltage applied)
Work done is also change in K.E. of electron

So (charge)X(voltage) $= \dfrac{1}{2}mv^2$ = K.E. ($E_{kinetic}$)

p= mv (non- relativistic),,,,v<<c, ***will discuss it when we study relativity***

p= $\sqrt{2mE_{kinetic}}$

$\lambda = \dfrac{h}{\sqrt{2mE_{kinetic}}}$ (non- relativistic)

Quantum Physics: Dual behaviour of particle

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Try some examples for electron, mass of electron =9.1X10^{-31} kg

1. 100 eV electron

2. 1 eV electron

3. 10eV electron

4. 100 eV proton

Quantum Physics: Dual behaviour of particle

So (charge)X(voltage) = $\frac{1}{2}mv^2$ = K.E. ($E_{kinetic}$)

p= mv (non- relativistic),,,,v<<c

p= $\sqrt{2mE_{kinetic}}$

λ = $\frac{h}{\sqrt{2mE_{kinetic}}}$ (non- relativistic)

Try some examples for electron, mass of electron =9.1X10^{-31} kg

1. 100 eV electron, λ=0.12 nm

2. 1 eV electron, λ=1.23 nm

3. 10eV electron, λ=0.39 nm

4. 100 eV proton, λ=2.9 pm

Quantum Physics: Dual behaviour of particle

Light: wave and particle nature..HOW??

$$E = hf = \frac{hc}{\lambda} = \frac{1240\ eV - nm}{\lambda} \qquad p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$$

- Has energy and momentum

- Applies to all electromagnetic radiation

- Light exhibits both wave and particle characteristics but not both at the same time

Atomic structure: Bohr's model-shortcomings

1) uncertainty principle, 2) dual behaviour of particle

concepts of quantum mechanics

- **<u>Quantum mechanics</u>** is a science that deals with the study of the motions of the microscopic objects that have both observable wave like and particle like properties.

- It specifies the laws of motion that these objects obey.

- *When quantum mechanics is applied to macroscopic objects (for which wave like properties are insignificant) the results are the same as those from the classical mechanics.*

Quantum Mechanics: What have we learnt so far??

1. Wave-particle duality

2. All waves can possess particle like nature

3. All particles are associated with matter waves (de Broglie's wavelength)

4. de Broglie's wavelength ($\lambda = \frac{h}{p}$)significant for microscopic particles

Always be happy and grateful