Unit IV

Quantum Mechanics

1) Introduction
2) Need of Quantum Mechanics (QM)
3) Photoelectric Effect
4) Concept of de-Broglie Matter Wave

Introduction

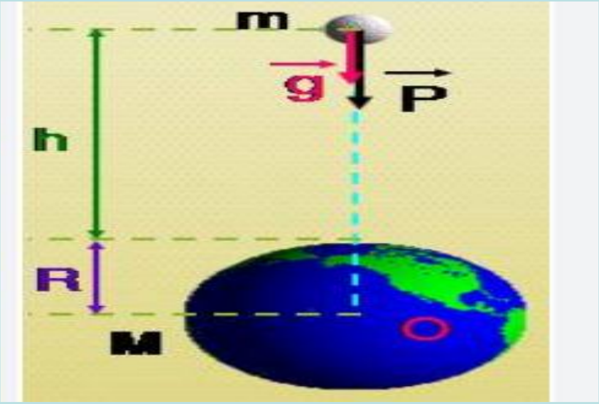
Classical mechanics deals with the question of how an macro-object moves when it is subjected to various forces, and also with the question of what forces act on an object which is not moving.

Uses: The laws of classical mechanics enable us to calculate the trajectories of bullets and baseballs, planets and space vehicles.

Fails to Explain

1) in which an object moves with a velocity comparable with the velocity of light (But solved by Einstein's Theory of Relativity)

2) phenomena on the atomic scale. (But can be solved by Quantum Mechanics)

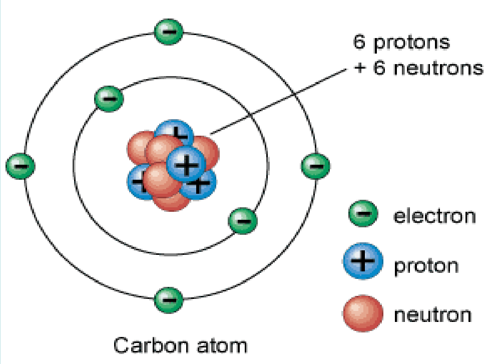


Falling Body

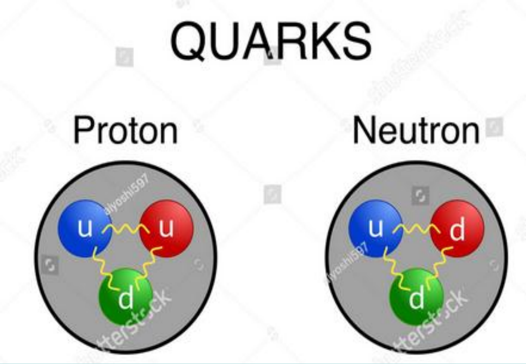

Simple Pendulum

Quantum Mechanics

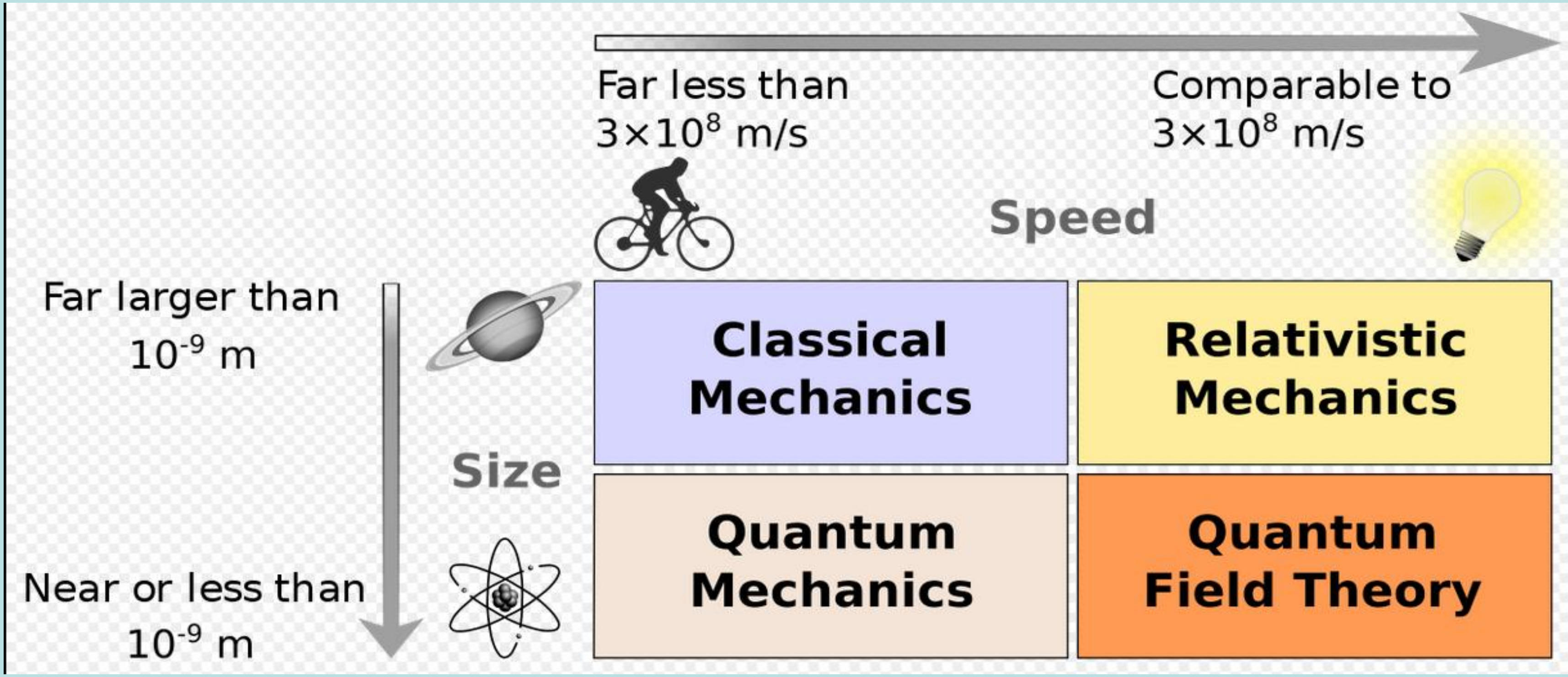
- Quantum mechanics was initially invented because classical mechanics, thermodynamics and electrodynamics provided **no means to explain the properties of atoms, electrons, and electromagnetic radiation**.



Electron is an elementary particle, but Proton and neutrons made of quarks



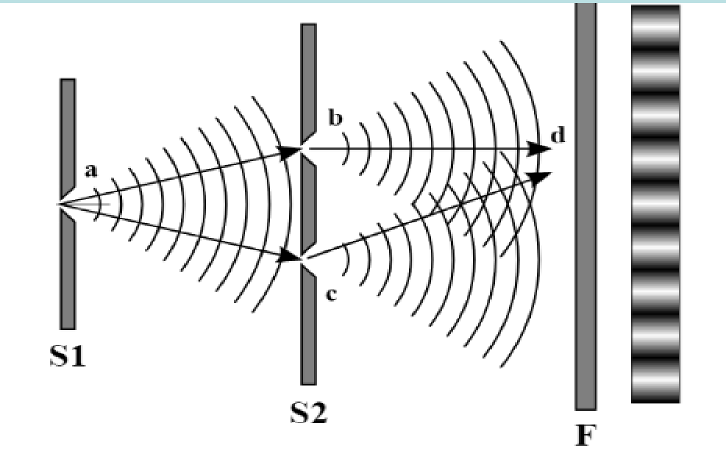
- The first evidence that classical physics was incomplete appeared in unexpected properties of electromagnetic spectra.
- Thin gases of atoms or molecules emit **line spectra which contradict the fact that a classical system of electric charges can oscillate at any frequency,** and therefore can emit radiation of any frequency. This was a major scientific puzzle from the 1850s until the inception of the Schrodinger equation in 1926.



quantum field theory, physical principles combining the elements of QM with those of relativity to explain the behavior of subatomic particles and their interactions via a variety of force fields. Two examples of modern quantum field theories are QED (Quantum Electrodynamics), describing the interaction of electrically charged particles and the electromagnetic force, and QCD (Quantum Chromodynamics), representing the interactions of quarks and the strong force.

Dual Nature of Light

For Particle Nature: Newton's corpuscular theory of light: In 1672, Newton's gave the corpuscular theory of light which states that light is made up of small discrete particles called "corpuscles" (little particles) which travel in a straight line with a finite velocity. This theory was unable to explain the interference , diffraction , polarization phenomena which leads to the wave theory of light

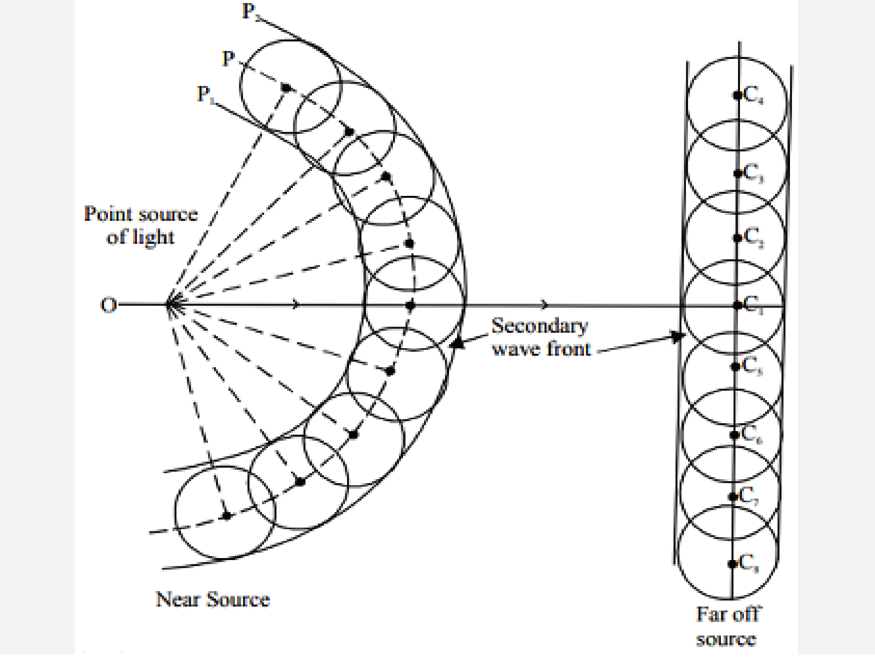


Interference of Light

Diffraction of Light

Introduction

Huygens wave theory of light: In 1678, Christian Huygens gave the wave theory of light. Huygens stated that an expanding sphere of light behaves as if each point on the wave front were a new source of radiation of the same frequency and phase.

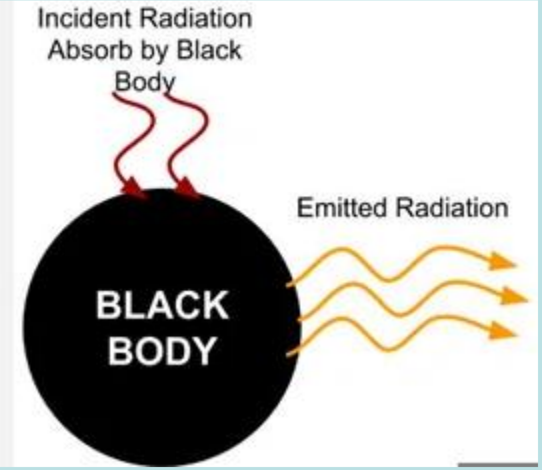


Electro magnetic theory of light

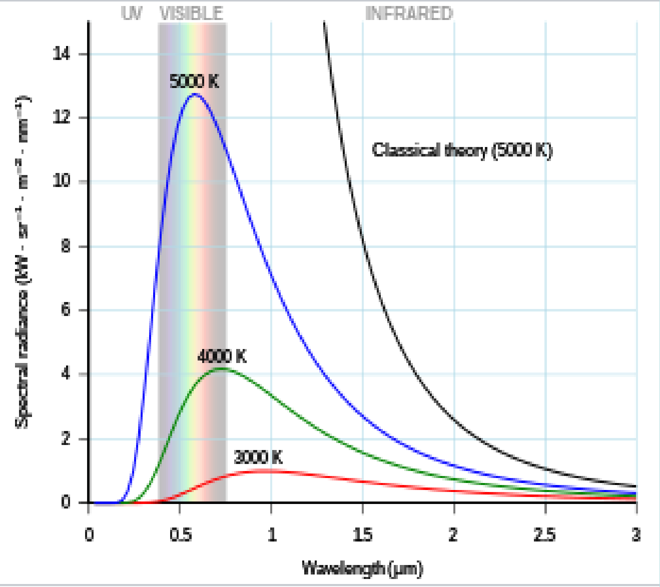
In the early 1860, Maxwell pioneered the electromagnetic theory of radiation and established four famous equations theoretically and calculated the velocity of the E M wave.

Quantum mechanics

It originates in 1900. Max Planks sir presented a paper on Black body radiation. A **black body** or **blackbody** is an idealized physical body that absorbs all incident EM radiation. The name "black body" is given because it absorbs all colors of light. A black body also emits black body radiation.



Classical Theory fails because this spectrum was not verified with the classical theory. It was explained by considering the EM radiations as a quanta (E=hv) of energy called as Photon particle. From here Quantum mechanics originates



Photoelectric Effect

Albert Einstein in 1905 explained the phenomenon in which electrically charged particles are released from or within a material when it absorbs EM radiation. The effect is often defined as the ejection of electrons from a metal plate when light falls on it.

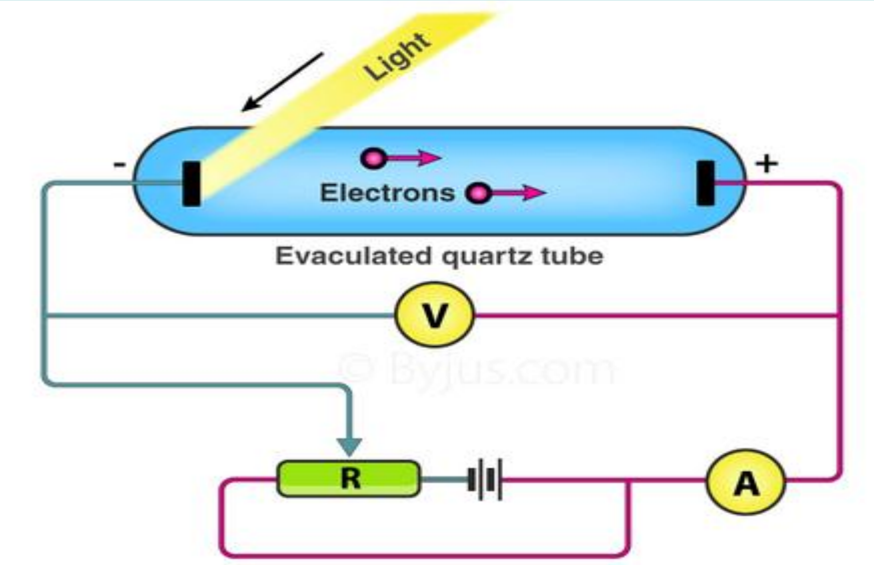
Note: In a broader definition, the radiant energy may be IR, visible, or UV light, X-Rays, or gamma rays; the material may be a solid, liquid, or gas; and the released particles may be ions (electrically charged atoms or molecules) as well as electrons.

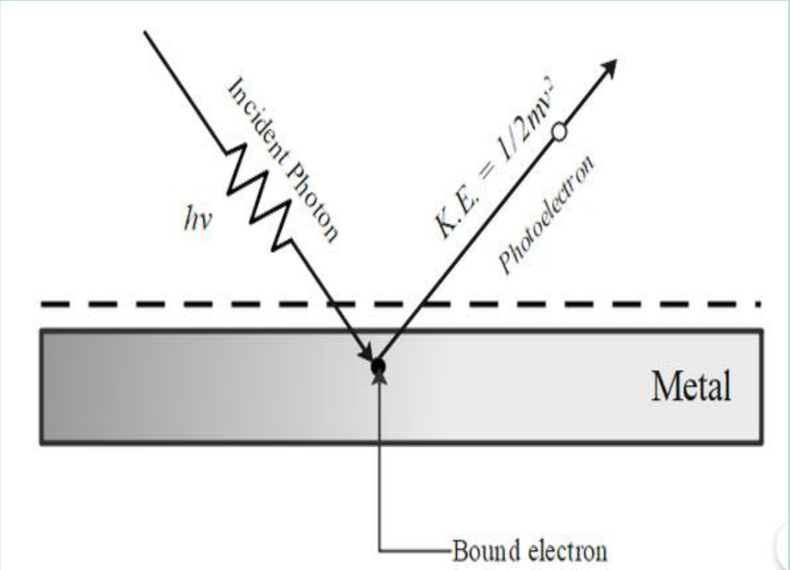
Photoelectric Effect

The main points of Einstein's theory of the photoelectric effect are:

The interaction between two particles results in photoelectric emission– one a photon of incident radiation and the other an electron of photosensitive metal.

The free electrons are bound within the metal due to restraining forces on the surface. The minimum energy required to liberate an electron from the metal surface is called the work function W_o of the metal.





The remaining energy of the photon is used in impairing kinetic energy to the ejected electron.

Very few (<1%) photons, whose energies are greater than $W_\circ$, capable of ejecting the photons.

By law of the conservation of energy,

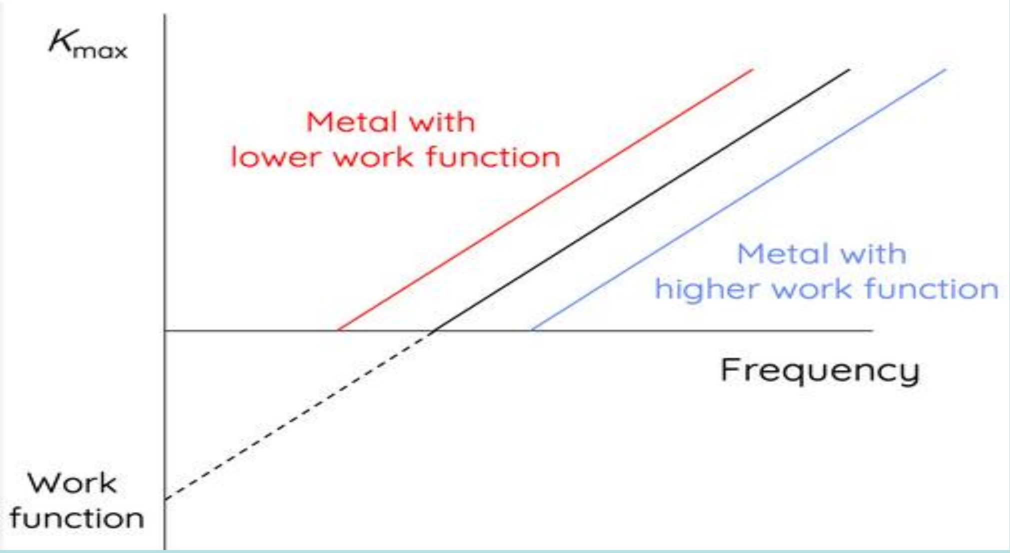
Energy of the incident photon = Maximum K.E. of photon + Work function

$$hv = \frac{1}{2}mv_{\max}^2 + W_\circ$$

$$\therefore K_{\max} = \frac{1}{2}mv_{\max}^2 = hv - W_\circ \cdots\cdots\cdots\cdots (1)$$

If the incident photon is threshold frequency $v_\circ$, then its energy $hv_\circ$ is just sufficient to free the electron from

the metal surface and does not give it any kinetic energy. So $hv_\circ = W_\circ$. Hence



$$K_{\max} = \frac{1}{2}mv_{\max}^2 = hv - hv_\circ = h\left(v - v_\circ\right)\cdots\cdots\cdots(2)$$

Equations (1) and (2) are called Einstein's photoelectric equations.

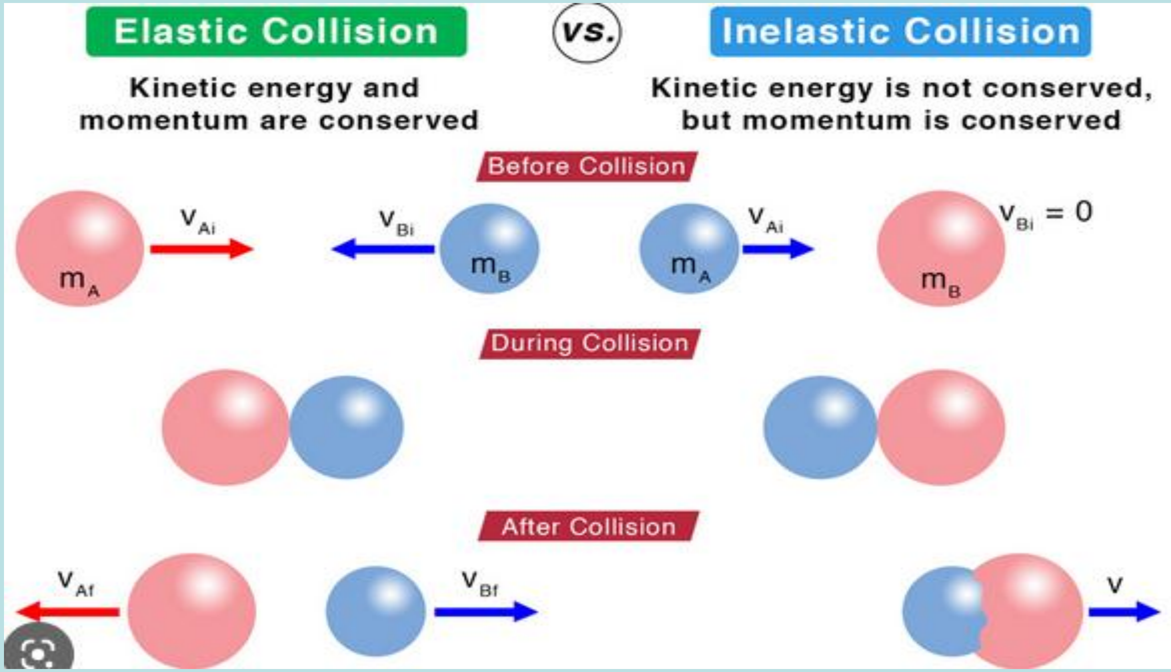
Note: Photoelectric emission is the result of an elastic collision between a photon and an electron. Thus the absorption of energy from a photon by a free electron inside the metal is a single event that involves the transfer of energy in one lump instead of the continuous absorption of energy as in the wave theory of light.

Elastic Collision: An elastic collision is **a collision in which there is no net loss in kinetic energy in the system as a result of the collision**. Both momentum and kinetic energy are conserved quantities in elastic collisions.

A useful special case of elastic collision is when the two bodies have equal mass, in which case they will simply exchange their momenta.

An inelastic collision is such **a type of collision that takes place between two objects in which some energy is lost**. In the case of inelastic collision, momentum is conserved but the kinetic energy is not conserved.

In collisions of macroscopic bodies, some K.E. is turned into vibrational energy of the atoms, causing a heating effect, and the bodies are deformed.



Typical Values of the Work Function for Some Common Metals	
Metal	**ϕ (eV)**
Na	2.46
Al	4.08
Pb	4.14
Zn	4.31
Fe	4.50
Cu	4.70
Ag	4.73
Pt	6.35

Numerical on Photoelectric effects

A radiationof wavelength 300 *nm* is incident on a silver surface. Will photoelectrons be observed?

Solution:

Energy of the incident photon is

$E = h\nu = hc/\lambda$ (in joules)

$E = hc/\lambda e$ (in eV)

Substituting the known values, we get

$E = 6.626\times10^{-34} \times3\times10^{8} / 300\times10^{-9} \times1.6\times10^{-19}$

$E = 4.14\ eV$

From Table 7.1, the work function of silver = 4.7 *eV*. Since the energy of the incident photon is less than the work function of silver, photoelectrons are not observed in this case.

de-Broglie wave/matter waves

- Louis de Broglie in 1924 suggests that any moving particle either microscopic or macroscopic will be associated with wave character, that is known as matter waves and associated wavelength

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

$$\lambda = wavelength$$
$$h = Planks\ constant$$
$$v = velocity\ of\ particle$$

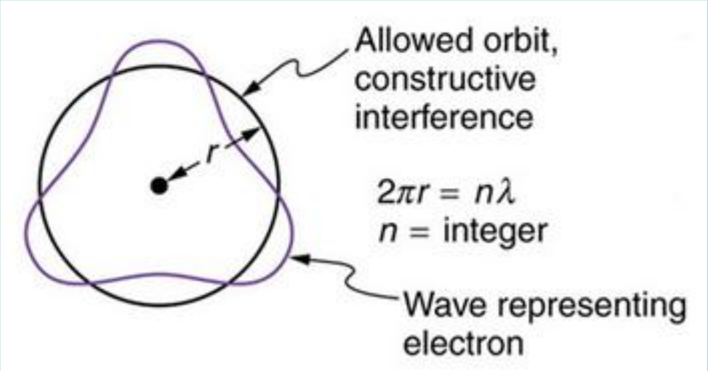
$$\lambda = \frac{h}{p} \qquad (p = mv)$$

$$h = 6.626\,7015 \times 10^{-34} J\ \mathrm{Hz}^{-1}$$

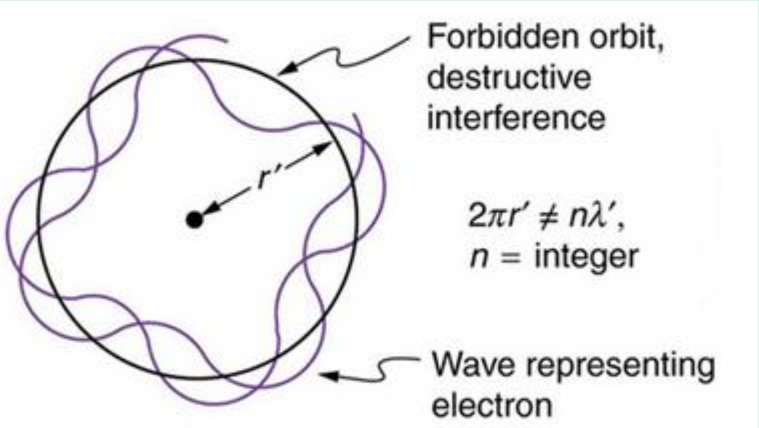
- Equation suggests that the de Broglie wavelength of a particle is inversely proportional to its momentum.
- de Broglie applied the concept of matter waves to the structure of the atom. He postulated that electrons orbit the nucleus as **standing waves** (stationary waves).

- de-Broglie explained that when moving electrons in orbit behave as standing waves, they no longer emit energy in the form of radiation (since this applies to particles). Therefore, de Broglie's matter wave theory provided an explanation for Bohr's first postulate that electrons orbit the nucleus in 'stationary states' and do not emit energy.

Quantization of Orbits: Allowed orbits are those orbits in which an electron constructively interferes with itself. Not all orbits produce constructive interference.



Constructive interference



Destructive interference

Derivation

According to plank’s theory energy of an electromagnetic wave

$$E = hv = \frac{hc}{\lambda} \qquad (1)$$

And according to Einstein energy of the photon

$$E = mc^2 \qquad (2)$$

De-Broglie equated both of these energy equations for a particle moving with velocity v and have mass m

$$E = \frac{hc}{\lambda} = mv^2 \longrightarrow h/\lambda = mv$$

$$\lambda = h/mv$$

This is de-Broglie equation

Thank You……