Applied Physics

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APPLIED PHYSICS: Course Syllabus

- Crystal Structures [CO1 - Apply]
- **Quantum Physics [CO2 - Apply]**
- Lasers and Fiber Optics [CO3 & CO4 - Understand]
- Magnetic & Superconducting Properties [CO5 - Understand]
- Nanotechnology [CO6- Understand]

MODULE - 2

QUANTUM PHYSICS

TOPICS IN QUANTUM PHYSICS

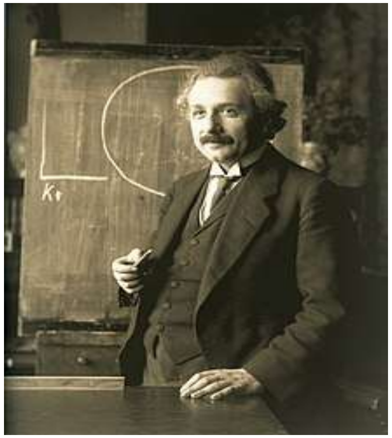
- Introduction to quantum physics
- Wave Particle Duality-de-Broglie's hypothesis
- Davisson and Germer experiment,
- Time-independent Schrodinger equation for wave function,
- Physical significance of the wave function,
- Schrodinger equation for one dimensional problems.

Introduction to Quantum Physics

Niels Bohr and Max Planck, two of the founding fathers of Quantum Theory, each received a Nobel Prize in Physics for their work on quanta. **Albert Einstein** is considered the third founder of Quantum Theory because he described light as quanta in his theory of the Photoelectric Effect, for which he won the 1921 Nobel Prize.

Niels Bohr

Max Plank



Albert Einstein

Quantum physics explains the behaviour of matter and radiation at the microscopic (atomic) level.

The laws of Quantum Mechanics:-

Within a few short years scientists developed a consistent theory of the atom that explained its fundamental structure and its interactions. Crucial to the development of the theory was new evidence indicating that **light and matter have both wave and particle characteristics** at the atomic and subatomic levels.

Theoreticians had objected to the fact that Bohr had used an hybrid of classical Newtonian dynamics for the orbits and some quantum postulates to arrive at the energy levels of atomic electrons. The new theory ignored the fact that electrons are particles and treated them as waves. **By 1926 physicists had developed the laws of quantum mechanics, also called wave mechanics, to explain atomic and subatomic phenomena.**

INTRODUCTION

- Newtonian Mechanics, Maxwell's Electro Magnetic Theory and Thermodynamics constitute the classical physics.

Some assumptions are

- Energy is continuous
- Position and Momentum of a particle can be determined exactly.
- If a charge oscillates with a constant frequency, it produces an EM wave of same frequency ν

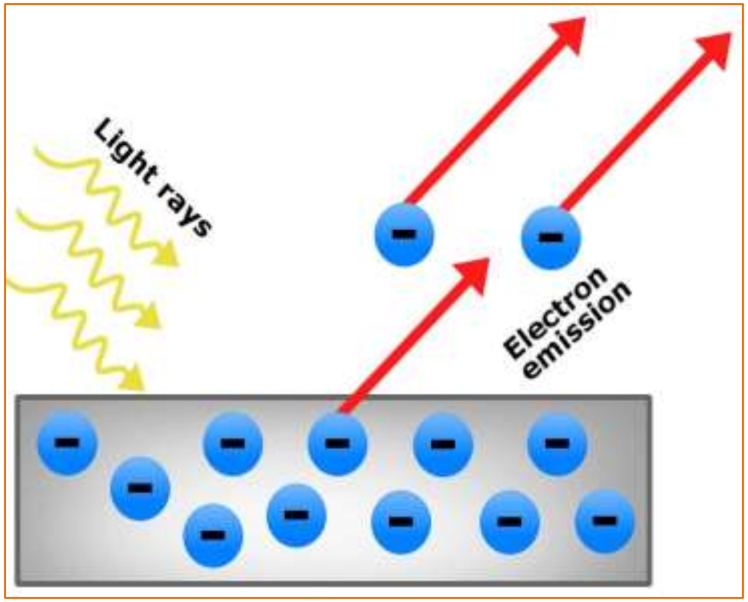
INTRODUCTION

Classical Physics failed to explain

- Stability of atoms
- Origin of discrete spectra of atoms.
- The spectrum of black body radiation
- The photo electric effect.

PHOTO ELECTRIC EFFECT

- When light is incident on certain metallic surfaces, electrons are released. These are called **photo electrons.**
- The effect is called **photo electric effect.**
- The photo electric effect was first observed by Heinrich Hertz in 1887 and was studied in detail by his student, Phillipp Lenard.

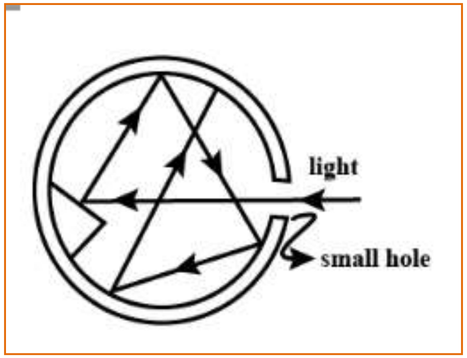


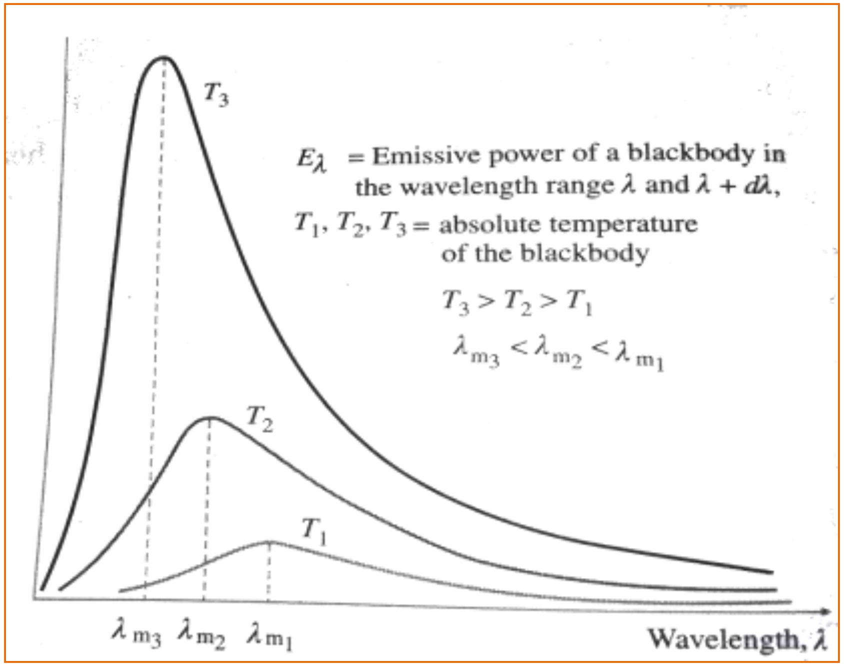
BLACK BODY RADIATION

A body which absorbs all the radiations falling on it is a black body.

❖When a black body is heated it radiates energy and is called **black body radiation.**

❖A practical realization of a black body is an iso thermal cavity painted with lamp black inside it and contains a small aperture such that light enters the cavity through it.





BLACK BODY RADIATION

Stefan- Boltzmann law:

According to Stefan-Boltzmann the energy radiated is directly proportional to fourth power of the temperature of the body.

$$E \propto T^4$$

Wien's displacement law:

$$\lambda_m T = constant \qquad E_m \propto T^5$$

$$E_\lambda \, d\lambda = C_1 \exp\left(-C_2/\lambda T\right) d\lambda$$

Ray-Leigh Jean's law:

$$E_\lambda \, d\lambda = \frac{8\pi KT}{\lambda^4} d\lambda$$

Planck's Quantum Theory

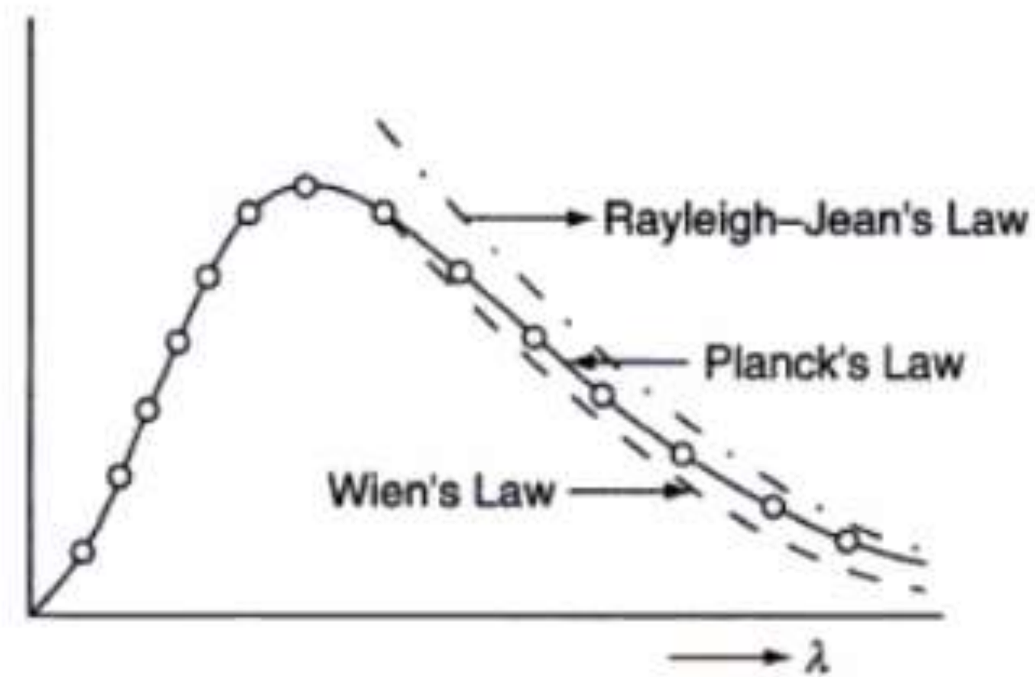
The Assumptions are :

- ❖ The atomic oscillators in a body cannot have any arbitrary amount of energy, they could have only a discrete unit of energy given as
- ❖ Where h is Planck's constant , n is quantum number, ν is frequency
- ❖ The atomic oscillators cannot absorb or emit energy of any arbitrary amount. They absorb or emit energy in indivisible discrete units. The amount of radiant energy in each unit is called a quantum of energy, each quanta carries an energy .

$$E_\lambda \, d\lambda = \frac{8\pi hc}{\lambda^5} \frac{1}{\exp\left(\frac{hc}{\lambda KT}\right) - 1} d\lambda$$

Planck's Quantum Theory

❖ At shorter wavelengths the Planck's quantum theory deduced to **Wein's law** and at longer wavelengths it deduced to **Ray-Leigh Jean's law**

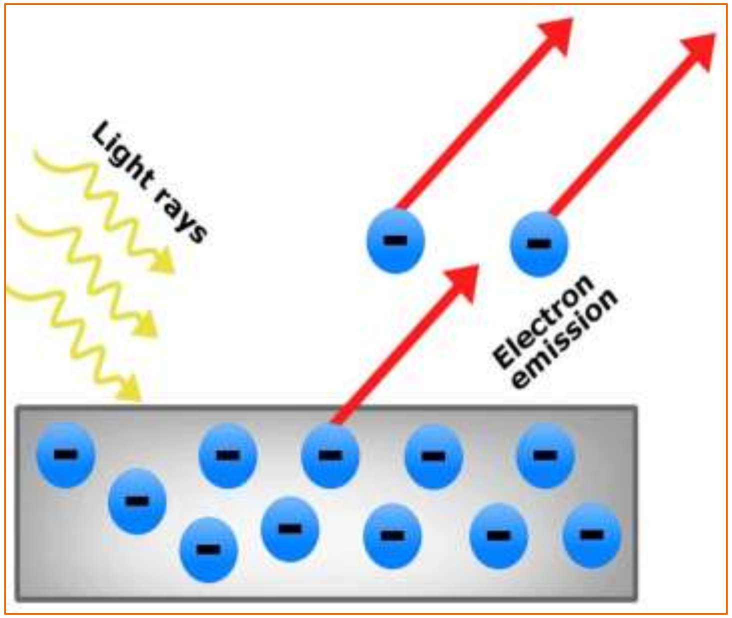


Einstein's Explanation to Photo-Electric Effect

Einstein assumed that light falling on the metallic surface to be a stream of photons, each photon having an energy of hv.

When electrons absorb the photon energy part of it is spent in overcoming potential barrier and the remaining part of energy gives into its kinetic Energy.

So, Energy of photon = Energy needed to liberate electron + Kinetic Energy of the electron.



$$h\nu = W + K.E$$

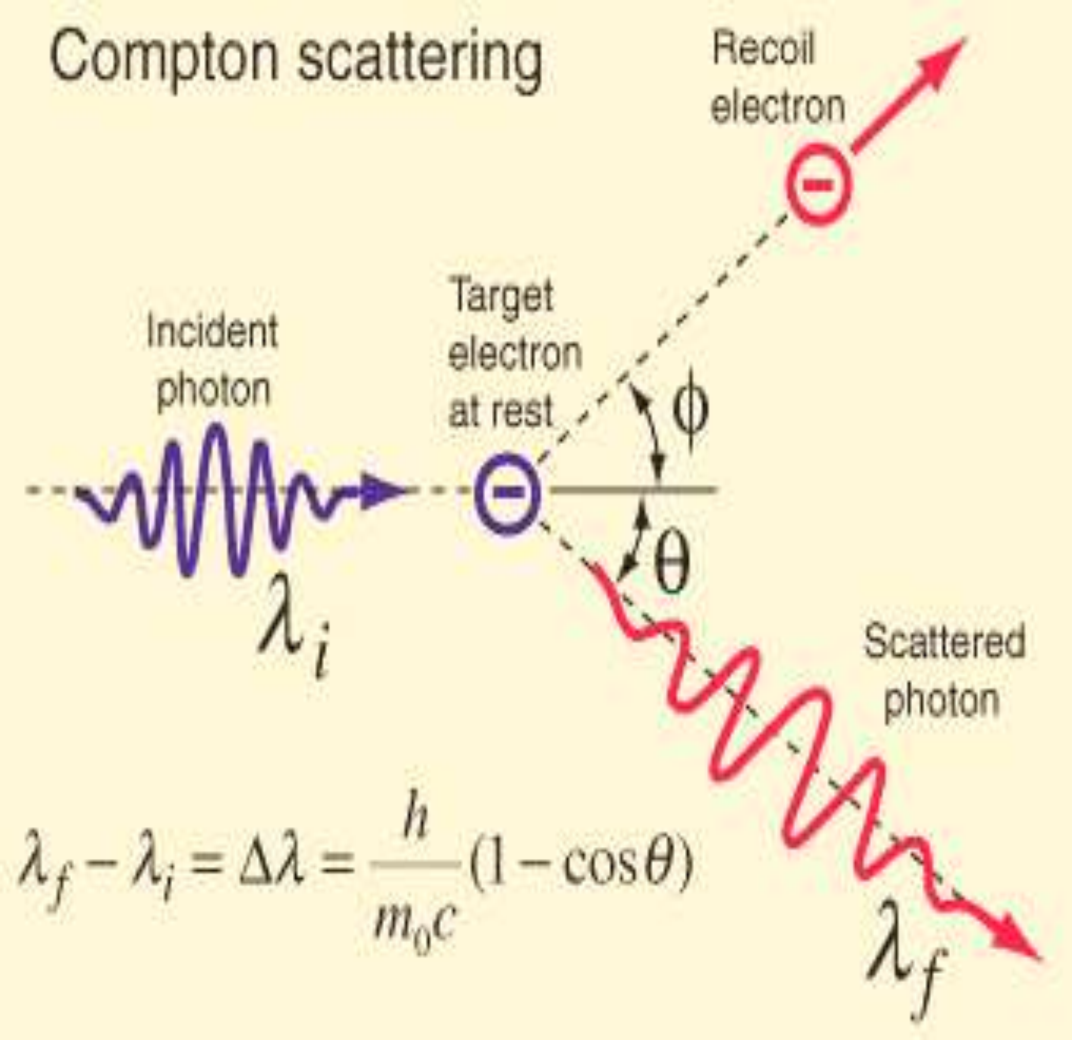
$$h\nu = h\nu_0 + K.E$$

Where $h\nu_0$ is called work function.

Where W is the minimum energy required to remove an electron from the surface of the material. It is called the work function of the surface

COMPTON EFFECT

- It is defined as scattering of a photon by a charged particle like an electron. It results in a decrease in energy of the photon called the Compton Effect. Part of the energy of the photon is transferred to the recoiling electron.




Thank you!

MODULE - II

QUANTUM PHYSICS

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QUANTUM PHYSICS

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Wave-Particle Duality

- Particle: It has mass, it is located at some definite point, and it can move from place to another, it gives energy when slowed down or stopped.

- The particle is specified by (i) mass (m) (ii) velocity (v) (iii) momentum (P) (iv) energy (E).

- The motion of particle can be explained by

$$F = ma$$

Wave-Particle Duality

❖ Wave: A wave is spread out over a relatively large region of space, it cannot be said to be located just here and there. Actually, a wave is nothing but rather a spread out of disturbance.

❖ A wave is specified by its (i) frequency (ii) wavelength (iii) phase or wave velocity (iv) amplitude (v) intensity

❖ Generally, the displacement regarding wave is $y = A \sin\omega t$.

Wave-Particle Duality

- The photo electric effect and the Compton Effect established that light behaves as a flux of photons.

- On the other hand, the phenomena of interference, diffraction and polarization can be explained only when light is treated as a continuous wave.

- Neither of the modes can separately explain all the experimental facts.

- The particle nature and wave nature appear mutually exclusive.

- So, Light exhibits both wave nature and particle nature i.e., called as wave-particle duality.

Debroglie hypothesis:

In 1924, Louis Debroglie put a bold suggestion that the correspondence between wave and particle should not be confined only to electromagnetic radiation, but it should also be valid for material particles i.e., like radiation matter also has a dual (particle like & wave like) characteristics.

According to Debroglie.

- Nature loves symmetry, since energy or radiation exhibits wave particle duality, matter must also possess this dual character.

Debroglie- Wavelength:

•According to Debroglie, a moving particle is associated with a wave which is known as Debroglie wave or matter wave.

The wavelength of matter wave is given by

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

The Proof is as follows

According to Planck's theory the energy E of a photon of frequency v is given by

$$E = h\nu = \frac{hc}{\lambda} \text{ ---------- (1)}$$

Where 'λ' is wavelength of photon

'C' is speed or velocity of light.

If photon is treated as a particle, its energy as given by Einstein's mass-energy relation

$$E = mC^2 \; = \; PC \text{ --------- (2)}$$

From (1) & (2)

$$\frac{\mathrm{hc}}{\lambda} = \mathrm{mC}^2 \Rightarrow \lambda = h/mc \; or \; \lambda = h/p$$

According to Bohr orbital angular momentum is given by

$$mvr = \frac{\text{nh}}{2\pi}$$

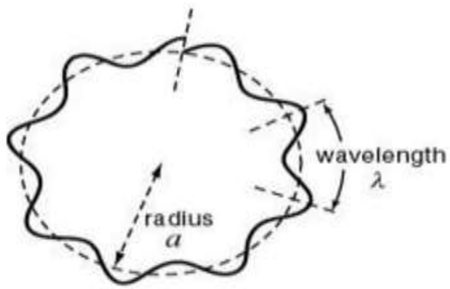
where 'r' is radius of permitted circular orbit, 'n' is integer.

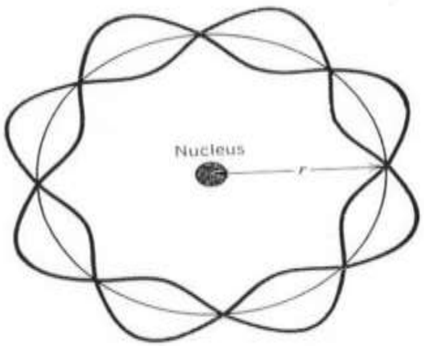
From above equation and 'λ' we have

$$2\pi r = \frac{\text{nh}}{\text{mv}} = n\lambda$$

(2πr) is circumference of electronic orbit.

Thus, the permitted orbits correspond to integral multiples of Debroglie wavelength.





$$\boxed{\begin{array}{l} m_e v r = n\hbar \quad n = 1, 2, 3\ldots \\ \hbar = h/2\pi \end{array}}$$

an integer number of wavelengths fits into the circular orbit

$$\boxed{n\lambda = 2\pi r}$$

where

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

λ is the de Broglie wavelength


Thank you!

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Properties of Matter Waves

❖ The wavelength of matter λ s= h/mv . So, wavelength is inversely proportional to velocity.

❖ A group of waves each wave having wavelength given above, is associated with the particle. This group as a whole must travel with the particle velocity v. Hence group velocity of matter waves= $v_{gr} = v$.

❖ Each wave of the group of matter waves travel with a velocity known as phase velocity of the wave. $v_{gr} \cdot v_{ph} = C^2$

❖ Wavelength of electron: $\sqrt{\frac{150}{V}}$ A^0

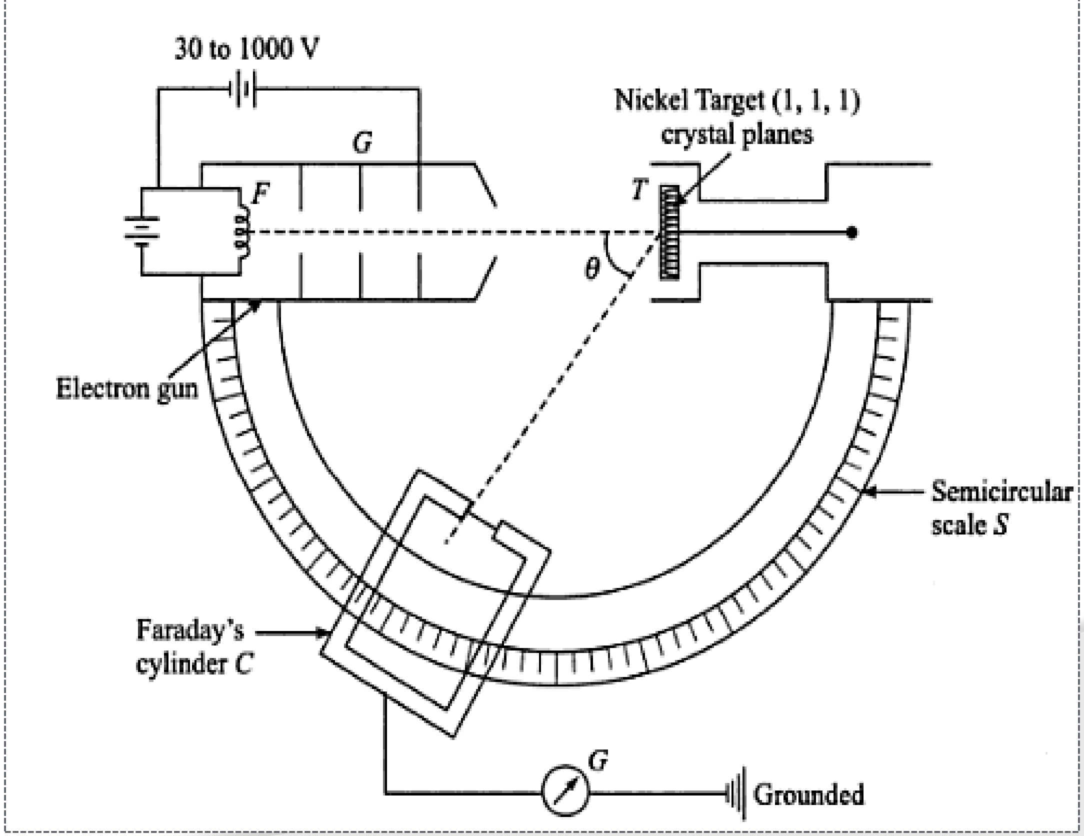
❖ We have to remember that no single phenomena either matter or radiation exhibits both particle nature and wave nature simultaneously.

MATTER WAVE	EM WAVE
Matter wave is associated with a particle.	Oscillating charged particle gives rise to electromagnetic wave.
Wavelength depends on the mass of the particle and its velocity $\lambda = h/mv$	Wavelength depends on the energy of the photon $\lambda = hC/E$
Can travel with a velocity greater than the velocity of light.	Travels with velocity of light.
Matter wave is not electromagnetic wave.	Electric field and magnetic field oscillate perpendicular to each other.
Matter wave require medium for propagation	Electromagnetic waves do not require medium i.e., they travel in vacuum also.

Davisson - Germer's Experiment

Initial atomic models proposed by scientists could only explain the particle nature of electrons but failed to explain the properties related to their wave nature. C.J. Davisson and L.H. Germer, in the year 1927, carried out an experiment, popularly known as Davisson Germer's experiment, to explain the wave nature of electrons through electron diffraction.

Electron gun G
Filament F.
Target T (large single crystal of Ni)
Detector D
Faraday cylinder C
Semi circular Scale S
Galvanometer G

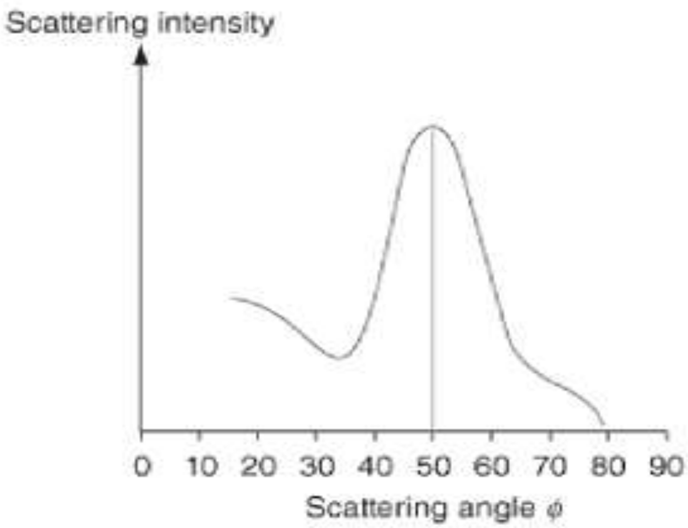


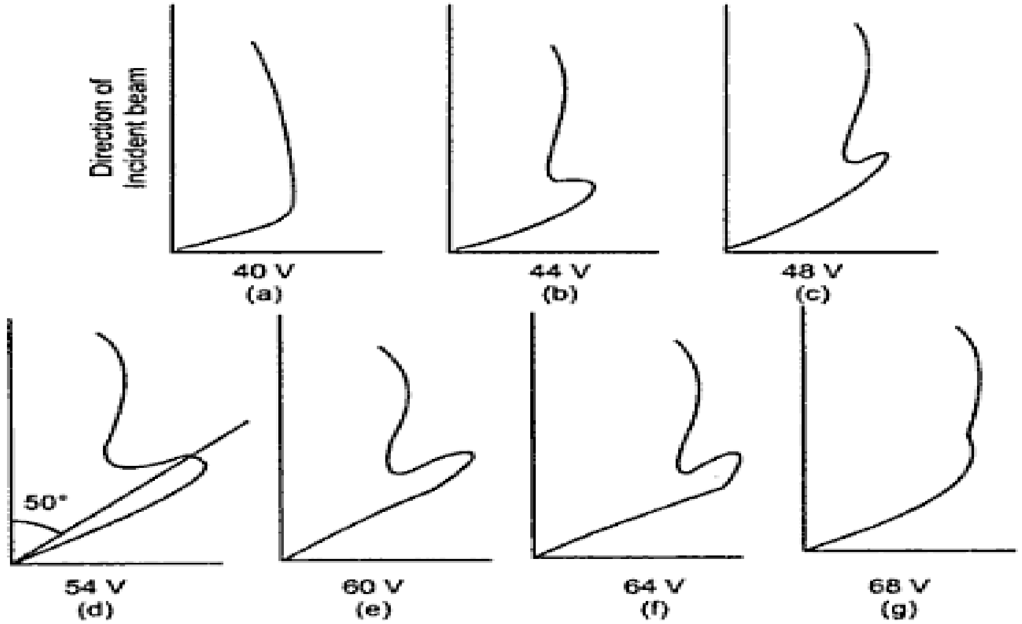
The electrons emitted from gun strikes, the target which is rotated about an axis along the direction of beam.

The speed of the electrons can be measured by the voltage used for accelerating electrons.

The scattered beam is detected by the chamber D and its intensity is measured in different directions.

The plot of the electron beam intensity I versus the angle Φ between the incident and scattered beams show maxima and minima.





The wavelength value depending on V is given as

$$\lambda = \sqrt{\frac{150}{V}}\, A^0 \Rightarrow \lambda = \sqrt{\frac{150}{54}} = 1.67\ A^0.$$

If θ is the correspondence angle of diffraction at the Bragg's plane then θ and Φ are related as $\theta = \frac{180-\Phi}{2}$

So if θ is diffraction angle, n is order of maxima, then from Bragg's law $2d\sin\theta = n\lambda$.

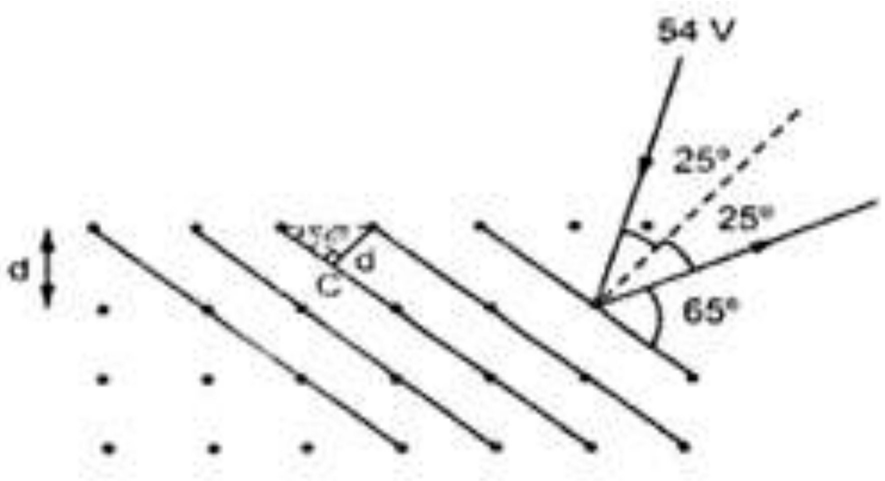
Davisson & Germer observed that maximum diffraction occurs at $\Phi = 50^0$ & $d = 0.91\ A^0$.

Now, $\Phi = 50^0 \Rightarrow \theta = \frac{180-50}{2} = 65^0$.

Therefore, $\lambda = 2d\sin\theta$ {for n=1}

$= > 2 \times 0.91 \times \sin 65$

$= 1.65\ A^0$.



Davisson- Germer's Experiment

So, the values of λ determined in these two ways are in agreement thus confirming the existence of matter waves.

The drawback of this experiment is that whether the diffraction pattern formed is due to electrons or E.M radiation generated by fast moving electrons is not known

De -Broglie Wavelength in terms of Energy

We know that Kinetic energy

$$E = \frac{1}{2} mv^2 \dots\dots (5)$$

$$Em = \frac{1}{2} m^2 v^2$$

$$m^2 v^2 = 2Em$$

$$\sqrt{m^2 v^2} = \sqrt{2Em}$$

$$mv = \sqrt{2Em} \dots\dots (6)$$

E = $\frac{1}{2}\ mv^2$

E = $\frac{1}{2m}\ m^2v^2$

E = $\frac{p^2}{2m} \quad (since\ p = mv)$

$p^2 = 2mE$

p = $\sqrt{2mE}$

λ = $\frac{h}{\sqrt{2mE}} \left(since \quad = \frac{h}{p}\right)$

Substituting in (4)

$$\lambda = \frac{h}{\sqrt{2Em}} \dots\dots (7)$$

de-Broglie's wavelength

$$for\ an\ electron\ with\ Kinetic\ Energy\ 'E'$$

$$accelerated\ by\ a\ Potential\ difference\ 'V'$$

$$Then\quad \lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2meV}}$$

$$substituting\ \ for\ \ h\ ,\ \ m\ ,\ and\ \ e\ \ we\ \ get$$

$$\lambda = \frac{6.625\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times1.602\times10^{-19}\times V}} = \frac{12.26}{\sqrt{V}}\,A$$

$$thus\quad for\quad V = 100\ Volts$$

$$\lambda = \frac{12.26}{\sqrt{100}} = 1.226\ A$$


Thank you!

QUANTUM PHYSICS

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MODULE - I

QUANTUM PHYSICS

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SCHRODINGER TIME INDEPENDENT WAVE EQUATION

- Austrian Scientist, Erwin Schrodinger developed the wave equation of (matter wave or de-Broglie wave) the moving particles whose solutions give the possible wave functions that can be associated with a particle in a given situation.

- This equation is popularly known as Schrodinger wave equation

Schrodinger wave equation is a mathematical expression describing the energy and position of the electron in space and time, taking into account the matter wave nature of the electron inside an atom.

Erwin Schrodinger

SCHRODINGER TIME INDEPENDENT WAVE EQUATION

wave function $\psi = \psi_0 \sin(\omega t - kx)$---------------> (1)

Where $\Psi = \Psi(x)$

Ψ_0 is amplitude,

$k = 2\pi/\lambda$,

$\omega = 2\pi\nu = \frac{2\pi}{T}$,

The **Schrödinger wave equation** is a linear partial differential equation that governs the wave function of a quantum-mechanical system.

SCHRODINGER TIME INDEPENDENT WAVE EQUATION

Now, differentiating (1) with respect to 'x' we get

$$\frac{\partial\Psi}{\partial x} = -K_{\psi 0}\cos(\omega t - kx)$$

$$=> \frac{\partial^2\psi}{\partial x^2} = -K^2{}_{\psi 0}\sin(\omega t - Kx)$$

$$=> \frac{\partial^2\psi}{\partial x^2} = -K^2\ \Psi \text{ [from (1)]}$$

$$=> \frac{\partial^2\psi}{\partial x^2}\ +K^2\,\Psi = 0 \text{ ----------------- (2)}$$

OR

$$=> \frac{\partial^2\psi}{\partial x^2} + \frac{4\pi^2}{\lambda^2}\Psi = 0 \text{ --------------- (3)}$$

SCHRODINGER TIME INDEPENDENT WAVE EQUATION

we know that Debroglie wavelength λ= h/mv

$$\frac{\partial^2\psi}{\partial x^2} + \frac{4\pi^2 m^2 v^2}{h^2}\ \psi = 0 \text{ ------------------- } (4)$$

Now, we know that the total energy E of the particle is sum of its kinetic energy K and potential energy V

Therefore,

E = K + V and K= ½ mv^2 =>

m^2v^2 = 2m (E-V)--------- (5)

From (4) & (5)

$$\frac{\partial^2\psi}{\partial x^2} + \frac{8\pi^2 m(E-V)}{h^2}\Psi = 0$$

The value of h/2π is considered as $\hbar$

Therefore, $\hbar$=h/2π

$$\frac{\partial^2\psi}{\partial x^2} + \frac{2m(E-V)}{\hbar^2}\Psi = 0 \text{ ---------- (6)}$$

This is Schrodinger time independent wave equation in 1-D

In three dimensional it can be written as

$$\frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2} + \frac{2m(E-V)}{\hbar^2}\Psi = 0 \text{ ---------- (7)}$$

Time dependent form of Schrodinger wave equation:

- It is expressed as

$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m} \nabla^2 \Psi + V(\bar{r}, t)\, \Psi$$

Where $\Psi = \Psi(\bar{r}, t)$

$$\vec{r} = x\,\vec{i} + y\,\vec{j} + z\,\vec{k}$$

$$i = \sqrt{-1}$$

(OR)

$\bar{E}\Psi = \bar{H}\Psi$ where $\bar{E} = i\hbar \frac{\partial}{\partial t}$ & $\bar{H} = -\frac{\hbar^2}{2m} \nabla^2 + V(\bar{r}, t)$

PHYSICAL SIGNIFICANCE OF ψ

The actual physical significance was not clear.

Max Born's interpretation of 'Ψ', given in 1926, is generally accepted at present.

As 'Ψ' is a complex function $\Psi^* \Psi = |\Psi|^2$ is a real value.

$|\Psi|^2$ at a point is proportional to the probability of finding the particle at the point at any given instant.

The probability density at any point is represented by $|\Psi|^2$, the probability P of finding the particle within any element of volume dxdydz is given by

$$P = \Psi^* \Psi \, dxdydz$$

Since the total probability of finding the particle somewhere is unity,

Ψ is such a function that satisfies condition

$$\iiint |\psi|^2 \, \mathrm{dxdydz} = 1$$

Ψ satisfying above equation is called a normalized function.

Besides this Ψ is a single valued continuous function.

Characteristics of Wave Function

An acceptable wave function Ψ must be normalized and fulfill the following requirements

- Ψ function must be finite

  The wave function should not tend to infinity. It must remain finite for all values of x, y, z.
- Ψ function must be single–valued

  Any physical quantity can have only one value at a point. For this reason, the function related to a physical quantity cannot have more than one value at that point.
- Ψ function must be continuous

  the wave function y and its space derivatives should be continuous across any boundary.

Wave functions satisfying the above mathematical conditions are called well-behaved wave functions.


Thank you!

MODULE - II

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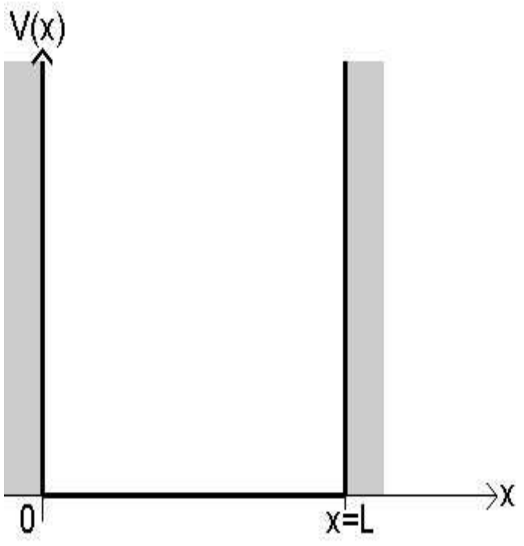
Particle in a Box

Quantum mechanics examines the behavior of the micro level units.



We consider a 1-D potential well of width 'L',
Let the potential is V=0 inside the well and V=∞ outside the well.
For potential well

$V(x) = 0, \text{for } 0 < x < L$------------------ (1)

$V(x) = \infty, \text{for } x > L$

The time independent Schrodinger wave equation in 1-D case is given by

$$\frac{d^2 \cdot \psi}{dx^2} + \frac{2m(E-V)}{\hbar^2}\Psi = 0 \text{ ----------------- (2)}$$

For the particle present inside the well V= 0 and $\Psi = \Psi(x)$

$$\frac{d^2 \cdot \psi}{dx^2} + \frac{2m(E)}{\hbar^2}\Psi = 0 \text{ ----------------- (3)}$$

Particle in a Box

Let the general solution of (3) is given as

$\Psi(\mathrm{x}) = \mathrm{A}\sin kx + \mathrm{B}\cos kx$ -------- (4)

Where A & B are constants are to be determined from the boundary conditions.

Boundary Conditions

$\Psi(x) = 0$ at $x = 0$ and

$\Psi(x) = 0$ at x = L.

So (4) simplifies to $\Psi(\mathrm{x}) = \mathrm{A}\sin\frac{n\pi}{L}x$ ------------ (5)

Particle in a Box

Differentiating twice we get

$$\frac{d^2 \cdot \psi}{dx^2} + \frac{n^2\pi^2}{L^2}\Psi = 0 \text{ ------------- } (6)$$

Comparing (3) & (6) we get

$$\frac{2mE}{\hbar^2} = \frac{n^2\pi^2}{L^2} = \mathrm{k}^2 \;=> \mathrm{E} = \frac{n^2\pi^2\hbar^2}{2mL^2}$$

Where n is called quantum number.

So, the particle cannot possess any value of energy, it possesses only a discrete set of energy values.

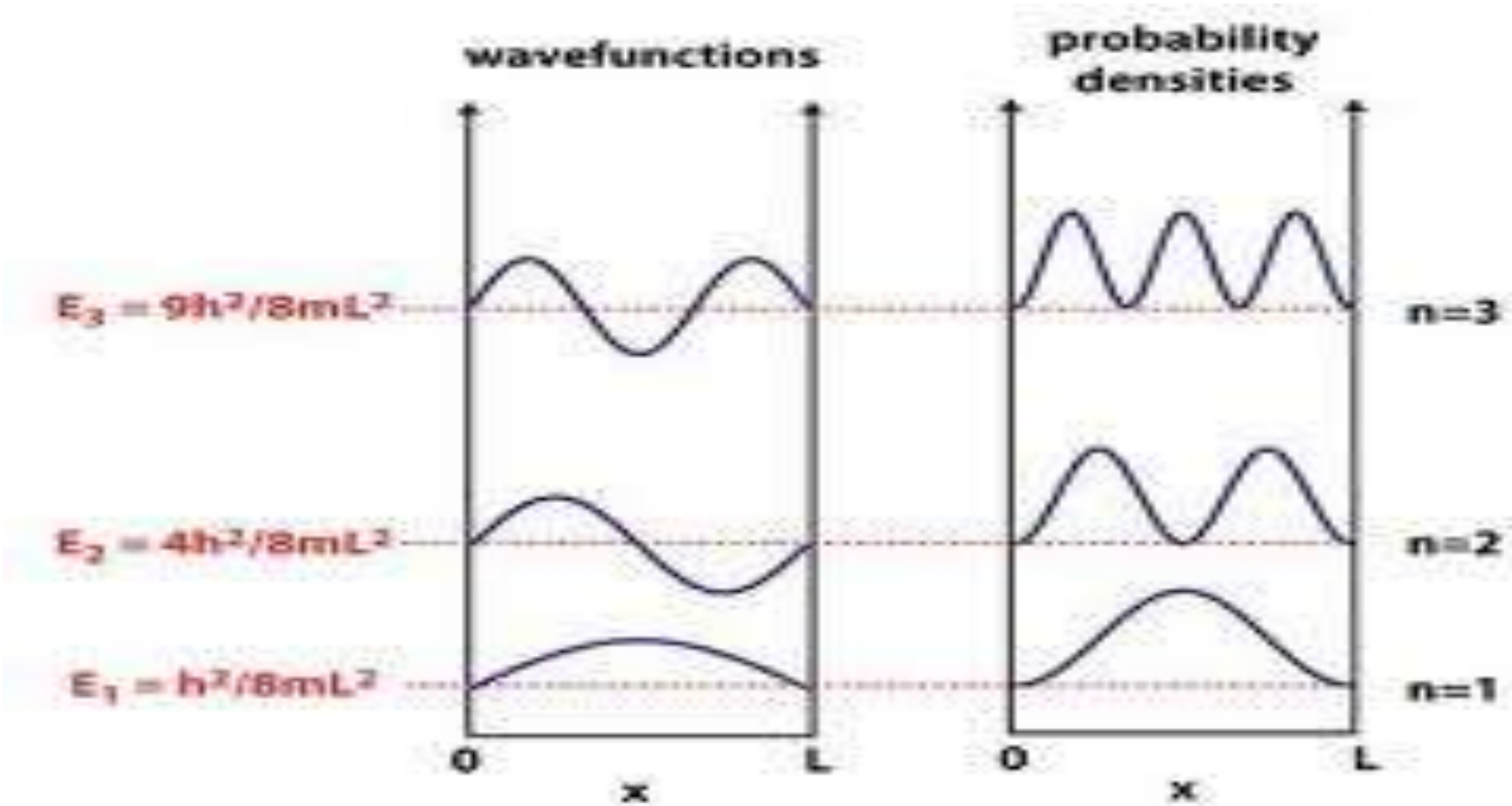
Energy of n^{th} level is $E_n = \frac{n^2\pi^2\hbar^2}{2mL^2} = \frac{n^2h^2}{8mL^2}$ ----------- (7)

In order to find value of A, we use normalization condition.

i.e., $\int_0^L \Psi^*\Psi \, dx = 1$ or $\int_0^L |\Psi(x)|^2 \, dx = 1$

Then we get $A = \sqrt{2/L}$

Particle in a Box



Particle in a Box

The quantum behavior in the box include

Energy quantization:
It is not possible for the particle to have any arbitrary definite energy. Instead only discrete definite energy levels are allowed.

Zero-point Energy:
The lowest possible energy level of the particle, called the zero-point energy, is non-zero.

Spatial-nodes:
In contrast to classical mechanics the Schrodinger equation predicts that for some energy levels there are nodes, implying positions at which the particle can never be found.


Thank you!