Introduction and Unit 1 Quantum Mechanics

I B Tech GR 22 Applied Physics

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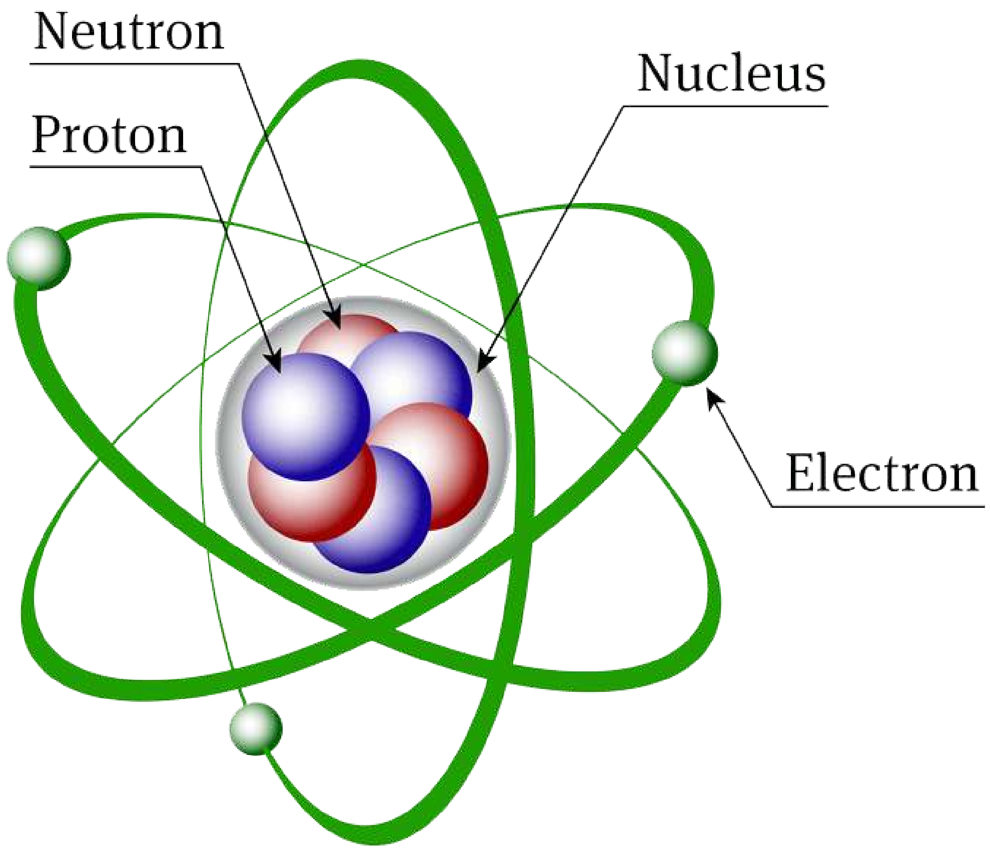
Unit 1
Quantum Mechanics

- Introduction, Black body radiation, Planck’s law, Photoelectric effect- Einstein's Photoelectric equation, Compton effect (Qualitative), Wave-Particle duality, de Broglie hypothesis, Davisson and Germer experiment, Heisenberg’s uncertainty principle, Born’s interpretation of the wave function, Schrodinger’s time independent wave equation, Particle in one dimensional infinite potential box.

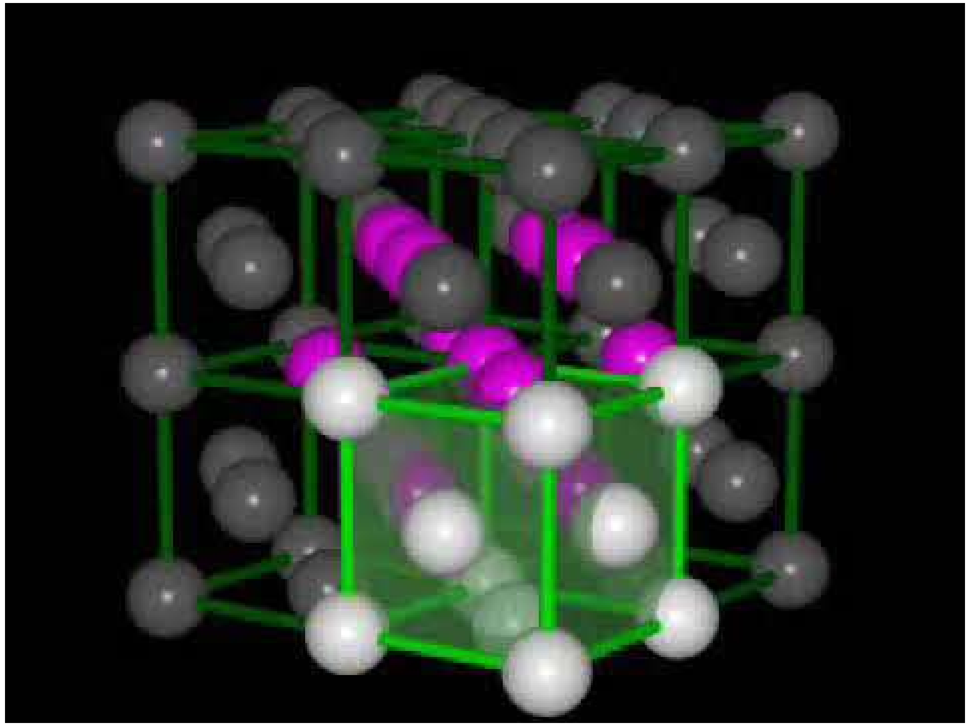
Atomic Structure



Atoms and ions

- Atoms are electrically neutral.
- Atoms lose or gain electrons to attain stability.
- When an atom looses an electron, it becomes a positive ion or cation.
- When an atom gains an electron, it becomes a negative ion or anion.
- A **crystal** or **crystalline solid** is a solid is a solid material whose constituents (such as atoms is a solid material whose constituents (such as atoms, molecules is a solid material whose constituents (such as atoms, molecules, or ions is a solid material whose constituents (such as atoms, molecules, or ions) are arranged in a highly ordered microscopic structure, forming a crystal lattice that extends in all directions.

Crystalline solid



Bonding in solids

- Types of bonding

1. Ionic bonding
2. Covalent bonding
3. Metallic bonding
4. Hydrogen bonding
5. Van der Waals bonding

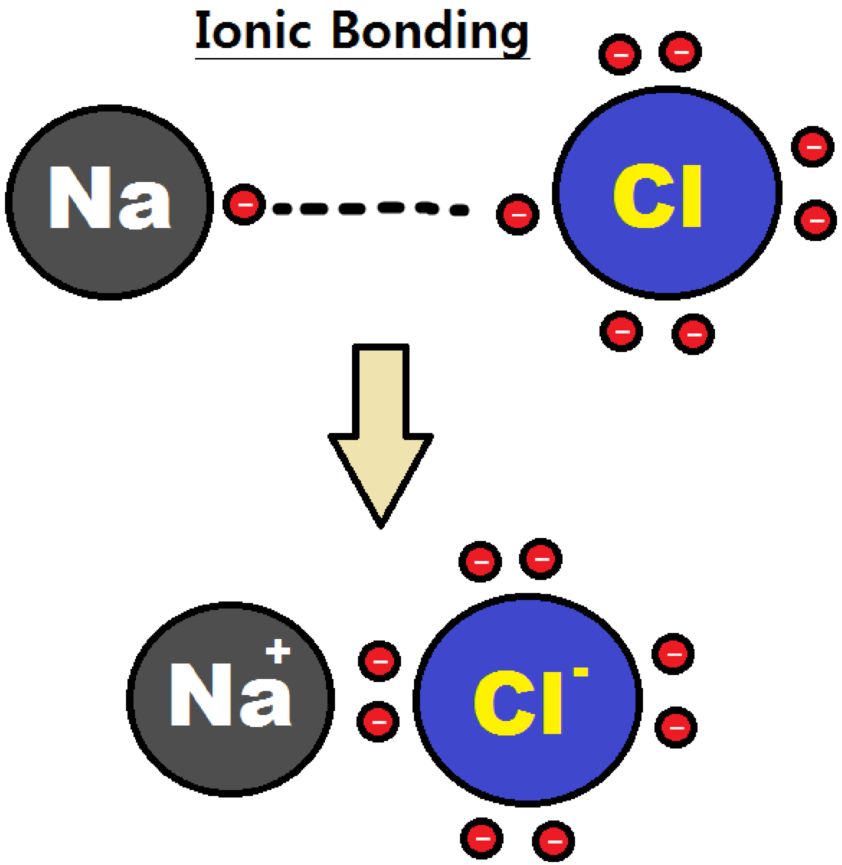
Orbits and Orbitals

- The innermost shell or orbit has the lowest energy level. The furthest orbit has the highest electron energy level.
- Each orbit has a certain capacity and can hold only a certain number of electrons.
- The inner shells must be filled first before going to the next level.
- An atom in its **lowest** possible **energy state** (**called the ground state**).

Ionic bonding

- An ionic bonding is the attractive force existing between a positive ion and a negative ion when they are brought close.
- Properties

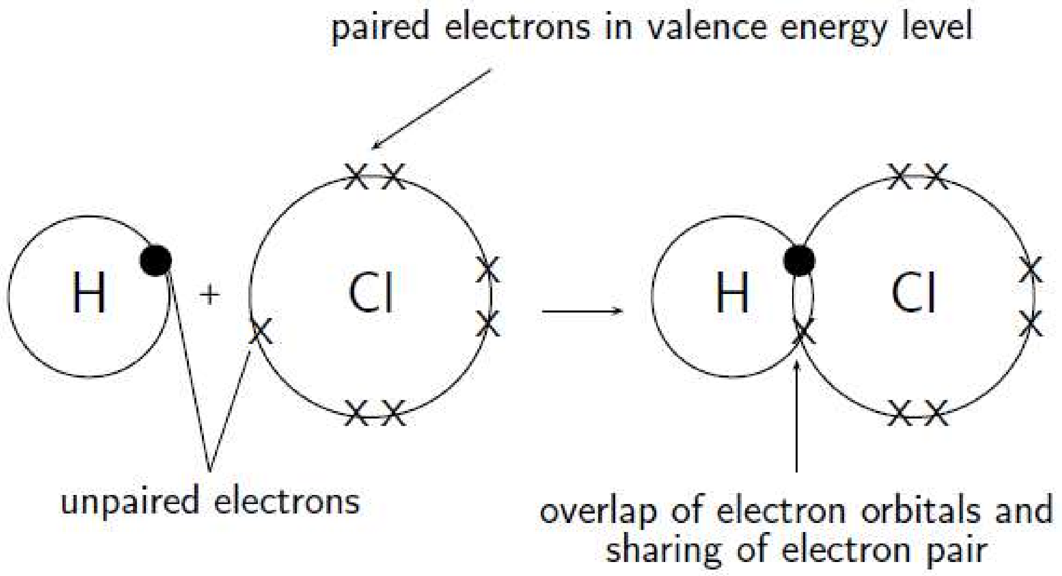
1. Crystalline in nature
2. Hard and brittle
3. High melting and boiling points
4. Good insulators of electricity.



Covalent bonding

- In covalent bonding the stable arrangement of electrons in an outer shell is achieved by a process of valence electron sharing rather than electron transfer.
- Properties

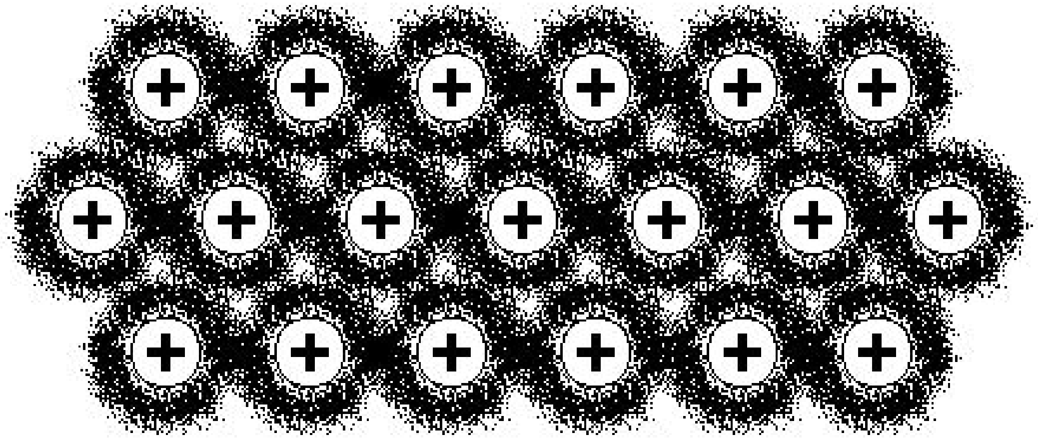
1. Directional
2. Low melting and boiling points compared to ionic bonds
3. Pure covalent solids are good insulators of electricity at low temperature.
4. Semiconductors like germanium and silicon are covalent solids.



Metallic bonding

- The valence electrons from all the atoms belonging to the crystal are free to move throughout the crystal.
- The crystal may be considered as an array of positive metals ions present in a cloud or sea of free electrons.

Metallic Sea of Electrons



Electrons are not bonded to any particular atom and are free to move about in the solid.

Metallic bonding

- Metallic bonds are relatively weak
- Metallic solids are malleable and ductile
- Metallic bond is non directional
- Possess high electrical and thermal conductivity
- Metals are opaque to light.

Classical and Quantum Mechanics

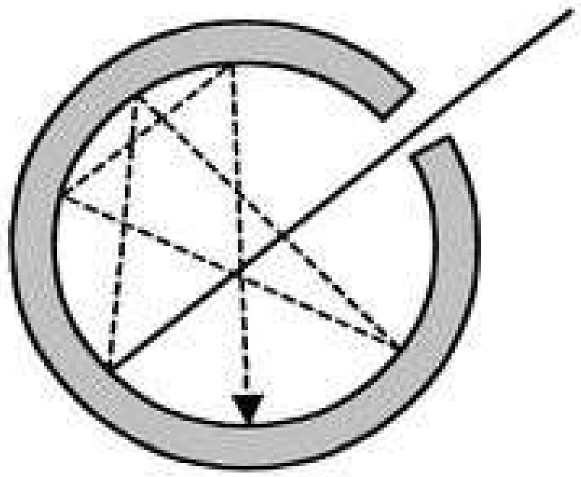
Classical Mechanics	Quantum Mechanics
It deals with macroscopic particles	It deals with microscopic particles
It is based on Newton's Law of motion	It takes into account Heisenberg's uncertainty principle and de Broglie concept of dual nature of matter
It is based on Maxwell's electromagnetic wave theory according to which any amount of energy may be emitted or absorbed continuously	It is based on Planck's quantum theory according to which only discreet values of energy are emitted or absorbed
The state of a system is defined by specifying all the forces acting on the particles as well as their positions and velocities (momentum). The future state can then be predicted with certainty.	It gives probabilities of finding the particles at various locations in space.

Black Body Radiation

- A body that completely absorbs radiation of all wavelengths incident on it is referred to as a blackbody. When such a body is heated, it emits radiation called as blackbody radiation.
- Radiation emitted by a body due to temperature is called thermal radiation.
- Thermal radiation is electromagnetic in nature and its energy is smoothly distributed over all wavelengths.
- A thermal source produces continuous spectrum.

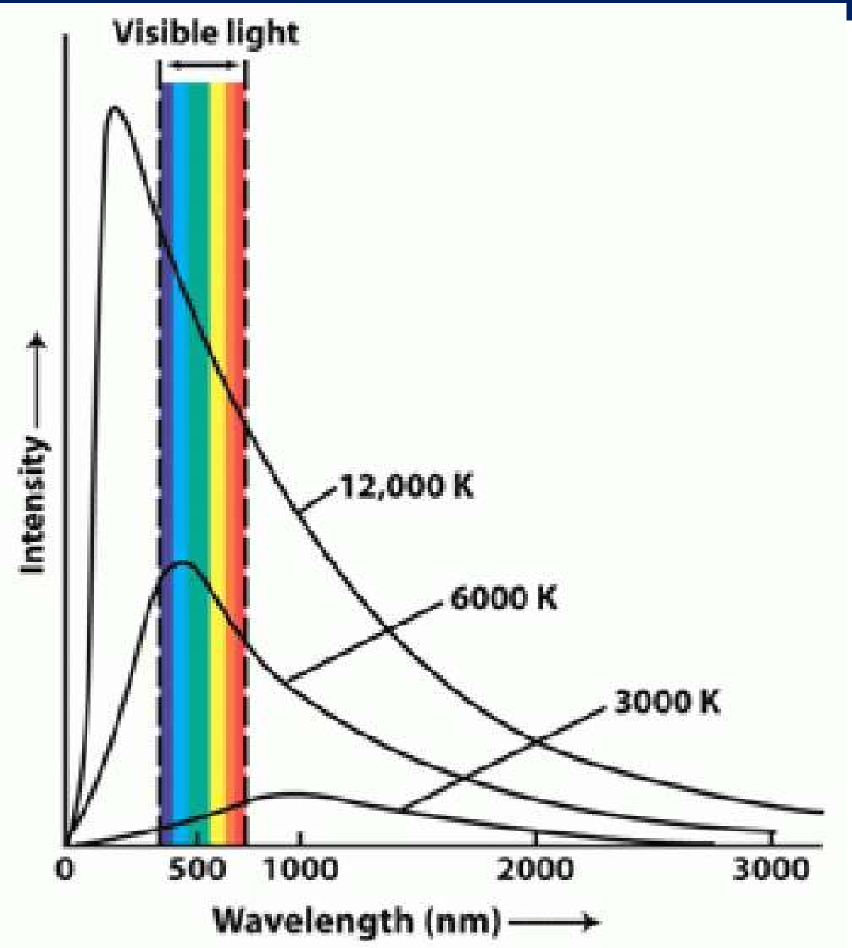
Black Body Radiation

- A cavity made out of a hollow container of any material (iron or copper) with a narrow opening and painted with lampblack in the inside portion resembles a blackbody.



Spectrum of Black Body Radiation

- At a given temperature, the intensity of radiation initially increases with increasing wavelength, reaches a peak and then decreases.
- The spectral distribution of radiation is a function of temperature alone.
- The position of maximum peak shifts towards lower wavelength with increasing equilibrium temperature.



Black Body Radiation

- Classical mechanics could not explain the spectrum of black body radiation.
- Max Planck proposed the Planck’s radiation law which could explain the spectrum of black body radiation.

Planck’s Law

- Max Planck in 1900 introduced the quantum theory of radiation to explain the distribution of energy in the spectrum of black body radiation i.e. frequency distribution of thermal radiation.
- He assumed that the atoms of the walls of the blackbody behave like small harmonic oscillators, each having a characteristic frequency of vibration.

Planck's Law

Planck's assumptions:

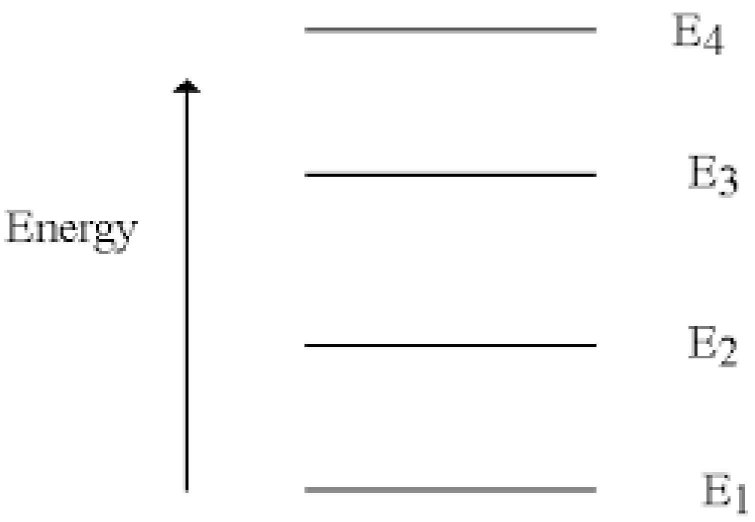
- An oscillating atom can absorb or reemit energy in discrete units. The indivisible discrete unit of energy is "hv" and is called energy quantum (E). $E = hv$

  Where h is the Planck's constant and v is the frequency of radiation.

- The energy of the oscillator is quantized. It can have only certain discrete values of energy E_n. $E_n = n\,hv$ where $n = 1, 2, 3, \ldots$

Planck’s Law

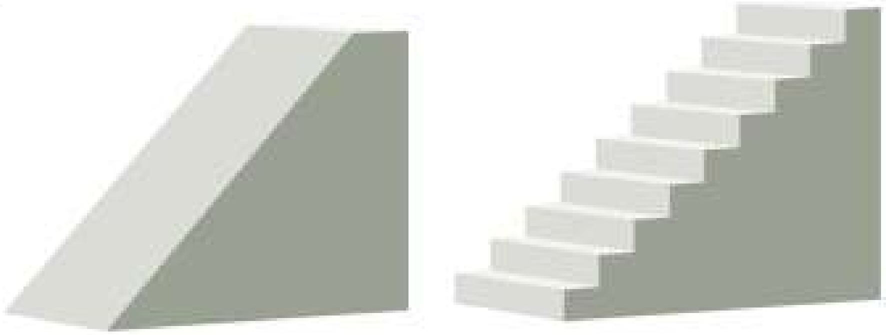
- The hypothesis that radiant energy is absorbed or emitted in a discontinuous manner and in the form of quanta is known as Planck’s quantum hypothesis.



Continuous and quantized

Quantized Energy Levels

- The energy levels of *all* atoms are quantized.



a

A ramp varies continously in elevation.

b

A flight of stairs allows only certain elevations; the elevations are quantized.

Properties of Photons

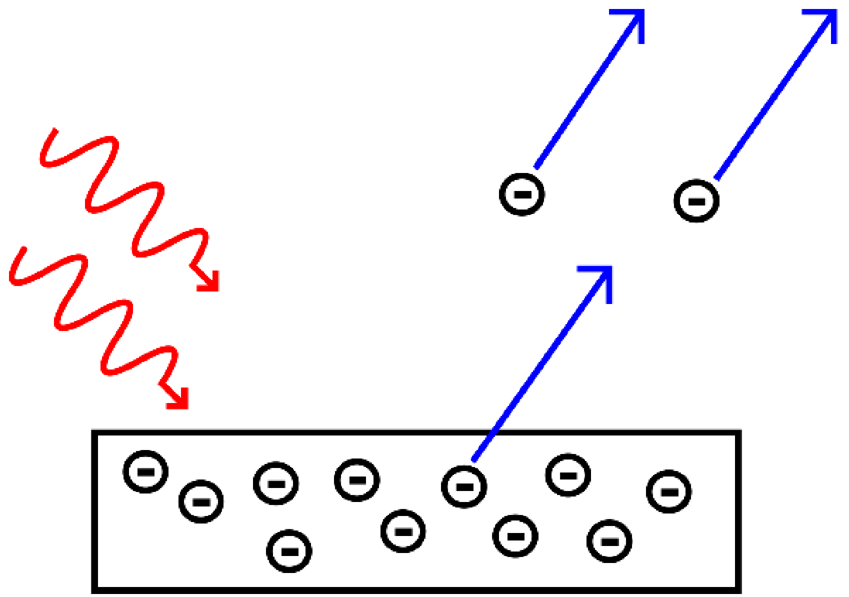
- Energy of photon: $E = h\nu$
- Velocity: Photons travel with velocity of light.
- Rest mass: Photon can never be at rest.
- Relativistic mass: $E = m c^2$ or $m = E/ c^2$
- Linear momentum $P = h/\lambda$
- Electric charge: Photons are electrically neutral and cannot be influenced by electric and magnetic field.
- They cannot ionize matter.

Photoelectric effect

- Photoelectric effect establishes that light behaves as streams of particles.
- Hertz gave experimental evidence of photoelectric effect.
- Einstein explained Photoelectric effect using Planck's quantum theory.

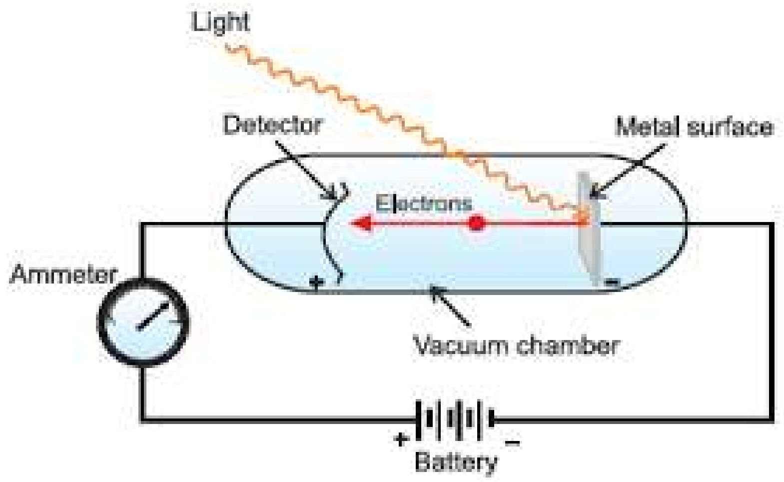
Photoelectric effect

- The emission of electrons from a metal plate when illuminated by light radiation of suitable wavelength or frequency is called photoelectric effect. The emitted electrons are called photo electrons.
- (Bound electrons are emitted in Photoelectric Effect)



Photoelectric effect – Experimental arrangement

- The set up consists of a vacuum chamber consisting of a metal surface and a detector metal plate.
- The metal surface is connected to negative terminal of the battery and the detector metal plate is connected to positive terminal of the battery.



Photoelectric effect – Experimental arrangement

- In the absence of light, there is no flow of current and hence there is no deflection in the ammeter. When monochromatic light falls on the metal surface, a current starts flowing in the circuit shown by the ammeter. The current is known as photo current.

Characteristics of Photoelectric effect

- Threshold frequency is different for different materials.
- Photoelectric current is directly proportional to the intensity of light.
- The kinetic energy and stopping potential of photoelectrons is directly proportional to the frequency of light.
- It is an instantaneous process.

Einstein’s Photoelectric equation

- Einstein explained Photoelectric effect using Planck's quantum theory i.e. energy is given out in packets called as quanta.
- Energy Supplied = Energy Consumed in ejecting an electron + maximum Kinetic energy of electron (or)
- Energy Supplied = Work function+ maximum Kinetic energy of electron
- $hv = hv_0 + K.E.$

Applications of Photoelectric effect

- Used to generate electricity in Solar Panels.
- Lighting sensors such as the ones used in smart phones enable automatic adjustment of screen brightness according to the lighting. This is because the amount of current generated via the photoelectric effect is dependent on the intensity of light hitting the sensor.
- Digital cameras can detect and record light because they have photoelectric sensors that respond to different colors of light.

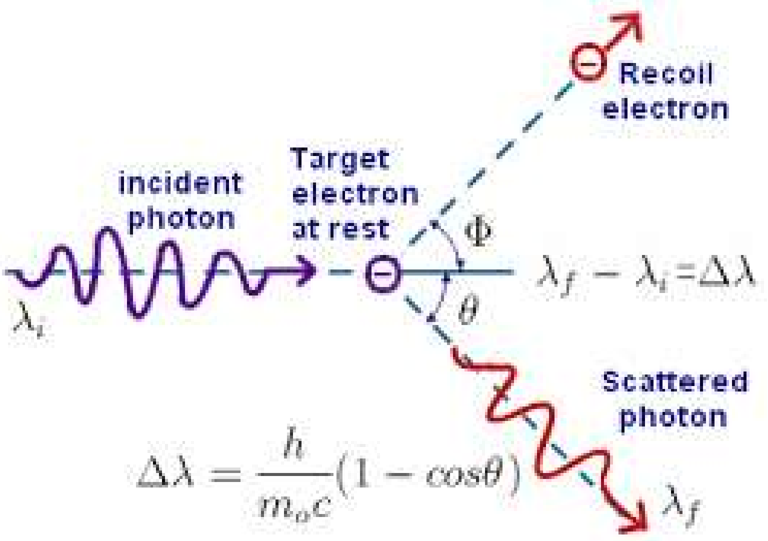
Compton Effect

- Compton effect is the name given to the scattering of x-ray radiations by electrons that are weakly bound to the atoms in the target.
- The American Physicist Arthur H. Compton discovered this effect.
- The Compton effect can be explained on the basis of quantum theory of light.
- Compton effect provides the direct confirmation of the particle nature of electromagnetic radiation.

Compton Effect

- Compton discovered that when a monochromatic radiation of high frequency like X-rays is scattered by a substance, the scattered radiation contains two components, one having a lower frequency or higher wave length and the other having same frequency or wave length. The radiation of unchanged frequency in the scattered beam is known as unmodified radiation while the radiation of lower frequency(or higher wavelength) is called as modified radiation. This phenomenon is known as Compton Effect.

Compton Effect



- A beam of monochromatic wavelength (λ_i) is incident on a target.
- The wavelength of the scattered x-rays are measured at various scattering angles(ϴ).
- The scattered radiation consists of a displaced component(λ_f)
- Compton shift

$$\Delta\lambda = \lambda_f - \lambda_i$$

Compton Effect

The Compton scattering results in

1) modified frequencies or wave length (λ_f)

2) unmodified frequencies or wave length (λ_i)

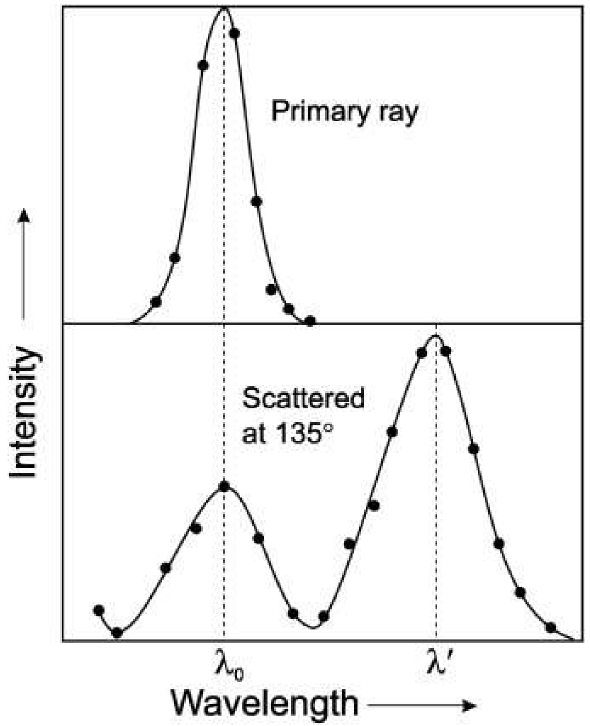
Compton found that the shift in wavelength depends on the scattering angle θ and is independent of the initial wavelength or the scattering substance.

$$\Delta\lambda = \lambda_f - \lambda_i$$

or

$$\Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$$

Compton shift $\lambda_0 = \lambda_i$ and $\lambda' = \lambda_f$



Compton Effect

- Modified wavelength occurs due to collision of x-ray photons with free electrons. On collusion the x-ray photon looses energy and hence frequency decreases or wavelength increases.
- Un modified wavelength is due to collision of x-ray photons with the tightly bound electrons in the target. The whole atom is involved in the collusion and hence m_0 is the mass of the atom which is large. Hence shift is negligible.

Wave particle duality: de-Broglie hypothesis

- In 1924 Louis de-Broglie extended the wave particle dualism to all matter particles.
- If light can act as a wave sometimes and as particles at other times, then matter particles like electron can also behave as waves.
- According to this hypothesis, all matter particles in motion possess a wave character also. The waves associated with matter particles is called as matter waves or de-Broglie waves.

de-Broglie wavelength of matter waves

- Energy of a photon $E = h\nu = \frac{hc}{\lambda}$
- Where c = velocity of light, λ = wavelength of photon and h = Planck's constant
- According to Einstein’s mass energy relation
- $E = mc^2$ where m = mass of photon
- From the above equations $mc^2 = \frac{hc}{\lambda}$
- Or $\lambda = \frac{hc}{mc^2} = \frac{h}{mc} = \frac{h}{p}$ where p is the momentum of the photon.

de-Broglie wavelength of matter waves

- de-Broglie proposed that like photons all matter particles have dualistic behaviour.
- For a matter particle of mass m moving with a velocity v, wavelength $\lambda = \frac{h}{mv}$

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

de-Broglie Wavelength in terms of K.E

- Wavelength in terms of kinetic energy
- Let E = K.E. of the particle = $\frac{1}{2}mv^2$
- Multiply and divide by m
- $E = p^2 / 2m$ or $p = \sqrt{2\,m\,E}$
- $\lambda = h/p$
- $\lambda = \dfrac{h}{\sqrt{2mE}}$

de-Broglie wavelength for electrons

- If a velocity v is given to an electron by accelerating it through a potential difference V , then the work done on the electron is 'eV', and the work done is converted into the kinetic energy of an electron.

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

$$v = \sqrt{\frac{2eV}{m}}$$

Multiply both sides with m

$$mv = \sqrt{2meV}$$

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

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$\lambda = \frac{12.27}{\sqrt{V}} A^0$$

where h= 6.625 x 10^{-34} J sec,

m = 9.1 x 10^{-31} kg and

e = 1.6 x 10^{-19} C

Properties of Matter waves

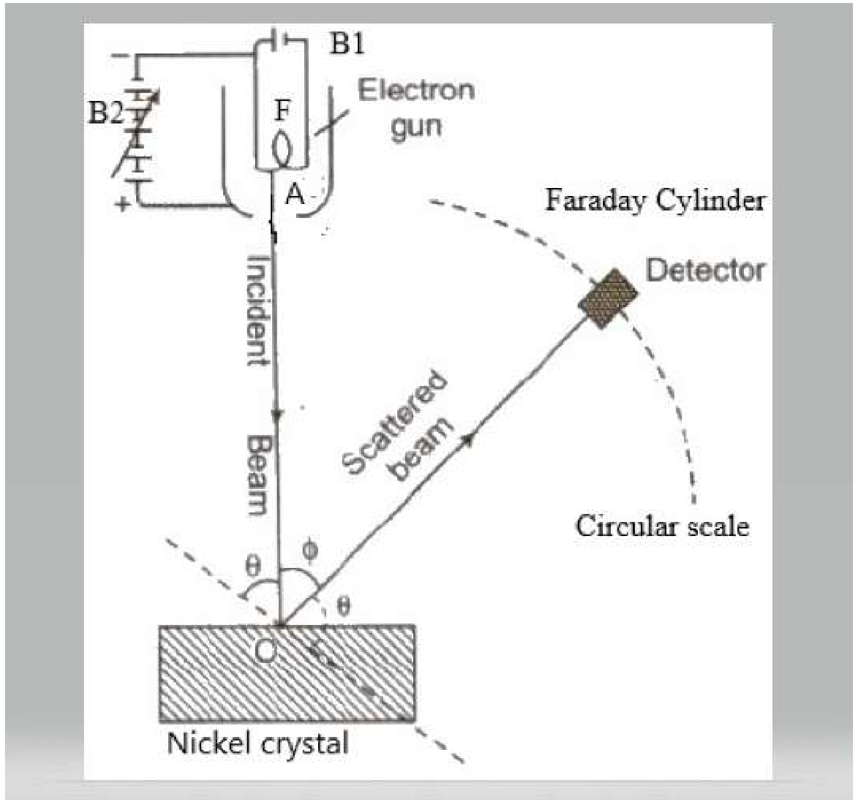
- Lighter the particle, greater will be the wavelength associated with it.
- Smaller the velocity of the particle, greater will be the wavelength associated with it.
- Matter waves are generated by the motion of the particles.
- Waves are produced whether the particles are charged or uncharged.
- Matter waves are not electromagnetic waves.
- The wavelength of matter waves is not a constant. It depends on the velocity of matter particles.

Davisson and Germer Experiment

- Waves exhibit diffraction and hence if de Broglie hypothesis is valid, then the matter waves should exhibit diffraction effects.
- In 1927, Davisson and Germer observed the diffraction of an electron beam incident on a nickel crystal.
- The experiment provided a convincing proof of the wave nature of matter particles.

Davisson and Germer Experiment

- Apparatus consists of a electron gun with a filament ’ F’ connected to battery B1 which produces collimated beam of electrons.
- An anode A connected to a variable voltage source, B2, accelerates the electrons.
- These electrons are scattered by the nickle crystal. The crystal can rotate about the axis.
- The number of electrons scattered by the crystal in different directions is measured by a detector called Faraday cylinder. The detector can move on a circular scale

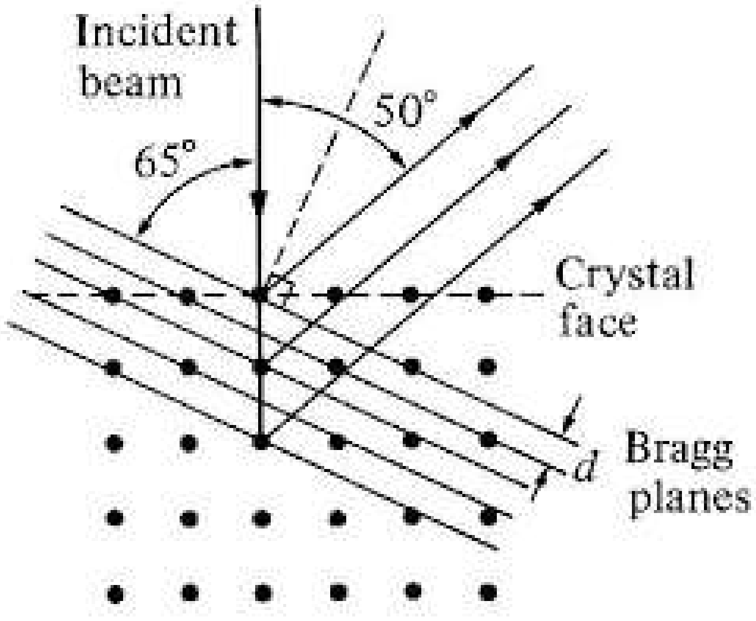


Davisson and Germer Experiment

- In the experiment the intensity of the scattered electron beam is determined as a function of the scattering angle, ϕ.
- It is found that for the accelerating voltage of 54 volts, the electrons are scattered more pronouncedly at an angle of 50° with the direction of the incident beam.
- Maximum indicates that the electrons are diffracted.

Davisson and Germer Experiment

- The rows of atoms at the surface of nickle crystal act like a diffraction grating and the de Broglie waves associated with the electrons undergo diffraction when incident on the crystal.



Davisson and Germer Experiment

- The incident beam make a glancing angle(θ) of 65^0 with the family of Bragg's planes.
- The spacing of planes(d) in Nickel crystal as determined by x-ray diffraction is 0.91 Å
- From Bragg's law $2d\sin\theta = n\,\lambda$
- $2 \times 0.91 \times 10^{-10} \times sin65^{\circ} = 1 \times$ λ
- λ = 1.65 Å

Davisson and Germer Experiment

- The wavelength of electron wave can be obtained from de Broglie equation $\lambda = \frac{12.27}{\sqrt{V}} A^0$
- V = 54 volts
- λ = 1.66 Å
- It is seen that the value obtained experimentally using Bragg's equation and de Broglie equation agreed well.
- Hence Davisson and Germer experiment gave conclusive evidence that electrons exhibit diffraction property.

Heisenberg's Uncertainty Principle

- Classically, the state of a particle can be defined by specifying its position and momentum at any given time “t”.
- At each instant, the position and momentum can be measured accurately.
- When a atomic particle is considered as a de Broglie wave packet, then such a accuracy is not possible.

Heisenberg's Uncertainty Principle

- A moving particle is equivalent to a wave group and having a group velocity.
- If the group is considered to be narrow, it is easier to locate its position, but the uncertainty in calculating its velocity and momentum increases.
- If the group is wide, its momentum is estimated easily, but there is great uncertainty about the exact location of the particle.

Heisenberg's Uncertainty Principle

- Heisenberg a German scientist in 1927 gave the uncertainty principle which states that "The determination of exact position and momentum of a moving particle simultaneously is impossible''.
- If $\triangle x$ is the uncertainty in measurement of position of particle along x-axis, and $\triangle p$ is the uncertainty in measurement of momentum, then
- $\triangle x \, . \, \triangle p \approx h$ Or $(\triangle x).(\triangle p) \geq \frac{h}{4\pi}$
- Statement: Heisenberg uncertainty principle states that both the position and momentum cannot be measured simultaneously with perfect accuracy.

Schrodinger 1 dimensional time independent wave equation

- Schrodinger describes the wave nature of a particle in mathematical form and is known as Schrodinger's wave equation.
- Consider a plane wave moving along +ve x- direction with velocity 'v'. The equation of the wave is written as

$$y = a\sin\frac{2\pi}{\lambda}(x - vt)$$

- Where, a= amplitude of wave

  y = displacement of wave in y- direction

  x = displacement along x- axis at any instant of time 't'.

Schrodinger 1 dimensional time independent wave equation

- Taking first and second order derivative w.r.to ‘x’ on both sides

$$\frac{dy}{dx} = a\cos\frac{2\pi}{\lambda}(x - vt)\frac{2\pi}{\lambda}$$

$$\frac{d^2y}{dx^2} = -a\left(\frac{2\pi}{\lambda}\right)^2 \sin\left(\frac{2\pi}{\lambda}\right)(x - vt)$$

- Using y in the above equation, where $y = a sin\frac{2\pi}{\lambda}(x - vt)$

$$\frac{d^2y}{dx^2} + \left(\frac{2\pi}{\lambda}\right)^2 y = 0$$

Schrodinger 1 dimensional time independent wave equation

- In complex wave, the displacement ‘y’ is replaced by ‘ψ’ and wavelength’ λ’ is replaced by de-Broglie’s wavelength

For a moving particle, the total energy is

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

$$E = U + V$$

$$U = E - V$$

Where E= total energy,

V= potential energy, U = kinetic energy

$$\frac{d^2\psi}{dx^2} + \left(\frac{2\pi}{\lambda}\right)^2 \psi = 0$$

$$\frac{d^2\psi}{dx^2} + \frac{4\pi^2 m^2 v^2}{h^2}\psi = 0$$

Schrodinger 1 dimensional time independent wave equation

- U = $\frac{1}{2}mv^2$

Multiply both sides with m

$$2mU = m^2v^2$$

But $U = E - V$

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

$$\frac{d^2\psi}{dx^2} + \frac{4\pi^2 m^2 v^2}{h^2}\psi = 0$$

Subs. The value of m^2v^2 in the above equation.

$$\frac{d^2\psi}{dx^2} + \frac{4\pi^2 2m(E - V)}{h^2}\psi = 0$$

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

This is 1 D equation.

Schrodinger 3 dimensional time independent wave equation

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

h	=	Planck's constant
m	=	mass of particle
E	=	total energy of particle
V	=	potential energy of particle

Physical significance of the wave function: Born's interpretation ψ

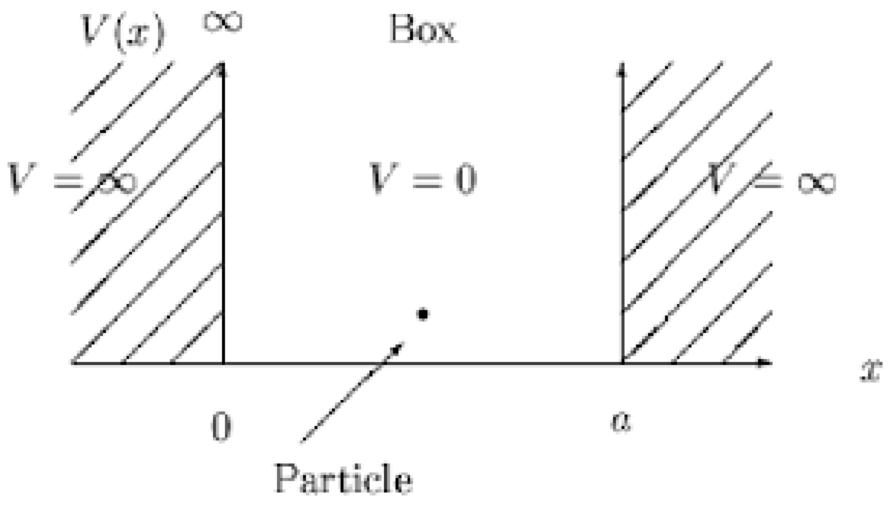
- The wave function has no direct physical significance as it is not an observable quantity. It is a complex quantity which connects the particle nature and its associated wave nature statistically.
- $\psi\psi^* = |\psi|^2$ is the probability density function.

$$\int_{-\infty}^{\infty} |\psi|^2 \, dx \, dy \, dz = 1 \; if \;\; particel \; is \;\; present$$

- ψ can be considered as probability amplitude since it is used to find the location of the particle.

Particle in 1 dimension infinite potential box

- If one –dimensional motion of a particle is assumed to take place with zero potential energy over a fixed distance, and if the potential energy is assumed to become infinite at the extremities of the distance, it is described as a particle in a 1-D box, and this is the simplest example of all motions in a bound state.



Particle in 1 dimension box

- The Schrodinger wave equation will be applied to study the motion of a particle in 1-D box to show how quantum numbers, discrete values of energy and zero point energy arise.
- This box can be represented by a potential well of width 'a'.
- The potential is assumed to be constant and equal to zero in the box. On the walls and outside the potential is infinite, i.e. $v = \infty$.
- The boundary condition are
- $v(x) = 0\,, when\ 0 < x < a$ and $\psi(x) = 1$.......... (1)
- $v(x) = \infty\,, when\ 0 \geq x \geq a$ and $\psi(x) = 0$ .... (2)
- Where $\psi(x)$ is the probability of finding the particle.

Particle in 1 dimension box

- The Schrodinger wave equation for the particle in the potential well can be written as

- $\frac{d^2\psi}{dx^2} + \frac{8\pi^2 m}{h^2}(\mathrm{E} - v)\psi = 0$, but $v = 0$ for a free particle in the box
- Hence we have $\frac{d^2\psi}{dx^2} + \frac{8\pi^2 m}{h^2}\mathrm{E}\psi = 0$ ……. (3)
- $\frac{d^2\psi}{dx^2} + k^2\psi = 0 \ldots\ldots (4),$
- where $k^2 = \frac{8\pi^2 m}{h^2}\mathrm{E}$ …….(5) and k is the propagation vector

Particle in 1 dimension box

- The general solution of equation (4) is $\psi(x) = \mathrm{Asinkx} + \mathrm{Bcoskx} \;\ldots\ldots(6)$
- At x = 0, $\psi(x)$ = 0

Hence, $0 = Asink(0) + Bcosk(0)$ or B = 0

- At x = a, $\psi(x)$ = 0

Hence, $0 = Asink(a) + 0$, it implies $A = 0\ or\ sinka = 0$

If $A = 0\ there\ is\ no\ solution.\quad Hence\ \ sinka = 0$

or Ka=nπ implies $k = \frac{n\pi}{a}$ Where n= 1,2,3,4,...and n ≠ 0, because if

n = 0, k = 0, E = 0 everywhere inside the box and the moving particle cannot have zero energy.

Particle in 1 dimension box

- Substituting the value of K in equation (5) we get $E = \frac{n^2h^2}{8ma^2}$
- $E_n = \frac{n^2h^2}{8ma^2}$ ..... (7), is the discrete energy level.
- The lowest energy of a particle is when, n=1, or $E_1 = \frac{h^2}{8ma^2}$ is the lowest energy or ground state energy or zero point energy of the system.
- The wave functions ψ_n corresponding to E_n are called Eigen functions of the particle, the integer 'n' corresponding to the energy E_n is called the quantum number of the energy level E_n.

Particle in 1 dimension box

- *Substitute the value of B = 0 and* $k = \frac{n\pi}{a}$*, in equation (6), i.e.*

  $$\psi(x) = \mathrm{Asinkx} + \mathrm{Bcoskx}.$$

- $\psi_n = Asin\frac{n\pi x}{a}$
- According to normalization condition, the total probability that the particle is somewhere in the box must be unity.

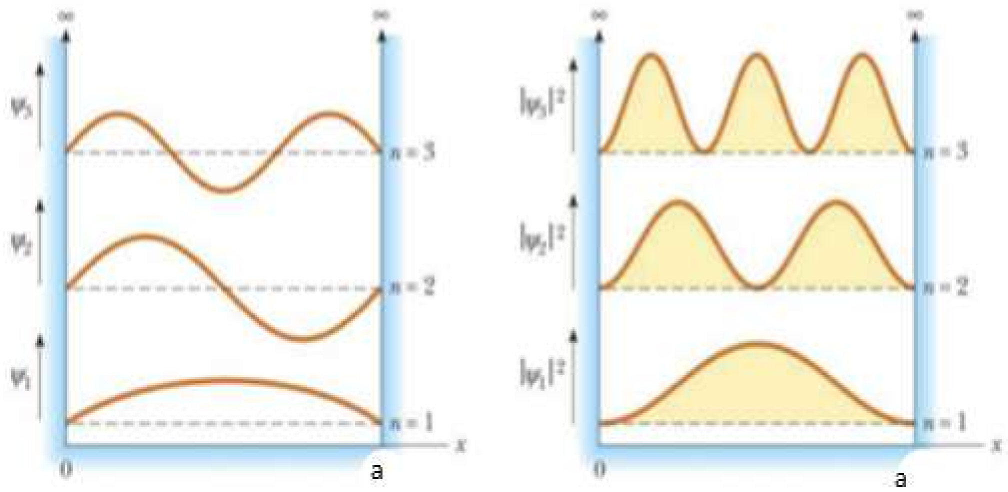
$$\int_0^a p_x = \int_0^a |\psi_n|^2 dx = 1$$

Substitute the value of wave function and integrate

Particle in Three dimensional box

- $\int_0^a A^2 sin^2 \frac{n\pi x}{a} dx = 1$
- $A^2 \int_0^a \frac{1}{2}\left[1 - cos\frac{2\pi nx}{a}\right] dx = 1$
- $\frac{A^2}{2}\left[x - \frac{a}{2\pi n} sin\frac{2\pi nx}{a}\right] = 1$
- $\frac{A^2}{2}$ [a] $= 1$ or $A = \sqrt{\frac{2}{a}}$
- The normalized wave function is $\psi_n = \sqrt{\frac{2}{a}} sin\frac{n\pi x}{a}$ ..... (8)

Particle in 1 dimension box



Numerical's

1. Calculate the wavelength associated with an electron raised to a potential of 1600 volt.

Numerical's

1. Calculate the wavelength associated with an electron raised to a potential of 1600 volt.

Solution: Given Potential(V) = 1600 volt

Formula: For an electron $$\lambda = \frac{12.27}{\sqrt{V}} A^0$$

Substitute the value of V.

Wavelength = 0.31 Å

Numerical's

2. Calculate the de Broglie wavelength of a proton whose kinetic energy

is $1 * 10^6$ eV. Given mass of proton is $1.67 * 10^{-27}$ kg.

Numerical's

2. Calculate the de Broglie wavelength of a proton whose kinetic energy

is $1 * 10^{6}$ eV. Given mass of proton is $1.67 * 10^{-27}$ kg.

Solution: Given K.E. = E = $1 * 10^{6}$ eV = $1 * 10^{6} * 1.6 * 10^{-19}$ J

Planck's constant = h = $6.626 * 10^{-34}$ Js

Mass of proton m = $1.67 * 10^{-27}$ kg.

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

Substituting

$\lambda = 2.86 * 10^{-14}$ m.

Numerical's

3. Calculate the velocity and kinetic energy of an electron of wavelength $1.66 * 10^{-10}$ m.

Unit 1: TPS Activity

Calculate the velocity and kinetic energy of an electron of wavelength $1.66 * 10^{-10}$ m.

Numerical's

3. Calculate the velocity and kinetic energy of an electron of wavelength $1.66 * 10^{-10}$ m.

Solution: Given wavelength of electron, $\lambda = 1.66 * 10^{-10}$ m

Planck's constant, $h = 6.626 * 10^{-34}$ Js

Mass of electron, $m = 9.1 * 10^{-31}$ kg.

Formula, $\lambda = \frac{h}{mv}$ on substituting, velocity, $v = 0.4386*10^{7}\ ms^{-1}$

K.E. = $\frac{1}{2}mv^2$ substituting, K.E. = 54.5 eV.

Numerical’s

4. Calculate the minimum energy that an electron can possess in an infinitively deep one dimensional potential well of width 4 nm.

Numerical's

- 4. Calculate the minimum energy that an electron can possess in an infinitively deep one dimensional potential well of width 4 nm.

Solution: Given Width, a = $4*10^{-9}$ m. And n = 1

Formula $E = \frac{n^2 h^2}{8ma^2}$

Substituting E = $0.03769*10^{-19}$ J

or E= 0.0235 eV.

Numerical's

5. The wavelength of yellow light is 5890 Å. What is the energy of the photon in the beam.

Numerical's

- 5. The wavelength of yellow light is 5890 Å. What is the energy of the photon in the beam.

Solution: Given wavelength, λ = 5890 Å = $5890*10^{-10}$ m.

Formula $E = h\nu = \frac{hc}{\lambda}$ where c = $3*10^{8}$ ms^{-1}.

on substituting, E = 2.11 eV.