U3.1) Wave-particle duality of radiation and matter – 1) We know all object in our environment are composed of matter **2)** Matter consists of a large number of Particles of atomic dimensions. **3)** The material particle in motion specified by mass m, velocity V, momentum P=mv and energy E. **4)** According to different phenomena like photoelectric effect, black body radiation etc, EM radiation shows particle nature and by optical phenomenon EM radiation shows wave nature i.e. radiation have dual nature i.e. wave and particle. **5)** De-Broglie proposed that like radiation, matter should also exhibit wave nature. The motion of e^- within an atom is wavelike. **6)** Even though matter is composed of particles and shows particle nature, but it can also exhibit wavelike properties.

U3.2) De-Broglie's hypothesis: 1) In 1924, Louis de Broglie proposed a new speculative hypothesis that electrons and particles of matter can behave like waves and wave-particle duality is not property of radiation but it is a universal ch^s of nature. **2)** According to him, matter composed of particles and shows particle nature, but it can also exhibit a wavelike properties. **3)**According to De-Broglie's hypothesis *"a moving particle always has a wave associated with it and motion of particles is guided by that wave in a similar manner as photon controlled by a wave.'*

- **1) *For any photon,*** $\nu = \frac{E}{h}$, & $\lambda = h/p$.
- **TYPE 1) Wave-Particle Duality:** The de Broglie hypothesis suggests that particles, traditionally considered as discrete and localized entities (like particles in classical physics), also exhibit wave-like properties. This concept is known as wave-particle duality. It implies that particles can display both particle-like and wave-like characteristics depending on the experimental setup or observation conditions.
- The de Broglie wavelength λ, associated with a particle and is related to its

momentum, through the Planck's constant; $\lambda = \frac{h}{p} = \frac{h}{mv}$ --------------- (1)

- The expression for wavelength can be derived using Planks -Einstein equat From

above equation we have; $h\nu = mc^2$ -> $\therefore h\nu = mc \times c$ -> $\therefore h\nu = p \times \nu\lambda$ $\therefore$ $\longrightarrow \lambda = \frac{h}{p} = \frac{h}{mv}$

- De-Broglie wavelength in terms of K.E:---> $\lambda = \frac{h}{p} = \frac{h}{mv}$ ---> But $E = \frac{mv^2}{2} = \frac{m^2v^2}{2m}$ ----> $= \frac{p^2}{2m}$ --->

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

- **De-Broglie wavelength in terms of Potential difference (P.D):**

Kinetic energy = Electrical energy : --> $\frac{mv^2}{2} = eV$--> $\frac{m^2v^2}{2m} = eV$--> $\frac{p^2}{2m}$ = eV -->

$p^2 = 2meV$--> $p = \sqrt{2meV}$---> $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$ --> $\lambda = \frac{12.26}{\sqrt{V}} A^0$ WHERE::-

$h = 6.63 \times 10^{-34}\ J.S.$ --> $m = 9.1 \times 10^{-31} Kg$ --> $e = 1.6 \times 10^{-19} C.$

U3.3) Heisenberg uncertainty principle:1) In 1927, Heisenberg proposed a very Interesting principle, which directly explains difficulty produced to dual nature of matter, known as uncertainty principle. **2)** a moving particle at any instant has fixed position in space and a definite momentum. **3)** In wave mechanics/quantum mechanics particle is described in terms of wavepacket because **Vg = v. 3)** A particle is always localized in space and hence a wavepacket or wave group represents moving particle. The particle lies some-where in wavepacket and probability of finding particle at given point is proportional to wave amplitude at that point. **4)** Therefore, although particle lies within, wave packet moving with group velocity, it is impossible to determine exact position and exact velocity at any particular moment. **5)** There is always certain uncertainty in experim-ental measurement of position and momentum of particle of very small size like an e^- in motion. **6)** Newtonian mechanics is applicable to motion of *microscopicparticles -> a) Infinitely small wave packet. B) Wide wave packet.*

- **Infinitely small wave packet/Narrow wave packet: 1)** In case of infinitely small wave packet amplitude is large over small region of space and 0 is negligible elsewhere. **2)** Due to this small region of space we can determine position of particle, Hence position of Particle can be fixed with minimum error or uncertainty **3)** But at the same time wavelength **(λ)** and hence momentum **(p=h/λ)** cannot be measured accurately and hence is uncertain.
- **Wide wave packet: 1)** If wave packet is sufficiently wide then wavelength **(λ)** and hence momentum **(p)** can be determined very easily with more accuracy. **2)** But we cannot find the position of particle.**3)** Therefore by using infinitely small and infinitely large wave packet, shows certainty about momentum involve complete uncertainty about position and vice-versa. **4)** Hence we never determine simultaneously both momentum and position of a moving particle.

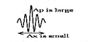

Figure 1.2a : Narrow wave Packet

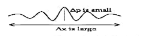

Figure 1.2b :Wide wave

5) Heisenberg was 1st to realize this effect and then he expressed them mathem - atically by means of relation known as uncertainty principle.' **6) The principle gives** that "It is impossible to determine accurately and simultaneously the values of both position & momentum.

7) There is always uncertainty between position &momentum. particle is expressed by writing x+Δx & Px+ ΔPx respectively.The particle always lies between x+Δx &Px- ΔPx or x- Δx&Px+ ΔPx.

8) **Therefore product** Δx.ΔPx>>h, Therefore **uncertainty principle states that** "in any simultaneous determination of position and momentum of a particle of atomic size, the product of uncertainties in position & in momentum is greater than or equal to planks constant h. **Δx .ΔPx>>ħ, Modified planks constant=ħ =h/2**

U3.4) Concept of wave function and probability interpretation:- 1) Wave function = ψ **(r⃗, t)** is nothing but a variable quantity which mathematically describes the wave of Moving particle. **2)** The wave variable associated with matter waves is called wave function ψ and mathematically it represents motion of particles. **3)** The value of the wave function of a particle at a given point of space and time (x,y,z,t) is related to the likelihood of finding the particle that point (x,y,z) at given time,(t). **4)** For sound waves pressure is wave variable which varies with space and time and they can exist only within a material medium. **5)** Wave function, $\psi = \psi(r, t)$ is analogous to pressure (P) in sound waves and electric field,(E) in electromagnetic waves. 6) However, Max Born in 1926 suggested that the quantity

$|\psi^2| = \psi^*\psi = (A + iB).(A - iB) = A^2 + B^2$ is always real and positive so it has physical significance.**7)** The **quantity P∝ |ψ(r⃗, t)²|dV** gives probability of finding moving particle at given point at given time. The term **|ψ(r⃗, t)²|dV** is also called as probability density **and ψ(r⃗, t)** as probability apltude

- **Physical significance of ψψ* and ψ –: 1)** In 1926, Max Born gave a physical

interpretation of wave function ψ. **2)** The ψ itself has no physical significance. **3)** According to Max Born, ψ 2 represents the probability density i.e. it represents probability per unit volume, it shows some particles found which described by wave function (ψ) at particular time, at particular point (x,y,z.) in volume. **4)** If wave function is complex, its probability density given by product ψψ*. **5)** When value of Ψ 2 is large, probability of finding particle there is strong and for small value of finding particle there is less. **6)** If Ψ 2 = 0, means there is no any particle present at that point at time t. $\iiint_{-\infty}^{+\infty} \Psi^2 dxdydz = 1 - (1)$

1) The wave function that satisfies by equation (1) is called a normalized wave function. It **2)** If wave function is to represent a moving material particle, it should satisfy following condition gives normalization condition. **A)** ψ should be a normalized wave function. **b)** ψ should be a single valued function of space and time. **C)** ψ must be finite. **d)** ψ and its **derivatives** $\frac{\partial\Psi}{\partial x}, \frac{\partial\Psi}{\partial y}, \frac{\partial\Psi}{\partial z}$ must be continuous everywhere in the region..

U3 ,5) Schrodinger's equation: 1) Erwin Schrodinger in 1926 developed wave equations that represent matter waves mathematically which are associated with a moving particle. **2)** These are linear partial differential equation helpful in understanding the nature of matter waves in quantum-mechanical systems. **3)** Schrodinger's equation defines the wave properties of sub atomic particles and also predicts particle- like behavior. These equations are basically wave equations predicting the probability of events or outcome which can be applied in various fields. **4)** The Schrodinger equation is used to find the allowed energy levels of quantum mechanical systems. **5)** The associated wave-function gives the probability of finding the particle certain postion.

U3 .6) Schrodinger's time independent wave equation:-

The general differential equation function 'Ψ' ,travelling with velocity 'u' in three dimensions.

$\frac{\partial^2\Psi}{\partial t^2} = u^2 [\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\Psi}{\partial z^2}]$

$\frac{\partial^2\Psi}{\partial t^2} = u^2\nabla^2\Psi$ -------- (1)

Where, $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ = Laplacian

STEP 2: $\Psi(x, y, z, t) = \Psi_0 (x, y, z)\, e^{-i\omega t}$

Where, $\Psi_0(x,y,z)$ is the amplitude of wave at point (x,y,z). Equation written as,

$\Psi (r,t) = \Psi_0 (r)\, e^{-i\omega t}$ ------ (2)

STEP 3: Diff partially with respect to t twice,

$$\frac{\partial\Psi}{\partial t} = -i\omega\Psi_0\, e^{-i\omega t}$$

$$\frac{\partial^2\Psi}{\partial t^2} = (-i\omega)(-i\omega)\,\Psi_0 e^{-i\omega t}$$

$$\frac{\partial^2\Psi}{\partial t^2} = -\omega^2\Psi_0\, e^{-i\omega t}$$

But, $\Psi = \Psi_0 e^{-i\omega t}$

$$\frac{\partial^2\Psi}{\partial t^2} = -\omega^2\Psi$$

STEP 4: Substitute in equation (1)

$$-\omega^2\Psi = u^2\nabla^2\Psi$$

$\nabla^2\Psi + \frac{\omega^2}{u^2}\Psi = 0$ --------- (3)

$$\omega = 2\pi\nu = 2\pi\,\frac{u}{\lambda}$$

$$\frac{\omega}{u} = \frac{2\pi}{\lambda} \qquad \frac{\omega^2}{u^2} = \frac{4\pi^2}{\lambda^2}$$

De-Broglie hypothesis for matter waves

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

$\lambda^2 = \frac{h^2}{p^2}$-------- (4)

The total energy (E) of particle is a sum of Kinetic energy (1/2 mV²) and potential energy V. $E = \frac{1}{2}mv^2 + v = \frac{m^2v^2}{2m}$+V

$$\therefore E = \frac{p^2}{2m} + V$$

$$\therefore p^2 = 2m(E - V)$$

Substitute in equation (4)

$$\lambda^2 = \frac{h^2}{2m(E - V)}$$

$$\frac{\omega^2}{u^2} = 4\pi^2 \times \frac{2m(E-V)}{h^2}$$

$$\frac{\omega^2}{u^2} = \frac{8\pi^2 m(E-V)}{h^2}$$

Substitute in equation (3)

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

The quantity $\frac{h}{2\pi}$ appears very frequently in quantum mechanics

$$\nabla^2\Psi + \frac{2m}{\hbar^2}(E - V)\Psi = 0$$

- **Q . Quantum Computing –**

1) Superposition 2) Entilegment

3) speed of quantum computer

- **Application – 1) Artificial intelligence , 2) Drug design 3) financial optimization , 4) logistics and scheduling 5) cyber siqurity**

U3.7) Schrodinger's time dependent wave equation:

STEP 1: The general differential equation for a wave function 'Ψ' travelling with velocity 'u' in.

$\frac{\partial^2\Psi}{\partial t^2} = u^2 [\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\Psi}{\partial z^2}]$

$\frac{\partial^2\Psi}{\partial t^2} = u^2\nabla^2\Psi$ ---------- (1)

Where, $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ = Laplacian.

STEP 2: The general solution of equation is of the form,

$\Psi(x, y, z, t) = \Psi_0 (x, y, z)\, e^{-i\omega t}$

Where, $\Psi_0(x,y,z)$ is the amplitude of wave at point (x,y,z).

Equation written as,

$\Psi (r,t) = \Psi_0 (r)\, e^{-i\omega t}$ ----- (2)

STEP 3:

Differentiating equation (2) partially with respect to t twice,

$$\frac{\partial\Psi}{\partial t} = -i\omega\Psi_0\, e^{-i\omega t}$$

$\frac{\partial\Psi}{\partial t} = -i\omega\Psi$----------- (3)

As ω =2πν and E =hν

But, $\Psi = \Psi_0 e^{-i\omega t}$

$\frac{\partial\Psi}{\partial t} = \frac{-i2\pi E}{h} \quad E\Psi = \frac{-h}{i2\pi}\frac{\partial\Psi}{\partial t}$

$E\Psi = \frac{ih}{2\pi}\frac{\partial\Psi}{\partial t}$ ------------ (4)

STEP 4: Schrodinger's time independent equation is

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

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

$$\therefore \frac{-h^2}{8\pi^2 m}\nabla^2\Psi + V\Psi = E\Psi$$

$$\therefore \frac{-h^2}{8\pi^2 m}\nabla^2\Psi + V\Psi = \frac{ih}{2\pi}\frac{\partial\Psi}{\partial t}$$

This is Schrodinger's time dependent wave equation.

- **Applications of Schrodinger's time independent wave equation:**
  - The Schrodinger equation is used to find the allowed energy levels of quantum mechanical systems (such as atoms, or transistors).
  - The wave function associated with motion of atomic/molecular systems gives the probability of finding the particle at a certain position.
  - The Schrodinger equation can be used to describe the behavior of a particle in a field of force.
  - We will now apply Schrodinger's wave equation in several examples using various potential functions.
  - These examples will demonstrate the techniques used in the solution of Schrodinger's differential equation and the results of these examples will provide an indication of the electron behavior under these various potentials
  - ---

U3.8) Particle in a rigid box (infinite potential well)- 1) If a quantum particle is in a potential well and the total energy of the particle is less than the height of the potential well, it is considered as trapped inside the well. **2)** In classical mechanics this particle can vibrate back and forth due to collision with walls but cannot escape out from the well. In quantum mechanics, it is called as bound state.
3) Consider a quantum particle of mass 'm' restricted to move along x axis between x=0 and x=L with velocity,' v' inside infinite rigid one dimensional box of length L
4) The potential can be taken as V(x) = 0 inside and since it cannot escape so potential outside the box is taken as V (x) = ∞.
5) Schrodinger time independent wave equation can be applied in order to estimate various energy states of particles.

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

But inside the box V(x) = 0

$\therefore \frac{\partial^2\Psi}{\partial x^2} + \frac{2mE}{\hbar^2}\Psi = 0$

$\therefore \frac{\partial^2\Psi}{\partial x^2} + k^2\Psi = 0$ --------- (1)

- This is second order linear differential equation.wave function can be written as.

$\Psi(x) = A\sin(kx) + B\cos(kx)$ ——(2)
where A and B are arbitrary constants can be be determined by the boundary conditions.

- Applying first boundary conditions i.e. Ψ(x)=0 at x=0 we get 0 = 0 + B

Put B = 0 in equation (2)
$\therefore \Psi(x) = A\sin(kx)$

- Applying second boundary conditions i.e. Ψ(x)=0 at x=L we get

Asin(kL) =0
∴sinKL=0=nπ, Where n=1,2,3-----
(n=o is not possible because if n=o,then KL becomes zero which is not possible.)

∴KL= nπ $\therefore K = \frac{n\pi}{L}$

$\therefore K^2 = \frac{n^2\pi^2}{L^2}$

$\therefore \frac{2mE}{\hbar^2} = \frac{n^2\pi^2}{L^2} \quad \therefore E_n = \frac{n^2\pi^2}{L^2} \times \frac{\hbar^2}{2m}$

$$\therefore But\ \hbar = \frac{h}{2\pi}$$

$$\therefore E_n = \frac{n^2\pi^2}{2mL^2} \times \frac{h^2}{4\pi^2}$$

$$\therefore E_n = \frac{n^2h^2}{8mL^2}$$

- **Normalization of wave function:**
  - For the particle in a rigid box

with infinite walls, the probability of finding it within the box must be equal to one. Therefore condition for normalization is written as;

$\int_0^L \Psi^*\Psi dx = 1$

$\Psi(x) = A\sin\frac{n\pi x}{L}$ ------------(3)

$$\int_0^L A\sin\frac{n\pi x}{L} A\sin\frac{n\pi x}{L} dx = 1$$

$$A^2 \int_0^L \sin^2\frac{n\pi x}{L} dx = 1$$

$$\frac{A^2}{2}\int_0^L \left(1 - \cos\frac{n\pi x}{L}\right) dx = 1$$

$\frac{A^2}{2}\int_0^L (1dx) - \frac{1}{2}\int_0^L (\cos\frac{n\pi x}{L}dx)] = 1$

$[A^2 \times \frac{L}{2}$-0] = 1 $\quad A^2 \times \frac{L}{2} = 1 \quad A = \sqrt{\frac{2}{L}}$

$\Psi(x) = \sqrt{\frac{2}{L}}\sin\frac{n\pi x}{L}$

U3 .10) Tunneling Effect:

1) According to classical ideas particle with energy less than potential barrier ($E < V_0$) striking to wall of potential barrier it cannot leak through it. **2)** However, quantum mechanics principle is different than classical one and particle posses a wave like behavior which enables it to leak through barrier. **3)** This type of penetration of particles is known as **tunneling effect. 4) Tunneling** effect plays an essential role in several physical phenomena, such as the nuclear fusion that occurs as main source of energy inside stars like the Sun. -------------------------------------

- **Tunneling of α-particle:**

1) Quantum mechanically, de Broglie waves are associated with α particle. **2)** The wave function of α particles (and hence- particles themselves) has a very small but definite value so that it can **"tunnel"** through the barrier of binding energy of nucleus and make free itself. **3) The** probability of escape of α particle is very small *i.e.*, 1 in 10^{38} *i.e.*, α particle has to strike potential well of nucleus 10^{38} or more times before it emerges, but it would defenetly escape from necloues

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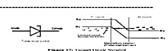


Figure 17: Tunnel Diode Symbol

U3 11) Tunnel diode–:

1) Tunnel diode (or Esaki diode) was invented by Leo Esaki and received Nobel Prize in Physics for the same. **2)** It is a *PN* junction device which exhibits negative resistance. **3)** It means when potential difference across tunnel diode is increases, current through it decreasesd. **4)** Tunnel diode is capable of making very fast operations and hence it is useful in microwave frequency region.

- **Principle of Tunnel diode:**

1) In tunnel diode *P* and *N* regions are heavily doped of the order of 1 dopant in 10^3 atoms of intrinsic semiconductor. **2)** The width of depletion layer is very narrow which is of the order of 10^{-8} m. **3)** When a very small potential difference is applied across the *PN* junction, there is a direct flow of electrons across the junctions even when electrons do not have sufficient energy to cross the potential barrier of depletion region. **4)** Quantum mechanically, de Broglie waves are associated with the electrons.

- **Advantages–and application tunnel diodes:**

1) Very fast switching, long life, high-speed operation, low noise, low power consumption are few advantages of tunnel diode. **2) Applications-Tunnel** diodes are used as logic memory storage devices, relaxation oscillator circuits, speed switch . Fm reciver

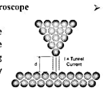
U3 .12Scanning Tunneling Microscope (STM):

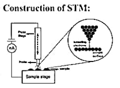
Scanning Tunneling Microscope (STM) is a non-optical microscope which is used for observing surfaces of materials atom by atom.

- **Principle of STM:**

1) In the STM, sharp tip of a tungsten needle is po- sitioned a few angstroms away from the sample surface. **2)** A small voltage is applied between the tip of the probe and the sample surface.
3) electrons are not permitted to leave the surface of the solid and enter into the regions of space **4)** Quantum mechanically, de Broglie waves are associated with the electrons. **5)** The wave function of electrons (and hence electrons themselves) has a very small but definite value so that it can tunnel across the gap between the tip and the sample. 6)The probability of tunneling electrons decreases exponentially as the distance of the tip from the surface increases. **7)** The probe is scanned over the surface of solid. Due to the variation in surface geometry of atoms, the tunneling current changes. **8)** When distance between atoms on the surface and tip is minimum, current through tip is maximum. Current is less at other locations. **9)** By processing information of position of the probe versus tunneling current, a topographical image of the surface can be created.

- **Construction of STM:**





1) Basically STM include scanning tip, piezoelectric controlled scanner, distance control and scanning unit, vibration isolation system, and computer.
2) Scanning tip - The STM has a metal needle that scans a sample horizontally.
3) The needle is so sharp that it has just a single atom on its tip.

- **Working Tunnel current:**

1) Tip of STM scans the sample surface. **2)** The electrons **tunnel** from tip to the sample. **3)**This creates a tunneling current of the order of few picoAmperes (pA) to a few nanoAmperes (nA). **4)** This current is amplified and given to data processing unit.

- **Sensitivity of STM:**

1) As the tip of the STM moves over the sample surface, its distance continuously changes due to curvature of atoms. **2)** Thus, the output current also changes. Approximately, for a distance of an atomic di- ameter, the current changes by a factor of 1000 time **3)** Thus, STM is very sensitive.

- **Applications of STM: 1)** STM is used

to study the arrangement of individual atoms on the solid surfaces. **2)** STM can be used for examining characteristics of material surface including roughness, surface defects and molecular size. **3)** nan

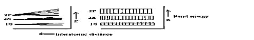
mind spark

U4.1) Valence band conduction band forbidden band :

- **Valence band :1)** The electrons in the inner shells are strongly bonded to their nuclei while the electrons in the outermost shells are not strongly bonded to their nuclei. **2)** The electrons in the outermost shell are called valence electrons. **3)** The band formed by a series of energy levels containing the valence electrons is known as valence band or highest occupied energy band. **4)** The valence band is completely filled with electrons at 0 K.
- **Conduction band :1)** The next higher **permitted** energy band is called the conduction band. **2)** This band may be either empty or partially filled with electrons. **3)** Conduction band may be defined as the lowest unfilled permitted energy band. **4)** The electrons occupying the conduction band are known as conduction electrons and these electrons move freely in the conduction band.
- **Forbidden gap: 1)**The conduction band and valence band are separated by a region or a gap known as Forbidden band or forbidden gap. **2)** This band is collectively formed by a series of non-permitted energy levels and is a measure of E_g **3)** Thus, E_g is the amount of energy that should be imparted to the electron in the valance band for its migration to the conduction band. **4)** These bands valance electron happens to absorb enough energy, it jump across the forbidden energy gap and enters the conduction band.

U4.2) Free electron theory: 1) The electrons in a partially filled conduction band are relatively free to move in the specimen as they are not bound to any atom but are in a band which is shared by entire crystal. **2)** These electrons are called as free electrons.
3) The electrons well inside the specimen are surrounded by positive ion cores from all the sides, hence net force exerted by the iron cores (or lattice points) on electrons is zero.
4) Due to the thermal energy, the electrons are in the constant motion with average velocity of 10^5 m/s path. 5) This results in net zero current. On the way it collides with the lattice points which are in vibration motion due to thermal energy. 6) This reduces the velocity of electrons and comes to almost rest. This result in small amount of resistivity and the loss of energy is converted into thermal energy. 7) The average time between collisions is called the mean free time and length of the path during this free time is called the mean free path.

U4.3) Band theory of solids: 1) In solids, the atoms are closely packed which vibrate about their mean position. **2)** The nucleus is considered at rest due to large mass and orbital electrons which are responsible for most of its properties of solids. **3)** To form a solid, a large number of atoms are to be brought very close to each other. **4)** Each atom get affected by neighboring atoms but out of which energy levels of inner shell electrons are not much affected by presence of neighboring atoms. **5)** The effect of bringing one atom close to other is to split single sharp energy levels into two levels. **6)** As per Paulie's exclusion principle, not more than two interacting electrons can have same energy level & therefore new energy levels must be established. **7)** This group of discrete but closely spaced energy levels is called as energy band. **8)** Each band contains many discrete levels depends on number of atoms are present, so there are N possible levels in each band & they can be occupied by 2N electrons



Q4.4) Hall Effect and Hall coefficient:-
1) If metal or a semiconductor strip carrying a current I is placed in a transverse magnetic field B, an electric field E is induced in direction perpendicular to both B & I, this phenomenon is known as Hall effect. **2)** It is used to detect whether a semiconductor in N-type or P-type. **3)** This Hall effect was discovered by Edwin H. Hall in 1879.
4) A semiconductor with current (Ix) is placed in magnetic field (Bz) perpendicular to current i.e. along z-axis. **5)** The current (Ix) flows due to external applied voltage (Vx) along positive X-direction.

- **Hall Voltage: -** These net charges induce an electric field (Ey) in y-direction & known as Hall field (EH) & this Hall field produces voltage across the semi-conductor called **Hall voltage (VH).**

VH =wEH --------------- (1) Hall voltage
VH = Measured Hall voltage.
w = Thickness of metallic strip.

- **In steady state, magnetic field force will be exactly balanced by induced electric field force**.:-

e E_H = Bz ----- e Vx-----(2) put (2) in (1)

V_H =w ----- Bz Vx ----(3)

E_H /Jx = - (Bz Vx)/(neVx)

E_H = - (Bz Jx)/(ne) Hall field

---

n-type semiconductor drift velocity Hall :-

Vx = Jx/eP = Ix /[ep(wd)] (4) Put (4) in (3)

VH =(w Bz Ix) /[ep(wd)]

VH =(Bz Ix) /[epd ---- (5)

P =(Bz Ix) /(VHed) (6) Holeconcentration.

In an n-type semiconductor,
VH =- (Bz Ix) /[end]----(7)

n = -(Bz Ix) /[VH ed]---(8) electron con---

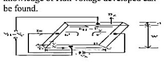
- **The Hall coefficient :-** is defined as,

electric field strength per unit surface current density due to unit transverse magnetic field.

1) RH = -1/ ne = 1/ρ = 1/ pe VH =[(Bz Ix)/d x 1/[ep]
VH =[(Bz Ix)/d] x RH
RH = (VHd)/[Bz Ix] = (EHwd)/(Bz Ix)
But J = I/ A = Ix/wd
RH = EH/(BzJ) Hall coefficient.
1)Hall coefficient is negative for free e^- and is constant for metal.2) In some cases, it has been found that RH is positive for some semiconductor; it means that charge carriers are positive known as holes.

- **Importance of Hall effect**

1) It can be used to determine whether the specimen is metal, semi-conductor or insulators.
2) The sign of current carrying charges can be found.
3) The mobility can be measured accurately.
4) Number of free electrons/unit volume of conductors can be calculated from Hall coefficient RH.
5) Knowing RH of given material, knowledge of Hall voltage developed can be found.



U4 5) Fermi-Dirac probability distribution function :-1) In solid, there are large no of atoms are closely packed. **2)** Each atomic level split into a large no. of closely packed levels and energy bands are formed. **3)** According to Pauli's exclusion principle, No two electrons occupied in same quantum state. **4)** The highest occupied energy levels by e- at 00k is called **Fermi level and energy corresponding to it is called Fermi energy(Ef). 5)**The distribution of electrons, among energy level is described by distribution function F(E). **6)** Distribution function is defined as the probability that level E is occupied by e_- **7)** At T =00k F(E) =) 1 0 E < E f E > E f .. **8)** It show that, all levels below Ef are completely filled and above Ef are empty. **9)** If temperature increases above 00k , then some e- gain energy and jump into higher state and therefore we get plot of distribution function w.r.t. energy for different temperature is shown below **,10)** The distribution function at **T = ook is**

F(E) = 1/[(e(E-Ef)/kT]+1, k = 1.38x 10-23 J/K = 8.63 x10-5 eV/k.This is known as Fermi-Dirac distribution function.

11) At T= 0ok, E< Ef all energy levels below Fermi level Ef are filled.
F(E) = 1/[(e(E-Ef)/kT]+1= 1/[(e-∞)+1 = 1/[(1/∞)+1] = 1

12) At T= 0ok, E > Ef

F(E) = 1/[(e(E-Ef)/kT]+1= 1/[(e∞)+1 = 1/[∞] = 0

13) At T> 0ok, E = Ef, e(E-Ef)/kT =1
F(E) = 1/(1+1) = ½

U4 6) Position of Fermi-level in intrinsic semiconductor :- 1) The Fermi level lies at centre of the forbidden gap because of equal concentration of free electrons and free holes. **2)** a) All levels have same energy.
3) Consider conduction band has energy (Ec) and valence band has energy (Ev). At T0k, Nv =Number of e^- in V.B. Nc =Number of e^- in C.B.
N =Nc +Nv , -----------------(A)
N =Total no of e-s in both bands.
4)the no. of e-s in conduction band is,
Nc =N F(Ec) ---- (1)
Where F(Ec) is probability of an e-s having energy (Ec) in conduction band.

5) By Fermi-Dirac distribution function,
F(Ec) = 1/[(e(E - Ef)/kT]+1---- (2)
Put (2) in (1)
Nc = N/[(e(E - Ef)/kT]+1-------- (3) Similarly,
Nv = N/[(e(E - Ef)/kT]+1 ---(4) Put (4) in (a)

N = {N/[(e(Ec- Ef)/kT]+1} + { N/[(e(E Ef)/kT]+1 }

1 = (1+ e(E - E)/ kT +1 + e(E - E)/kT)/(e(E - E)/kT+1) x(e(E - E)/kT]+1]

[(e(E - E)/kT+1) x (e(E - E)/kT+1] = 2 + e(E - E)/kT + /(e(E - E)/kT

1 + e(Ec+ Ev-2Ef)/KT =2

e(E + E -2E)/KT = 2-1=1

(Ec-Ev -2Ef)/(KT) = ln1 = 0 Ec-Ev -2Ef =0

Ef = (Ec-Ev)/2----- (5)

Dependence of Fermi level on temperature for extrinsic semiconductor =
U4.7) 1) Effect of temperature on n-type material ------>

- **At low temperature :- 1)** When temperature of semiconductor is low, only few donar atoms get ionized and electrons move from donar level to conduction band. **2)** Hence Fermi level for n-type semiconductor at low temperature lies midway between bottom of conduction band and donar level.
- **At moderate temperature :- 1)** At moderate temp' all donar atoms are ionized so concentration of electrons in conduction band is equal to concentration of donar atoms. **2)** When temp' increases Upto moderate value, Fermi level slowly shifts away from conduction band and moves towards centre of forbidden gap.
- **At higher temperature-: 1)** At higher temperature, concentration of transfer of electrons from valence band to Conduction band is more compared to concentration of electron from donar atoms and Fermi level is shifted to middle of forbidden gap.

Q2, Effect of temperature on P-type material--->

- **At low temperature :- 1)** multaneously, holes are produced in valence band.

2) So, Fermi level lies in middle of top of valence band and acceptor level.

- **At moderate temperature :-1)** At moderate temperature all acceptor levels are filled.

2) So, at moderate temperature, Fermi level gradually moves up i.e. moves towards middle of forbidden gap.

- **At high temperature:- 1)** At very higher temperature, contribution of C.B. for formation of holes in V.B. is more Compared to acceptor impurity. **2)** Hence at very high temperature, Fermi level approaches middle of energy gap i.e. position of Efi for intrinsic semiconductor.

U4.8) P-N junction diode:- 1) A P-N junction is a metallurgical boundary in a semiconductors crystal in which, holes are majority carriers on one side and e-s are majority carriers on other side. **2)** As a result , the free e-s from n-type diffuse into P-type and holes from P-type diffuse into N-type. **3)** As free electrons from N-type diffuse into P-type the pentavalent atoms loose electrons to become positive ions. **4)** When holes move away from P-type, the acceptor impurity atoms gain electrons to become negative ions.
5) Thus positive ions are formed in N-type and negative ions in P-type near junction due to which an electric field develops which oppose further diffusion of charge carriers.
6)Under eqm conditions, the electric field becomes sufficient to oppose the diffusion and a region is formed near junction which contains positive and negative immobile ions.
7) This region is known as depletion region as space charge region and potential difference across this region is known as barrier potential.

U4. 9)Band structure of P-N junction diode under zero bias, forward bias and reverse bias

- **ZERO Bias:- 1)** In P-type material Fermi level is located close to top of V.B. while in N-type material Fermi level located close to bottom of C.B. **2)** During formation of P-N junction, carriers cross junction. **3)** Crossing continues till Fermi level on two sides equalize **4)** The C.B. in P-region is above conduction band in N-region by an energy eVB, where VB is potential barrier across junction. **5)** Due to presence of potential barrier across junction, e-s in C.B. of N- region cannot cross junction, so no any current flow through diode.
- **Forward Bias :- 1)** When battery of voltage V is connected with its positive terminal to P- region and negative to N- region. **2)** Due to F.B eqm condition get disturbed & position of Fermi level & energy bands are changed. **3)** Due to forward bias mode, the energy of e-s in N-region increases by an amount eV. **4)** Fermi level on N-side rises by eV and energy band adjust position Hence potential barrier reduced to e(VB - V) & barrier width is reduced. **5)** So e-s in N-region now face small potential and can cross junction more easily.
- **Reverse Bias :-1)** When battery of voltage V is connected with its positive terminal to N- region and negative to P- region. **2)** Energy of electrons in N- region reduced by an amount eV. Hence potential barrier increases to e(VB+V) so barrier with increases. **3)** Due to greater potential barrier e-s cannot cross the junction or majority carrier not cross junction.

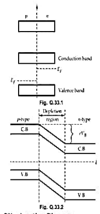
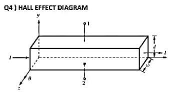


Fig. G.33.1
Fig. G.33.2
PN – Junction Diagram

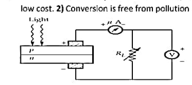
Q4) HALL EFFECT DIAGRAM



U4.10) Photovoltaic Effect & Solar cell -: 1) The phenomenon of emission of e^- from a substance when exposed by light or any other radiation of suitable wavelength and frequency is called photoelectric effect and that electrons thus emitted are called photoelectrons. **2)** Photovoltaic is direct conversion of light into electricity at atomic level. **3)** The photovoltaic effect was 1[st] noted by Edmund, Becquerel in 1839.**4)** In 1905, Albert Einstein described nature of light & photoelectric effect.

U4. 11) Solar cell ---> Principle:- 1) Solar cell is totally based on photovoltaic effect. **2)** It is used to convert solar energy into electrical energy.

- **Construction:- 1)** A solar cell is made by P-N junction which is used to convert solar energy into electrical energy. **2)** A solar cell are made from semiconductor materials like Si, Ge etc. **3)** Large no. of solar cells are made from a high purity single crystal of Si with minute amount of impurity boron & phosphorous. **4)** A thin layer of P-type material doped on N-type material to form P-N junction. **5)** Thickness of P-layer is very small. **6)** To enhance or to increase value of transmission of light into material, an anti-reflection coating is layered on P-type layer.
- **Working :- 1)** When P-N junction is exposed to sunlight, photons of energy hV are absorbed, if hV is greater than band gap Eg. **2)** Electron-hole pairs are then generated in both P-side & N-side of junction. **3)** The e' & holes that are produced within small distance of junction reach space charge region by diffusion. **4)** The electron-hole pairs are separated by strong barriers field existing across space charge region. **5)** Electron in P-side slide down barrier potential to move to N-side while holes in N-side move towards P-side. **6)** When load resistance is connected across the diode currents flows in ckt. **7)** When diode terminals are short circuited, maximum currett obtained is called short-circuit current (Isc).
- **I-v characteristics of solar cell :- 1)**Fill factor : Fill factor of solar cell is defined as ratio of expirationally maxm power to ideal power. Im xVmFill factor = - Isc xVoc
  2) Efficiency of solar cell = Im xVm ή = - Isc xVoc
- **Application of solar cell : 1)** Solar cells are used in satellite & space vehicle. **2)** Solar cells are used in telecommunication system i.e. in T.V. transmitter. **3)** Again used in burglar alarm, fire alarm. **4)** Solar cells are used in PV street lighting is most applicable in rural areas. **6)** Solar cells are used in many home applications.
- **Merits of solar cell :-1)** For this conversion, solar energy available in large amount at low cost. **2)** Conversion is free from pollution like chemical thermal or radioactive.



- **Demerits of solar cell :- 1)** Solar energy is not always constant. **2)** It changes with time of day. **3)** Hence output is not constant energy.

mind spark

U5.1) Magnetic dipole :- 1) Magnetic dipole is generally a tiny magnet of microscopic to subatomic dimensions generated due to current loop. **2)** Electrons circulating around atomic nuclei, electrons spinning around their axes, and rotating positively charged atomic nuclei all are magnetic dipoles. **3)** Magnetic dipole is referred to smallest magnetic unit having two poles (north and south) that produces magnetic field and are inseparable from each other. **4)** A single monopole has never been observed.

U5. 2)Magnetic dipole moment -: 1) The strength of a magnetic dipole is represented by magnetic dipole moment. It is a measure of a dipole's ability to align itself according to direction of external magnetic field. **2)** The magnetic moment can be considered to be a vector quantity with direction perpendicular to the current loop in the right-hand-rule direction. **3)** Magnetic dipole moment is defined as the maximum amount of torque caused by magnetic force on a dipole that arises per unit value of surrounding magnetic field in vacuum.

U5.3) Magnetic field strength (H)-: 1) The strength (or intensity) of magnetic field at any point in magnetic field is force experienced by a unit north pole placed at that point. It is denoted by H. **2)** The unit of H is ampere-turns per meter (A/m) in SI system.

U5.4) Magnetization (M) :- 1) Magnetization (or intensity of magnetization) is the measure of magnetism of magnetic materials. It is defined as magnetic moment per unit volume and denoted by M. **2)** The unit of magnetization in SI system is amperes per meter (A/m). **3)** As magnetization is induced by magnetic field, M is proportional to H. Thus, M ∝ H or M =χ H Where, χ is called as magnetic susceptibility.

U5.5) Magnetic Susceptibility (χ)-: 1) The magnetic susceptibility of a material is a measure of the ease with which the material can be magnetized. It is defined as magnetization (M) produced in the material per unit applied magnetic field (H). **2)** Hence, χ= M/H **3)** Materials having high susceptibility are easily magnetized.

U5.6) Magnetic induction or magnetic flux density (B) :1) A magnetic field is schematically represented by lines of magnetic induction or magnetic flux density). **2)** The magnetic flux per unit area is defined as magnetic flux density. **3)** Magnetic induction is the number of lines of force through a unit area of cross section perpendicularly. **4)** Thus, B = ϕ/A.

U5. Magneto optical recording:- Basic arrangement 1) Magneto-optical recording is a method of storing and retrieving data using a laser and a magnet **Recording the data 1)** The disk is coated with film that initially is uniformly magnetized. The magnetic layer side faces towards the laser beam. **2)** A laser beam is used to demagnetize a small spot on the film by heating it above a critical temperature (the Curie point) by disordering the magnetic domains. A local magnetic field determines the direction in which the spot is magnetized when it cools. **3)** A relatively weak magnetic field is applied to this region to modify its magnetization. The tiny region that is magnetized is treated as 1 while the un magnetized region is treated as 0. **Reading the data 1)** To read the information, the disk is scanned by polarized light from a low-power laser. The laser light is reflected from the surface of the media. Its Polarization rotate according direction(kerr effect) ..

U5.7) Absolute Permeability:-1) Absolute permeability is a fundamental property of a material in the context of magnetism and electromagnetism.**2)** It is represented by the symbol "μ" (mu) and is measured in henries per meter (H/m) or tesla meters per ampere (T·m/A) **3)** Absolute permeability describes how easily a material can be magnetized when subjected to an external magnetic field.**4)** In simple terms, it quantifies how much magnetic flux a material can support for a given magnetic field intensity.

U5.8)Relative Permeability:-1) Relative permeability is a dimensionless quantity that relates the magnetic permeability of a material to the permeability of free space (vacuum).**2)** It is represented by the symbol "μ_r" (mu_r) and has no units since it is a ratio. **3)** Relative permeability is used to describe the magnetic behavior of a material concerning the behavior of a vacuum or air in the same magnetic field.**4)** It is often used to compare the magnetizing capabilities of different materials and their response to an applied magnetic fld

U5.9) Relationship between Absolute and Relative Permeability:-1) The relative permeability (μ_r) of a material is defined as the ratio of its absolute permeability (μ) to the permeability of free space (μ_0).**2)** Mathematically, it can be expressed as: $\mu_r = \mu / \mu_0$. **3)** In SI units, the permeability of free space (μ_0) is approximately 4π × 10^(-7) H/m.

U5.10) Diamagnetic Materials: 1) Diamagnetic materials are substances which when placed in an external magnetic field develop a weak magnetism in opposite direction of the external magnetic field. **2)** The atoms have very small magnetic moment. **3)** They slightly repel the magnetic lines of forces. **4)** The examples are bismuth, silver, copper and hydrogen. **5)** The relative permeability of these materials is slightly less than one i.e. μr < 1.

U5.11)Paramagnetic Materials:-1) Paramagnetic materials are substances which when placed in external magnetic field acquire a feeble (small) magnetism in the direction of the magnetic field. **2)** The atoms are slightly oriented along the direction of the external magnetic field. **3)** They attract the lines of force slightly. **4)** The examples are aluminum, tin magnesium etc.**5)** The relative permeability materials is slightly above than one i.e. μr > 1.

U5.12)Ferromagnetic Materials:- 1) Ferromagnetic materials are metallic crystals which when placed in external magnetic field becomes strongly magnetized in the direction of the field. These materials are strongly attracted by a magnetic field. **2)** These materials are strongly oriented along the direction of the external magnetic field. **3)** They attract the lines of force strongly. **4)** The examples are iron, steel, nickel, cobalt etc.

U5.13) Orbital motion of electrons-: Inside an atom, electrons move around a nucleus in specific orbits. Each electron orbit is equivalent to a tiny current loop. It behaves as an elementary magnet having a magnetic dipole moment. The sum of orbital magnetic moments of individual electrons generates the total orbital magnetic moment of an atom. by Bohr Magneton ***The nuclear spin:- 1)**The nucleus spins around itself and it also contributes to magnetic moment of atoms due to magnetic field produced by protons. **2)** It can be shown that elementary nuclear magnetic moment is given by
μ = 5.05 × 10-27��/m2 ��

U5.14) Diff Diamagnetic, paramagnetic Ferromagnetic

Sr.	Property	Diamagnetics	Paramagnetics	Ferromagnetics
1	Behavior in external magnetic field	Develop a weak magnetism in opposite direction	Develop a weak magnetism in the same direction	Develop a strong magnetism in the same direction
2	Alignment of magnetic dipoles in external magnetic field	Opposite direction	and weak	Same direction and strong
3	Response to external magnetic field	Slightly repelled by external magnetic field	Slightly attracted by external magnetic field	Strongly attracted by external magnetic field
4	Relative permeability (μ)	μ < 1	μ > 1	μ >> 1
5	Susceptibility (χ)	Very small and negative	Less than one but positive	Very high
6	Effect of temperature on susceptibility χ	Is independent of temperature	Obeys Curie law	Susceptibility χ decrease with temperature in complex way
7	Curie Point (above which become paramagnetic)	No Curie point	No Curie point	Have definite Curie point
8	Hysteresis (lag in change on magnetization)	Not exhibited	Not exhibited	Exhibited
9	Retentivity (Residual magnetism)	Not exhibited	Not exhibited	Exhibited
10	Examples	Bismuth, silver, copper, hydrogen, etc	Aluminum, tin magnesium etc	Iron, steel, nickel, cobalt etc

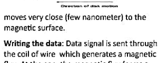
U5.15) Magnetic storage :-Magnetic storage is one of the most widely used digital data storage using a magnetized medium. Several types of magnetized media are used to store data such as **magnetic tape, floppy disks and hard disk drives.**

- **Storage medium:-**The medium used in

magnetic storage devices is coated with iron oxide, which is a ferromagnetic material. The storage media contains magnetic surface and it is divided into very small regions of mostly uniform magnetization.

Basic Principle ;-There are two types of magnetic polarities i.e. N-S and S-N each one used to represent either zero or one. Computer systems need to store data in digital format consists of binary information

Read and write heads:-The drive uses a motor to rotate the media at a high speed. The data is written and read using a small device called heads. Each head has a tiny electromagnetic, which consists of an iron core wrapped with wire. A read-write head



moves very close (few nanometer) to the magnetic surface.

Writing the data: Data signal is sent through the coil of wire which generates a magnetic flux. At the gap, the magnetic flux forms a fringe pattern. This flux magnetizes small region of the oxide on the media and magnetization of that area change. The information is stored on the disk in the form of zero's (unmagnetized region) and ones (magnetized regions).

Reading the data:-The read head is moved along the surface of the storage media. The information stored on the magnetic devices i.e. the regions of magnetization and demagnetizations are detected by the read

U5.16) Explain zero electrical resistance property of superconductor---> property :-
1) The electrical resistivity of superconductors is zero. **2)** The experimental testing of zero resistance was tried by connecting the speciman at room temperature to a battery. Avoltmeter was connected across the specimane **3)** The temperature of the speciman is then lowered.**4)** It was observed that below a particular temperature, known as the critical temperature, the potential difference across the speciman suddenly dropped to zero. --

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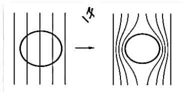
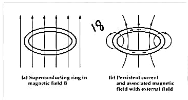
U5.17) Meissner effect :- 1) When a specimen is placed in a weak magnetic field and cooled below the critical temperature, the magnetic flux originally present in the specimen This effect is known as Meissner effect. **2)** This effect is reversible and the specimen returns to its normal state when its temperature is raised above its critical temperature. Thus superconductors act as perfect dia-magnets with zero magnetic induction in the interior when placed in weak magnetic fields. **3)** This indicates perfect diamagnetism.**4)** Meissner effect cannot be explained by assuming that the super-conductor is a perfect conductor with zero electrical conductivity.

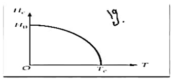
--U5.18) Persistent Current:-
1) The magnitude of current remains constant even though there is no source of e.m.f. as the resistance of the superconducting ring is zero. **2)** Such steady currents flowing in a super-conductor are called persistent currents. These currents flowing in the ring produce a magnetic field. **3)** Thus superconducting rings can be used to produce magnetic fields which do not require any power supply to maintain a constant field.

U5.19) Critical Magnetic Field:-
1) Superconductivity is destroyed by sufficiently strong magnetic fields.
2) The minimum value of the applied magnetic field required to destroy superconductivity is called the critical field H_C and is a function of temperature.
3) The Crictical Temprature Hc=0

Hc= H0 {1-(T/Tc)^2} Hc critical field abst 0







U5.20) Types Of Superconductors -: Type -| Superconductors :- 1) Type-I superconductors show complete Meissner effect when the applied magnetic field H is less than the critical field H_C. **2)** The magnetization in the specimen is proportional to the applied field and the specimen acts like a perfect diamagnet. **3)** For H > H_C, the magnetization is negligible and the specimen becomes a normal conductor. **4)** Pure elements show such magnetization curves. The values of H_C are very low.

- **Type -|| Superconductors:- 1)** Type-II superconductors are characterized by two critical fields H_{C1} and H_{C2}. **2)** Upto the lower critical field H_{C1} the specimen is perfectly diamagnetic and flux is completely ejected out from the specimen. **3)** The magnetization in the specimen is proportional to the applied field. Between H_{C1} and Hc2 Meissner effect is incomplete but electrically the specimen is a superconductor. **4)** his state is called the mixed state or the vortex state as the specimen is a electrically a superconductor but not magnetically. **5)** The values of H., may be 100 times or more higher than the critical field H, for type-I superconductors.

Property	Type-I Superconductor	Type-II Superconductor
Meissner effect	They exhibit complete Meissner effect.	They do not completely.exhibit Meissner effect
Diamagnetic Behavior	They show perfect diamagnetic behavior	They do not show perfect diamagnetic behavior
Critical magnetic field	They have only one critical magnetic field *H*..	They have two critical magnetic fields. At lower critical magnetic field *Hc*,flux starts penetrating the superconductor. At upper critical magnetic field *Hc*,flux enters into superconductor and it loses superconductivity.
Critical magnetic field	Highest value for *H*.is about 0.01 to 0.2 Wb/m	Highest value for *H* is about 30 Wb/m c2
Type	They are known as soft superconductors	They are known as hard superconductors
Applications	Not much useful due to low H.	Useful due to high H.
Examples	Aluminum, lead, mercury, etc	Nb-Sn, Nb-Ti, Nb-Zr, Va-Ga, etc

U5 .21) Explain D.C. and A.C. Josephson effect.---> 1) Two superconductors separated by a thin layer of insulator is called a weak link or Josephson junction. **2)**The superconducting electron pairs (Cooper pairs) tunnel through the insulating layer from one superconductor to another.

D.C. Josephson effect:- The insulating layer introduces a phase difference between the wave function of cooper pairs on opposite sides. Due to this, a super-current appears across the junction even though the applied voltage is zero. This effect is known as dc Josephson effect.

A.C. Josephson effect : 1) Radio frequency current oscillations are produced across the junction when a d.c. voltage is applied across it. Also, when a radio frequency voltage is applied along with the d.c. voltage, it can cause d.c. current across the junction. **2)** If a dc. voltage 'V' is applied across the junction, the current oscillates with frequency 2eV/h. **3)** Josephson junctions are used in superconducting quantum interference devices (SQUIDS) which are used as diagnostic tools in detecting brain signals.

U5.22) Superconducting Quantum Interference Devices (SQUID)

A SQUID (Superconducting Quantum Interference Device) is a very sensitive magnetometer used to measure extremely subtle (small) magnetic flux of the order of 10−18 Tesla. Their working is based on superconducting loops containing Josephson junctions.

Construction of SQUID-: There are two main types of SQUID: direct current (DC) and radio frequency (RF). A radio frequency (RF) SQUID is made up of one Josephson junction, which is mounted on a superconducting ring. A direct current (DC) SQUID consists of two Josephson junctions in parallel, which is more sensitive.
--> Construction:- SQUIDs are usually fabricated from lead or pure niobium. The tunnel barrier is oxidized onto lead or niobium surface.

- **Applications of SQUID :- a) Magnetoencephalography (MEG):-** is a technique for mapping brain activities. It can detect magnetic fields produced naturally in the brain which is of the order of 10-14 T. The human heart also produces a feeble magnetic field of the order of 10 -14 T which can also be detected by SQUIDs.

B) MRI Scan: Magnetic resonance imaging (MRI), also known as nuclear magnetic resonance imaging, is a scanning technique for creating detailed images of the human body. The scan uses a strong magnetic field and radio waves to generate images of parts of the body that can't be seen with X-rays, CT scans or ultrasound. Water molecules in human body contain hydrogen nuclei (protons).

C) Non-destructive corrosion testing: The magnetism of the material changes due to the corrosion, which can be detected using SQUID .. **D) Earthquake prediction** :- can be done by detecting change in earth's magnetism **E) Mineral exploration** by detecting variation in magnetic fields inside earth crust .. **Geothermal energy survey, etc.**

U6.1)Non Distructive testing - Non-destructive testing (NDT) is a set of techniques used to evaluate and inspect materials, components, or structures without causing any permanent damage or alteration to them. These testing methods are essential in ensuring the safety, reliability, and quality of various objects without the need for destructive measures that would render the item unusable. NDT is widely used in industries such as manufacturing, aerospace, construction, oil and gas, automotive, and more.

- **Types Of Non Distructive testing:-1) Ultrasonic Testing :-** This method uses high frequency sound waves to inspect materials for internal flaws or changes in material properties. Ultrasonic waves are sent into the material, and the reflections or echoes from interfaces or defects are analyzed to detect cracks, voids, thickness variations, and other discontinuities. **2) Radiographic Testing (RT):-** In radiographic testing, X-rays or gamma rays are used to inspect materials. The object being tested is placed between the radiation source and a detector film or digital sensor. The transmitted radiation creates a shadow image on the detector, revealing internal defects like cracks, porosity, and inclusions. **3) Magnetic Particle Testing (MT):-**MT is primarily used for detecting surface and near-surface defects in ferromagnetic materials. The material is magnetized, and iron particles, either dry or suspended in liquid, are applied to the surface. These particles will be attracted to and gather around areas with magnetic flux leakage caused by defects, making them visible for inspection.

Sr.	Destructive testing	Non-destructive testing
1	Tests are carried out to find properties and behavior of the material under different external conditions.	Tests are carried out to find properties and the defects inside the material.
2	Properties of the material such as bending, tensile strength, compression, strength can be found out.	Properties of the materials cannot be found out.
3	Defects inside the material such as flaw, cracks, porosity cannot be located.	Defects inside the material can be located.
4	Tests are not possible to carry out on entire batch of products as it will destroy all parts in production.	Tests can be carried out on selected samples randomly and results can be correlated to other parts.
5	The object under testing is destroyed.	The object under testing remains intact.

U6.3) Ultrasonic Testing for Thickness (or gauge) measurement :- Method: 1) Using a transducer, ultrasonic waves of known frequency and velocity are sent along the thickness of a metal block or sheet. **2)** Ultrasonic waves travel through metal block and gets reflected from its bottom. **3)** The time required for reflection is calculated. **4)** As speed of ultrasonic waves and reflection time (echo time) is known, thickness or gauge of the metal block can be calculated using Thickness (T) = (Velocity of Ultrasonic Wave in Material) x (Time of Flight of Ultrasonic Wave) / 2. ※ **Applications:** This technique is used for gauge or thickness of the metal block or sheet..

U6.2)Acoustic Emission Technique (AET);-Principle: A mechanical load or rapid temperature or pressure is applied to the material under test and resulting stress waves generated are sensed by sensors. **Method: 1)** A localized external force such as an abrupt mechanical load or rapid temp-erature or pressure is applied to the part of the material being tested. **2)** A small material displacement or plastic deformation is produced inside the material. 3) This results into generation of stress waves inside the material in the form of short-lived, high frequency elastic waves. **4)** These stress waves are detected by sensors that have been attached to the material. The stress waves show discontinuities in the material where flaws or irregularities inside the materials. **5)** When multiple sensors are used, the resulting data can be analyzed by a CRO to evaluate locate discontinuities in the part. **Applications:** AET is applied to inspect and monitor pipelines, pressure vessels, storage tanks, bridges, aircraft, and bucket trucks, and a variety of composite and ceramic compont

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U6.3)Radiography Testing X-rays or γ-rays:- Principle: X-rays or γ-rays are passed through the material. The radiations are partially absorbed and partially scattered by the medium and partially by the defects. The characteristics of the radiations such as intensity get modified. ※ **Method:- 1)** X-rays or γ-rays are produces by a source of radiation (e.g. Coolidge tube in x-rays). **2)** The material under investigation is placed in the path of the radiation and the photographic plate. **3)** The beam of radiation is allowed to fall on the material. 4) Depending on the thickness and absorption characteristics of the material, some amount of radiation will be absorbed and scattered. **5)** Absorption of radiations is different in regions inside the material where defect is present and that are free of defect. **6)** The scattered radiations produce an image on the photographic plate. After developing the photographic plate and its analysis, the defects inside the material can be identified. - With a single radiogram the presence of defect can be detected. **7)** For getting exact position of the defect, the radiation should be passed through different angles in the material and resulting set of radiogram is analyzed. **Applications:-** Using radiography techniques various irregularities inside the material such as flaw, Cracks, presence of Cavities, Porosity can be detected.

U6.4)Ultrasonic Testing :-1) The frequency of sound waves audible to human ear ranges from 20 Hz to 20kHz.The sound waves having frequencies greater than 20 kHz are called ultrasonic or supersonics. ※ **Principle of Echo Sounding** :-Echo sounding is process in ultrasonic waves are generated by a transmitter, they are directed towards the object and reflection is received. 2) By knowing the time required to cover distance (transmitter and object) and velocity, distance of the object from transmitter can determined.------ **Q5**

Ultrasonic Testing for Flaw detection Method: 1) The testing mechanism mainly consists of transmitting transducer, receiving transducer and CRO. **2)** A transmitting transducer sends ultrasonic waves into the specimen. Reflected signals from back surface of the specimen are detected by receiving transducer and are input to a CRO. **3)** If there are no flaws in the specimen, output of CRO screen shows normal peaks. If there is any flaw present inside the specimen then CRO screen shows small peaks corresponding to the reflection of ultrasonic waves from flaw. **Applications**:- Flaw detector detects like holes, casting, flakes, cracks, tiny.

U6.5) What are nano-particles – 1) The radii of atoms and most of the molecules are less than a nanometer. **2)** Nanoparticles are generally considered to have radius in the range of 7 nm to 100 nm which can have 25 to 10° atoms. A cluster of 1 nm radius has approximately 25 atoms. **3)** This definition of nanoparticles based on size does not distinguish between molecules and nanoparticles as many organic molecules contain more than 25 atoms. **4)** particle size is less than the characteristic length of some physical phenomena, the particles show different properties. The nanoparticles show unique properties that change with their size. Its Known as Nano particle ,,

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U6.6) Optical properties of Nanoparticles metallic nanoparticles -The color of nanoparticles is different from bulk material. One of the daily life examples is of glass. Glasses are transparent, but when doped with different nanoparticles, adopt different colors like red, pink, blue, green, etc depending upon the dissolved nanoparticles.

Metal	Color for bulk	Color at nano-level
Gold	Yellow	Bright red
Silver	Colorless	Pale yellow

Optical properties:- 1) Every material has a characteristic size only below which size depend properties are realized. In semiconductors this size is the size of the exciton. **2)** In semi-conductor nanoparticles, as the particles become smaller and smaller, the energy gap increases and absorption peak shifts towards higher energy/frequency values. - This leads to shift in the absorption spectrum and change in color of particles.

U6,7) Electrical properties of Nanoparticles-: Electrical properties characterized by the free path of electron (path of the electron collision due atoms or ions). The free path changes at nanoscale to collision and tunneling within the conductor.
※ **Bulk conductor:** When voltage V is applied across the conductor, current I flowing through it is governed by Ohm's Law and has a linear variation.
※ **Characteristics at nanoscale:** If dimensions of conductor are in nanoscale (1-100 nm), there appears region around zero voltage for there no current. A single electron is transferred by tunneling when the voltage is ± e/2C. Therefore,the voltage is less than electron cannot be transferred. This gives a region of zero current at low bias voltage and is known as **'Coulomb blockade region'**. The electrons are transferred when the voltage is ± e/2C. The repeated tunneling single electron **produces 'Coulomb staircase'**.
※ **Electrical resistivity:** The materials of nano-sized grains have larger number of grain boundaries than corresponding polycrystalline materials. Electrical resistivity of materials having nano-sized grain is larger than the polycrystalline materials due to scattering of electrons at grain boundaries.

U6.8) Mechanical properties of Nanoparticles:- 1) Mechanical properties of materials depend upon the composition of material, bonds between the atoms and presence of impurity. When the size of materials is reduced to nano-scale (1-100 nm), materials tend to be single **crystal.** The measurements of elasticity, hardness, ductility show different behavior as compared to the bulk material. For example, in the case of metallic nanocrystalline materials, elastic modulii reduce dramatically. **2)** Plastic deformation in nanocrystalline materials strongly differ from that of polycrystalline bulk material i.e. if stress is removed the recovery to original shape/size is recovered more effectively. **3)** Hardness of materials is also related to the grain size. In the nanometer size range, the hardness increases with decrease of particle size.

Material	Form	Grain size	Young's modulus
Mg	Nanocrystal	~12 nm	Y = 3900 N/mm^2
	Polycrystalline	> 1μm	Y = 4100 N/mm^2

U6.9) Applications in medicine (targeted drug delivery) :- 1) The traditional drug delivery system, the drug is distributed to the affected tissues or organs of the patient's body as well as to the healthy tissues or organs. This leads to the side effects. 2) In the targeted drug delivery system, the drug is dissolved, entrapped, encapsulated or attached to a nano particle. The system is then embedded in a capsule which is guided towards the affected part of the body. 3) The capsule is opening at the specific tissues or organs controlled by externally applied magnetic field or infrared light or physiologically. Then drug can be delivered in controlled manner...
Drug is dissolved ==> Carriers for targeting drug
The system is injected in the body and guided towards targeted tissues or organs body
Nanoparticles and durgs are actived at the location of tissues or organ

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U6.10) Applications of nanotechnology in Electronics :-In the spin-electronic devices, spin property of electrons (instead of charge) is taken into consideration. Advantage with spin is that it cannot be easily destroyed by scattering from collisions other charges, impurities or defects. The electronic devices with typical dimensions of few nanometers in either of three directions display unique properties. Such devices are fast, compact, and relatively cheap. Such devices are typically known as **spin-electronic (spin-electronic) devices.**
Application Of SPIN:- 1) Single electron transistor (SET) -: The single electron transistor is a switching device in which a quantum dot is placed between the source and the drain. It uses controlled electron tunneling to amplify current. They offer low power consumption and high operating speed. **2) Spin valves:-**Spin values are commercially used in computer read heads. Their use has enabled to increase the data storage capacity of magnetic memory devices due to their ability to detect small magnetic fields.
3) Nanophotonics:- In nanophotonics, nanostructures (quantum dots, nanowires or 2-D thin films) or nanocomposites are used to produce light or detect light. They can be used for light production, propagation, manipulation like amplification, filter, detection etc.
6 Display technologies for TV and monitor The flat panel television or computer monitors are products of nanotechnology.

U6.11) Applications of nanotechnology in Space and defense:- Nanomaterials in various forms are used for reduction of weights of space vehicles, improving efficiency of solar cell, insulation of space vehicle. **1) Aerogels :-** Aerogels are designed using nanomaterials and have very low density typically 0.01–0.8 g/cm3. They are very light weight and poor conductor of heat and have potential **Applications in designing-** spacecrafts, defense equipment. **2) High efficiency light weight solar cells**:- Satellites or spacecrafts are mainly powered by solar energy. Currently solar cells have reached an efficiency of 30 - 40 %. Using luminescent dye sensitized nanoparticle based or nanoparticle-based solar cell arrays have potential to reduce the weight of solar cells as well as increase in efficiency.
3) Insulation for space vehicles :- Space vehicles should with stand harsh and extreme environments during launching and in space. Materials should also sustain high or low temperature and high or low pressure. Use of silica fibers and nanoparticles provide insulation in solid rocket motors and also they are better radiation protectors.
6) Detection of biological weapons :- Biological weapons may use dangerous microbes or viruses as weapons. Some nanoparticle oxides like CaO, Al2O3 and MgO interact with such chemicals much faster than microparticles and are ideally suited for fast decomposition of warfare chemicals ..

U6.12) Applications of nanotechnology in Automobiles:- Nanomaterials in various forms are used for designing sturdy structural parts, smooth and non-scratch paints, self-cleaning windows, better tires, reduction of harmful emission,
1) Sturdy structural parts:- Various body parts of vehicles are made up of steel, some alloys, rubbers, plastics etc. Nanotube composites have mechanical strength better than steel. **2) Smooth and non-scratch Paints:-** Cars are spray painted with fine particles. Nanoparticle paints provide smooth, non-scratch thin attractive coating.
3) Self cleaning glass for windows:- Self cleaning glass can be made by dissolving small amount of titania (TiO2) nanoparticles while manufacturing glass. Titania is able to dissociate organic dust in presence of UV light available in the sunlight. Drops of waters on glass give hazy look, but TiO2-containing glass can spread water evenly giving clear sight.
4) Better tires :-Tires of vehicles undergo wear and tear with use and also increase its weight. By using nanoparticle clay, better, light weight, less rubber consuming thinner tires are possible that can reduce the overall weight, increase in fuel consumption and speed.
5) Hydrogen fuel :-Instead of using conventional petro fuels, there are numerous advantg of using hydrogen as a fuel. When hydrogen fuel is burned it can only produce harmless water vapor. Hydrogen gas is normally stored in a metal cylinder under high pressure. Nanocylinders of carbon nanotubes have potential to store hydrogen in very small space.

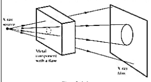

Fig. Q.6.1