Fill in the blank questions:

1. If an electron is confined to one-dimensional potential box of length L, the allowed energy values are given by E_n =_____.
2. According to de Broglie's hypothesis, a moving particle has _____ properties associated with it.
3. The wavelength λ associated with any moving particle of momentum p is ___.
4. The waves associated with material particles are called _____ or _____.
5. _____Possesses dual nature.

ANSWERS:
1. $n^2\pi^2\hbar^2/2mL^2$ 2. wave 3. h/p 4. matter waves, de Broglie waves 5.light

MULTLIPLE CHOICE QUESTIONS:

1. The wave function for the motion of the particle in a one dimensional potential box of lengths a is given by
   $\psi_n = A\sin(n\pi x/a)$, where A is the normalization constant. The value of A is
   (a) 1/a b)√2/a c) a d) √2/2

2. The energy of the lowest state in a one dimensional potential box of length a is
   (a) zero b)$2h^2/8ma^2$ c)$h^2/8ma^2$ d) $h/8ma^2$

3. The spacing between the n^{th} energy level and the next higher level in a one dimensional potential box increases by
   (a) (2n - 1) b)(2n + 1) c) (n-1) d) (n + 1)

4. Energy E of the photon of wavelength λ is
   (a) hc/λ (b) hcλ (c) c/λ (d) hλ/c

5. The equation that relates particle and wave aspects of matter.
   (a) v=h/p (b) λ=h/p (c) λ =h/c (d) v= p/h

ANSWERS

1.b 2. c 3.b 4.a 5.b

TRUE OR FALSE TYPE QUESTIONS:

1. Schrodinger's theory tells us how to obtain the wave function associated with a particle.
2. Laws of classical physics can explain the motion of micro particles.
3. λ=h/p is called de Broglie wave length.
4. $\Delta p_x . \Delta x < h$.
5. In German eigen means proper.

ANSWERS:
1. True 2. False 3.True 4.False 5.True

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At steady state / equilibrium $F_E = F_f$

$\rightarrow -eE = mv/\tau$

$\rightarrow \mathbf{v = (-e\tau/m)\ E}$ $\rightarrow(1)$

The above velocity of electron in equation (1) is known as **drift velocity**.

We know that current density J= Charge density X drift velocity

Charge density = -Ne (N = no. of electrons per unit volume)

Therefore $J = (-Ne)(-e\tau/m\ E)$

$\rightarrow \mathbf{J= (Ne^2\tau/m) * E \rightarrow (2)}$

Comparing (2) with (1)

We have $\boldsymbol{\sigma = Ne^2\tau/m}$

σ is directly proportional to τ. This is because τ is the time between 2 consecutive collisions i.e, mean free lifetime. $\boldsymbol{\tau}$ is also called **relaxation time**.

Let us suppose that an electric field is applied till the time drift velocity is established. Now, let the field be suddenly removed at some instant. The drift velocity after this instant is governed by:-

$F_E = -e\ E$; $F_F = -m\ v/\tau$

$\rightarrow m\ (dv / dt) = -e\ E - (m\ v)/\tau$ ---------- If E = 0 then

$m\ dv/dt = -mv/\tau \rightarrow dv/dt = -\ v/\tau$ ---------- (1)

$\rightarrow 1/v\ dv = -dt/\tau \rightarrow \int 1/v\ dv = -\int dt/\tau + C$

$\rightarrow \log v = -t/\tau + C$

$\rightarrow \log v = \log e^{-t/\tau} + \log C$

$\rightarrow \log v = \log(e^{-t/\tau}.\ C)$

$\rightarrow v = e^{-t/\tau}.C$, now at t = 0

$v_o = C$ therefore $C = v_o$

$\rightarrow \mathbf{v = v_o\ e^{-t/\tau}}$

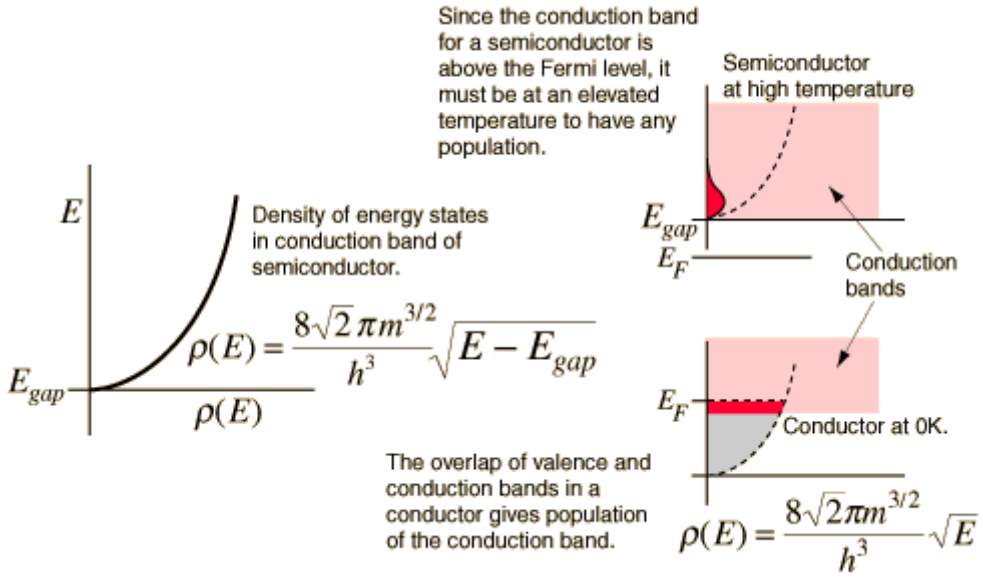
From (1) $\mathbf{v_{d,t} = v_{d,o}\ e^{-t/\tau}}$

Since $\tau$is the time between 2 successive collisions, it can be expressed as

$$\boldsymbol{\tau = (\lambda/v_d)}$$

λ = distance between 2 successive collisions, called mean free path of collisions.

same form, but the density of states for conduction electrons begins at the top of the gap.



CAUSES OF ELECTRICAL RESISTANCE

When electrons travel under the influence of an electric field, they are scattered causing resistance to its motion.

Other possible scattering mechanisms are due to vacancies, dislocations and other lattice imperfections.

Due to these scatterings, there is a change in the resistance of the conductors. Some theories attribute the resistance due to scattering of conduction electrons by the positive ion cores.

If an external field is applied or a heat source is supplied, then because of scattering the resistivity of the metal changes and this is a function of the temperature. This is a common feature of all metals except those of which are super conducting in nature. It should be noted that the resistivity ρ does not vanish even at OK. At low temperatures it varies at T^5. For other temperatures it is linear to temperature.

The resistivity of the metals with impurities exhibits similar behavior. This resistivity is expressed as:- $\rho = \rho_i + \rho(T)$

Where ρ_i = resistivity due to impurity

P(T) = resistivity due to thermal motion

As **T** $\rightarrow$**0**, the resistivity **$\rho = \rho_i$** " The temperature independent nature of ρ_i for small impurities is called as**" Mathiessens rule."**

BAND THEORY OF SOLIDS:

ORIGIN OF ENERGY BAND STRUCTURE IN SOLIDS

Bloch Theorem

The solutions of the Schrodinger equation for a periodic potential must be of the form:

$$\psi_k = u_k(r)e^{i\mathbf{k}\cdot\mathbf{r}}$$

where $u_k(\mathbf{r})=u_k(\mathbf{r}+\mathbf{T})$ is an amplitude function of the plane wave exp(i**kr**) and **T** is a translation vector of the crystal. The eigenfunctions of the wave equation for a periodic potential are the product of a plane wave exp(i**kr**) times a function $u_k(\mathbf{r})$ with the periodicity of the lattice. Wave functions of this form are called Bloch functions and they are very useful in calculations because they allow us to concentrate on only one period of the lattice to solve for the wave function of the electrons throughout the entire crystal.

1. It can be shown that for a 1D system, two and only two distinct values of k exist for each and every allowed value of energy E.
2. For a given E, values of k differing by a reciprocal lattice vector **G** give rise to one and the same wavefunction solution. Therefore, a complete set of distinct k-values will always be obtained if the allowed k-values are limited to 0 to **G** or equivalently. This leads to the concept of *Brillouin Zones.*
3. For an infinite crystal, k can assume a continuum of real values in the range specified in statement 2.
4. For a finite crystal, we adopt periodic boundary conditions. This means that we construct a ring of N atoms such that:

$$\psi_k(x) = \psi_k(x + Na)$$

$$\psi_k(x) = \psi_k(x + Na) = e^{ikNa}\psi_k(x)$$

Hence, $e^{ikNa} = 1$ and therefore:

Where k represents the state of motion of an electron having a momentum

$p = hK/2\pi$

and de – Broglie wavelength $\lambda = 2\pi/K$.

In simple one – dimensional model, we are considering K as directed along the x-axis and in general K is to be treated as a vector and it is called as a propagation vector. The above is for a one – dimensional model.

For a vector (sinusoial wave) or a 3 – dimensional wave, Kroing & Penny introduced a simple model for the shape of potential variation. The potential inside the crystal is approximation to the shape of rectangular steps.

1).Calculate the lowest energy of a Newton of mass $1.67 * 10^{-27}$ kg,, confined to move along the edge of an impenetrable box of length 10 -14 metre, plank's constant = $6.63 * 10^{-34}$ JS.

$E_n = n^2h^2/8ma^2$; Lowest Energy State, n= 1

Therefore $E_1 = 3.29 * 10^{-13}$ Joules.

$E1 = 3.29 * 10^{-13} / 1.6 * 10^{-19} =$ **$2.05 * 10^{6}$ ev**

2). Calculate the energy difference between the ground state and the first excited state for an electron in a one – dimensional rigid box of length 10^{-8} cm.

Mass of electron = $9.1 * 10^{-31}$ Kg h = $6.6 * 10^{-34}$ Js.

$E_n = n^2 h^2 / 8ma^2 = n^2 * (6.6 * 10^{-34})2/ 8 * 9.1 * 10^{-31} * (10^{-10})^2$

$= 0.5 * 10^{-17} n^2 J = 37 n^2$ev.

For ground state n = 1; E_1 = **36 ev**

First excited state, n =2 ; E_2 = **148 ev**

Hence, energy difference ($E_2 - E_1$) = **111ev**

3. An electron is tapped with near infinite potential well of length 0.1nm. What are the first three energy levels?

Soln. $E_n = n^2h^2/8ma^2 = 37.7n^2$ ev

$E_1 = 37.7$ev, $E_2 = 151$ev, $E_3 = 339$ ev.

4. What is the de Broglie wavelength of an electron accelerated from rest by 54V?

$\lambda = h/P = h/\sqrt{2mev} = 0.167$nm

5. An electron is tapped in a one dimensional box of length 10^{-10} m. Find a> how much energy must be supplied to excite the electron from the ground state to the first excited?

$E_n = n^2h^2/8mL^2$; $E_1 = 37$ev

$E_2 = 148$ ev; $E_2 - E_1 = 111$ev

Metals, insulators and semiconductors

Once we know the bandstructure of a given material we still need to find out which energy levels are occupied and whether specific bands are empty, partially filled or completely filled.

Empty bands do not contain electrons. Therefore, they are not expected to contribute to the electrical conductivity of the material. Partially filled bands do contain electrons as well as available energy levels at slightly higher energies. These unoccupied energy levels enable carriers to gain energy when moving in an applied electric field. Electrons in a partially filled band therefore do contribute to the electrical conductivity of the material.

Completely filled bands do contain plenty of electrons but do not contribute to the conductivity of the

Microstates

Macrostate	Possible Arrangements		No. of Microstates
	Compartment I	Compartment II	
0,3	0	a,b,c	1
1,2	a b c	b,c c,a a,b	3
2,1	a,b b,c c,a	c a b	3
3,0	a,b,c	0	1

Each distinct arrangement is known as the microstate of the system. For ex: the macro State (0, 3) and (3, 0) have only one microstate each where as the macro states (1,2) and (2, 1) have three microstates each.
In the above example, for 3 particles there are 8 micro states. That means for n particles there will be 2^n micro states.
"*The state of a system specified by the actual properties of each individual component*
in detail permitted by the uncertainty principle is known as microstate".I

Phase Space
The three dimensional space in which the location of the particle is completely specified by the three position coordinates(*dx,dy,dz*) is known as the position space.
A small volume element in the position space is given by: $dV = dx\,dy\,dz$

Similarly, The three dimensional space in which the momentum of the particle is completely specified by the three momentum coordinates(dp_x, dp_y, dp_z) is known as the momentum space.

A small volume element Γ in the momentum space is given by: $d\Gamma = dp_x\,dp_y\,dp_z$A combination of position space and momentum space is known as ***phase space.***

A small volume in phase space is given by: $\mathbf{d\tau} = dx\,dy\,dz\,dp_x\,dp_y\,dp_z$
i.e. $\mathbf{d\tau} = dV\,d\Gamma$

Thus a volume element **dτ** in phase space is the product of a volume element dV in position space and volume element d Γ in momentum space.

Cells in Phase Space:
The small volume **dτ** in phase space is called a cell.
The total no. of cells in phase space is given by:

It is assumed that the negative charge in electron cloud is uniformly distributed over a sphere of radius R and the spherical shape of the electron cloud is not altered on the application of the electric field.

. · . Charge density(i.e. charge/volume)of the charged sphere=$Ze/(4/3\pi r^3)$---(1)

Where Ze is the total negative charge.

Total negative charge in the sphere of radius x ,is $Q_e=-Ze(4/3\pi x^3)/\ 4/3\pi R^3$

→ $Q_e=-Ze(x^3/\ R^3)$-----(2)

The coulomb attractive force between the nucleus with charge $Q_P=+Ze$ and the electron cloud at a distance x from the center of the nucleus is given by:

$F=(1/4\pi\varepsilon_o)(Q_eQ_P/x^2) = -(Ze/R^3)x^3(Ze)/(\ 4\pi\varepsilon_o x^2)$

→ $F=(1/4\pi\varepsilon_o)[-Z^2e^2x/R^3]$----------(3)

Also the force between the nucleus and the electron cloud is given by

$F'=qE=ZeE$----------(4)

Under equilibrium conditions, these two forces are equal and opposite.

Therefore,from equations(3) and (4)

$ZeE= (Z^2e^2x/\ 4\pi\varepsilon_o\ R^3)$ →$E= Zex/\ 4\pi\varepsilon_o\ R^3$----------(5)

Due to shifting of the electron cloud,the amount of induced dipole moment is given by: $\mu(ind)=Zex$----------(6)

But from definition,the electronic polarisability of a molecule is the dipole moment induced per unit field strength resulting from shifts of electron clouds relative to nucleus , i.e. $\mu(ind)= \alpha_eE$----------(7)

Where α_e is the electronic polarisability

Therefore, from equations (6) and (7) : $Zex= \alpha_eE$-----(8)

Or $E= Zex/\alpha_e$

Now comparing equations (5) and (8) $Zex/\ \alpha_e = Zex/\ 4\pi\varepsilon_o\ R^3$

→ **$\alpha_e=4\pi\varepsilon_o\ R^3$**

Thus electronic polarisability is directly proportional to the volume of the atom.

1). The radius of helium atom is 0.55 A°. Calculate the polarisability of helium atoms

Sol) Given :r = 0.55 A^o

$\alpha_e = 4\pi E_o r^3$

$= 4 * 3.14 * 8.85 * 10^{-12} * (0.55)^3 * (10^{-10})^3$

➔ **$\alpha_e = 18.49 * 10^{-42}$ F/m^2**

2).A parallel plate capacitor consists of 2 plates of 2m x 1m.The space between the plates is 1mm and filled with a dielectric of relative permittivity ε_o. A potential difference of 300V is applied across the plates. Find:

1.The capacitance
2.The charge on the capacitor
3.The electric flux density
4. The potential gradient

Sol).Given:d=1mm;P.D.=300V;area=2mx1m

$C = kA\varepsilon_o/d$

$C = 2 X 1 X 7 X 8.85 X10^{-12} / (1 X 10^{-3)}$

➔**$C = 1.239 X 10^{-7}$ F**

$C = Q / V$ ➔ **$Q = 1.239 X 10^{-7} X 300$ ➔$Q = 371.7 X 10^{-7}$C**

Flux density : $D = k\varepsilon_o E$ ➔ $E = D / k\varepsilon_o$; Also $D = Q/A$ ➔ $D = 1.8585X10^{-5}$C/m^2

➔$E = 1.8585 X 10^{-5} / (7 X 8.85 X 10^{-12})$

➔**$E = 3 X 10^5$ N**

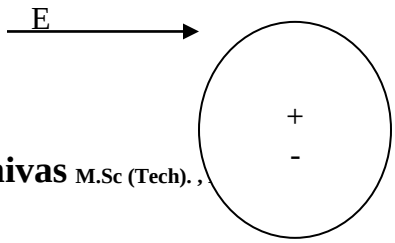
The Ionic Polarization:

The polarization produced by the relative displacement of the ions is called the ionic polarization.

The molecules of some materials are formed by combination of positive & negative ions. The combined structure of opposite ions in many of these materials is such that the molecules are neutral and without a net dipole moment. But when an electric field **E** is applied to such a material, the opposite kind of ions are pulled apart & the normal separation of ions increases. This process is resisted by binding forces and stops when 2 opposing forces balance each other. But the original form of the molecules is disturbed; dipoles are formed & polarized under **E**. This is in addition to the electronic polarization produced in all kinds of materials.

The corresponding polarizability is denoted by α_i.In most materials $\alpha_i << \alpha_e$ as the ions are heavier than the electrons.

The sum $(\alpha_e + \alpha_i)$ is sometimes called as the deformation polarizability.

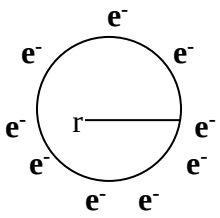


ORIGIN OF MAGNETIC MOMENT:

The magnetic moment which areises is due to three reasons .They are:

1. Magnetic moment due to orbital motion of electrons
2. Magnetic moment due to the spin of electron
3. Magnetic moment due to spin of nucleus

1.MAGNETIC MOMENT DUE TO ORBITAL MOTION:



we know

i = -e/T

Linear velocity v = displacement / Time

→ T = displacement / velocity (angular velocity)

T = displacement / ω = 2π/ ω

→i = -e ω /2π

Magnetic moment μ= i * A

μ=-e ω /2π * π r^2

μ=-e ω r^2 /2

Again, we know that angular momentum L = mv * r

v = r ω

→ L = m r ω

→ r^2 ω = L /M

The net magnetic moment μ = eL/2m

➔ μ= $(-e/2m)^2$

L is angular moment

e/2m is called as gyro magnetic ratio

L = l (ħ)

ħ = h/2π

lh/2 π = L

μ= -e/2m * hl/2 π →-(eh/4 πm)l

(eh/4πm)is called Bohr – magneton

1 Bohr magneton = 9.2 X 10^{-24} Jm^2 /Wb

l → orbital quantum number

2.MAGNETIC MOMENT DUE TO DUE TO SPIN OF ELECTRONS:

μ_s = (eh / 4πm_e)1/2 m_e → mass of electron

3.MAGNETIC MOMENT DUE TO SPIN OF NUCLEUS:

μ_p = (eh /4πm_p) m_p → mass of Proton

able to retain their magnetic properties after the external field has been removed.
2. Ferromagnetic materials have some unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of magnetic domains.
3. In these domains, large numbers of atom's moments (1012 to 1015) are aligned parallel so that the magnetic force within the domain is strong. When a ferromagnetic material is in the unmagnitized state, the domains are nearly randomly organized and the net magnetic field for the part as a whole is zero.
4. When a magnetizing force is applied, the domains become aligned to produce a strong magnetic field within the part.
5. Iron, nickel, and cobalt are examples of ferromagnetic materials. Components with these materials are commonly inspected using the magnetic particle method.

6.The magnetic moment, intensity of magnetisation and magnetic susceptibility are all positive and quite large and magnetic permeability is of the order of hundreds and thousands.

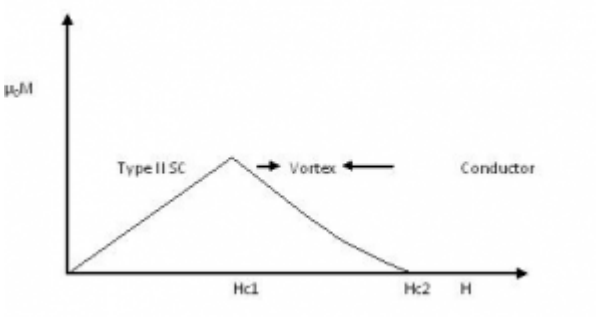
7.The magnetic susceptibility decreases with rise of temperature.

Antiferromagnetism

1. Antiferromagnetism, type of magnetism in solids such as manganese oxide (MnO) in which adjacent ions that behave as tiny magnets (in this case manganese ions, Mn^{2+}) spontaneously align themselves at relatively low temperatures into opposite, or antiparallel, arrangements throughout the material so that it exhibits almost no gross external magnetism.

2. In antiferromagnetic materials, which include certain metals and alloys in addition to some ionic solids, the magnetism from magnetic atoms or ions oriented in one direction is canceled out by the set of magnetic atoms or ions that are aligned in the reverse direction.

3. This spontaneous antiparallel coupling of atomic magnets is disrupted by heating and disappears entirely above a certain temperature, called the Néel



b) The state between the lower critical magnetic field (Hc1) and upper critical magnetic field (Hc2) is known as vortex state or intermediate state.

After Hc2, the Type II superconductor will become conductor.

c). Type II superconductors are also known as **hard superconductors** because of this reason that is they loose their superconductivity gradually but not easily.

c) Type II superconductors obey Meissner effect but not completely.

d) Example of Type II superconductors: NbN (Hc = 8 x 10^6 Tesla), Babi$_2$ (Hc = 52 x 10^3 Tesla)

e) Application of Type II superconductors: Type II superconductors are used for strong field superconducting magnets.

Applications of Superconductors

HIGH-ENERGY APPLICATIONS:

Superconducting inductors that must transport relatively high current densities in high magnetic field have a variety of applicatrons:

1. Coils for windings in motors and generators (Utility, automotive, marine propulsion applications).
2. High-field magnets for research applications (Particle accelerators, material research).
3. Magnetic Levitating (MAGLEV) coils for high-speed ground transportation.
4. Superconducting Magnetic Energy Storage (SMES)(Electric utilities, Military applications).
5. Magnetic containment fields for thermonuclear fusion research.
6. MHD (Magnetohydrodynamic) EMT (electromagnetic thrust) systems for marine propulsion applications.
7. MRI (Magnetic Resonance Imaging) which requires extremely uniform magnetic fields at the 10-20 kgauss level (formerly known as NMR, nuclear magnetic resonance).