APPLIED PHYSICS 1

(CBCGS MAY 2017)

Q1](a) Draw the unit cell of HCP structure and work out the no. of atoms per unit cell. (3)

Ans:- *Each corner atom is shared by 6 neighbouring unit cells. Hence each corner carriers (1/6)th of an atom as shown:-*

Each face centre carriers ½ atom. In the middle layer there are three atoms. Hence total number of atoms/unit cells are

$$n = 2\left(6\times\frac{1}{6}\right) + 2\left(\frac{1}{2}\right) + 3 = 6$$

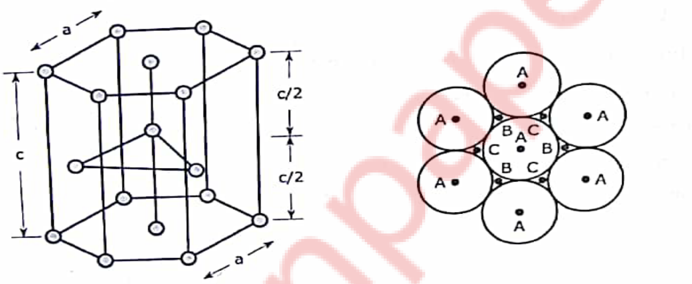


Figure 1.9 (a) : HCP structure

Figure 1.9 (b) : Atomic arrangement of HCP structure

Q1](b)The mobility of holes is 0.025m^2/V-sec. what would be the resistivity of n-type Si if the Hall coefficient of the sample is 2.25× $10^{-5}m^3$/C. (3)

Ans:- *Given Data :-* μ_h *= 0.025*m^2*/V-sec* R_H *= 2.25×* $10^{-5}m^3$*/C*

Formula :- $\rho = \frac{1}{\sigma}$, $\mu_h = \sigma R_H$

Calculations :- $\sigma = \frac{\mu_H}{R_H} = \frac{0.025}{2.25\times10^{-5}}$ = *1111.11 mho/m*

$$\rho = 9\times10^{-4}\Omega\text{ - m}$$

Answer :- *Resistivity =* $9\times10^{-4}\ \Omega\text{ - m}$

Q1](c) What is the principle of solar cell? Write its advantages and disadvantages. (3)

Ans:- *PRINCIPLE :-*

In photoelectric effect when radiation is incident on a metal surface electron are ejected. In photovoltaic effect, certain materials being exposed to radiation generates electron hole pairs available for conduction. As a result a voltage is developed across the material. The radiation energy E= $h\vartheta$ *is required to be greater then the band gap energy* E_g *of the material. This is a phenomenon in which light energy is converted into electrical energy.*

ADVANTAGES :-

- *Environmentally friendly.*
- *No noise, no moving parts.*
- *No emission.*
- *Minimum maintenance required.*
- *Long lifetime, up to 30 years.*
- *PV operator even in cloudy weather condition.*

Disadvantages:-

- *PV cannot operate without light .*
- *High initial costs that overshadow the low maintenance costs and lack of fuel costs.*
- *Large area needed for large scale applications.*
- *PV generates direct current special DC appliances or an inverter are needed.*

Q1](d) An electron is confined in a box of dimension 1A°. calculate minimum uncertainty in its velocity. (3)

Ans:- *Given Data :- L =* 10^{-10} *m*

Formula :- $\Delta X_{ma}.\Delta p_{mi} = \hbar$

Calculations :- since the electron is probable anywhere within the box of length 10^{-10} *m, the maximum uncertainty in locating it is,*

$$\Delta X_{ma} = 10^{-10} m$$

$$\Delta X_{ma}.m.\Delta v_{mi} = \hbar$$

$$\Delta v_{mi} = \frac{\hbar}{m\Delta X_{ma}}$$

$$= \frac{6.63\times10^{-34}}{2\times3.14\times9.1\times10^{-31}\times10^{-8}}$$

$$\Delta v_{mi} = 1.16\times10^{5} m/sec$$

Answer :- minimum uncertainty in velocity = 1.16×10^{5} *m/s*

Q1](e) Explain the factors on which reverberation time depends . (3)

Ans:- *The most important factor in all regulations is reverberation time, which is defined as the time it takes for the sound pressure level to drop 60 dB below its original level.*

In most cases, a low reverberation time improves the acoustical comfort. In some situations, however, such as concerts or conference halls, a higher reverberation time can improve listening comfort.

Reverberation time depends on the size and shape of the space along with the amount, quality and positioning of absorbing surfaces within the space. The more sound absorption in the room, the lower the reverberation time.

Q1](f) Explain cavitation effect. (3)

Ans:- *Liquids contains microscopic bubbles of size* 10^{-9} *m to* 10^{-8} *m. ultrasonic waves propagates longitudinally through liquids. The molecules of the medium moves back and forth in the direction of propagation of the wave. This movement induces alternate regions of compression and rare fraction. A decrease in pressure at the area of rarefaction causes local boiling of the liquid. This causes an intense evaporation in the bubbles and the bubbles grow in size. The growth of the bubbles leads to their collapse within a very short span of one millisecond. The collapse of numerous bubbles results into a large number of shockwaves due to which the local temperature increases by about* 10^{4} *°C. The shock waves develop high crushing power of the liquid due to which the cavitation effect has applications like.*

1. *Ultrasonic cleaning.*
2. *Emulsification.*
3. *Alloy formation.*

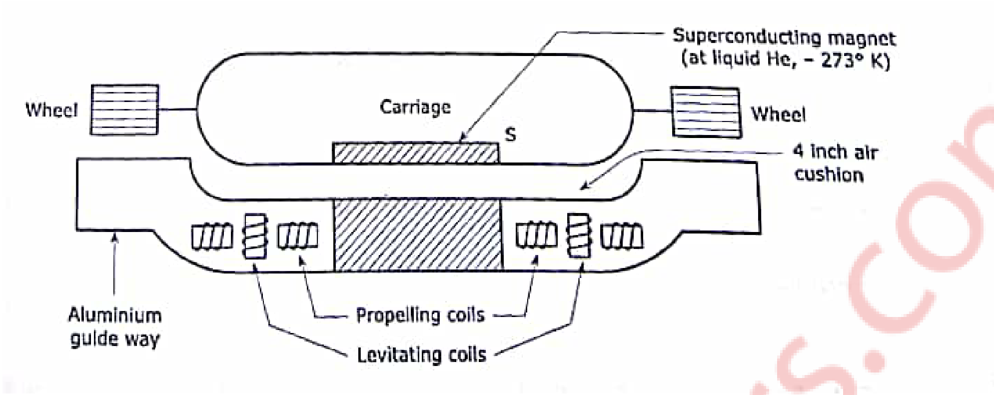
This method is also called as agglomeration.

Q1](g) What is Maglev? How it can have very high speed? (3)

Ans:- *MAGLEV is an acronym of magnetic levitation. The most spectacular applications of this would be maglev trains. The coaches of the train do not slide over steel rails but float on a four inch air cushion above the track using Meissner effect of super conducting magnets.*

The current flowing through its horizontal coils produce a vertical magnetic field. By Meissner effect the superconducting magnet S expels the vertical magnetic flux. This levitates the train and keeps it afloat the guide way, the horizontal coils are thus called levitating coils. On the other hand current passing through the vertical coil produce a horizontal magnetic field which pushes the train forward. Thus the vertical coils are called propelling coils.

The train is fitted with retractable wheels similar to the wheels of an aircraft. Once the train is levitated in air the wheels are retracted into the body and the train glides forward on the air cushion.

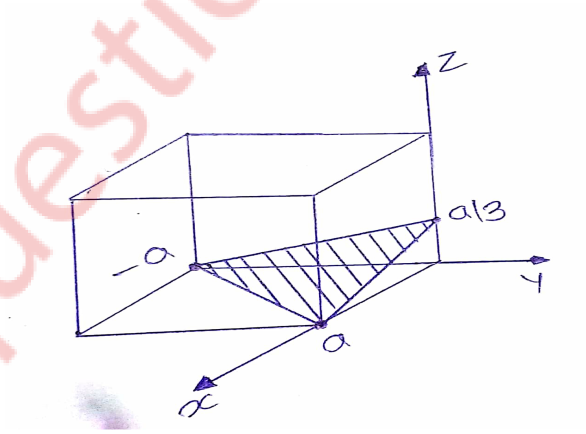


Q2](a) Draw the following : (1,-1,3) ,(2,0,0) , [0,0,-1]

An electron is accelerated through 1200 volts and is reflected from a crystal. The second order reflection occurs when glancing angle is 60°. Calculate the inter planar spacing of the crystal. (8)

Ans:- *1. Miller indices : (1 1 3)*

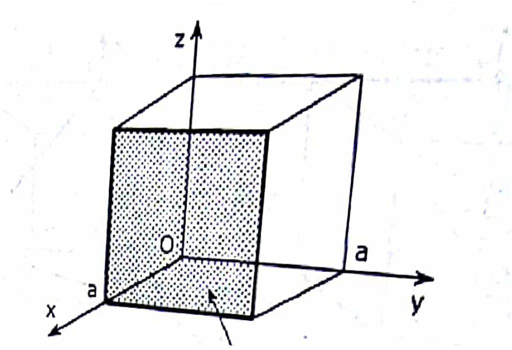
Intercepts : a , -a, a/3



2. Miller indices : (200) …………(can also be written as (100))

Reciprocals : 1, ∞ ,∞

Intercepts : a, ∞ ,∞



Q2](b) Explain the concept of fermi level. Prove that the Fermi level exactly at the centre of the Forbidden energy gap in intrinsic semiconductor. (7)

Ans:- *FERMI LEVEL*

Fermi level is not an allowed energy level it is an imaginary reference level used to specify other energy levels. Fermi level is defined as the highest filled energy level in any solid at absolute zero temperature.

Hence, at absolute zero temperature all energy levels below E_F *are empty for which the probability of occupancy can be written from Fermi-Dirac distribution function.*

At any temperature T>0K in an intrinsic semiconductor a number of electrons are found in the conduction band and the rest of the valence electrons are left behind in the valence band.

$$N = n_c + n_V$$

$$f(E_C) = \frac{1}{1+e^{(E_C-E_F)/kT}} \quad \text{..........................(1)}$$

$$f(E_v) = \frac{1}{1+e^{-(E_C-E_F)/kT}} \quad \text{..........................(2)}$$

$$n_V = Nf(E_v) = \frac{N}{1+e^{-(E_C-E_F)/kT}}$$

$$N = \frac{N}{1+e^{-(E_C-E_F)/kT}} + \frac{N}{1+e^{(E_C-E_F)/kT}}$$

$$1 = \frac{1}{1+e^{-(E_C-E_F)/kT}} + \frac{1}{1+e^{(E_C-E_F)/kT}}$$

$$1 = \frac{2+e^{(E_C-E_F)/kT}+e^{-(E_C-E_F)/kT}}{\left[1+e^{\frac{E_C-E_F}{kT}}\right]\left[1+e^{\frac{-E_C+E_F}{kT}}\right]}$$

Solving above equation using cross multiplication method.

$$e^{(E_C-2E_F+E_V)/kT} = 1$$

$$\frac{E_C - 2E_F + E_V}{kT} = 0$$

$$E_F = \frac{E_C + E_V}{2}$$

Hence it is proved that fermi energy level in intrinsic semiconductor is at the Centre of forbidden energy gap.

Q3](a) Find the following parameter for DC(Diamond Cubic) structure:- (8)

1. ***No. of atoms per unit cell.***
2. ***Co-ordination number.***
3. ***Nearest atomic distance.***
4. ***Atomic radius.***
5. ***APF.***

Ans:- *This can be thought of as a combination of two FCC sublattice as if one FCC sublattice is translated along a body diagonal of the other sublattice through a distance* $\sqrt{3}a/4$ *from one of its corners. Therefore in addition to regular FCC atoms additional atoms, one on each of the four body diagonals are found in this structure. Two FCC sublattice can form the DC structure.*

1. *NUMBER OF ATOMS/ UNIT CELL(n):-*

Total number of atoms/ unit cell = $(\frac{1}{8} \times 8 \text{ corners}) + \left(\frac{1}{2} \times 6 \text{ face corners}\right) + (4 \times 1 \text{ on each body diagonal})$

$$\therefore n = 8$$

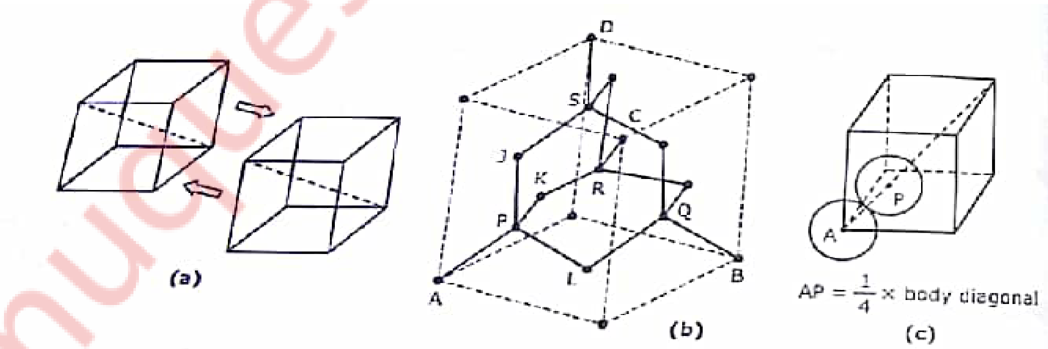


Figure 1.6 : Diamond Cubic Structure

2. *CO-ORDINATION NUMBER(N)*

Every atom with co-ordination (a/4, a/4, a/4) has four nearest neighbour, one at the nearest corner and three at the face centres of the three adjacent faces passing through the nearest corner. For example, the atom A, J, K and L are the nearest neighbours of the additional atom P. the five atoms A, J, K and P from a tetrahedron

$$\therefore N = 4$$

3. ATOMIC RADIUS (r):-

The distance between two nearest neighbours is

$$AP = \frac{\sqrt{3}a}{4} = 2r \qquad \therefore r = \frac{\sqrt{3}a}{8}$$

4. ATOMIC PACKING FACTOR(APF):-

$$APF = \frac{8 \times \frac{4\pi}{3}\left(\frac{\sqrt{3}a}{8}\right)^3}{a^3} = 0.34$$

Packing efficiency = 34%

Hence , it is a loosely packed structure. But as all the atoms are attached with covalent bonds this is a strong structure.

5. VOID SPACE:-

The void space in a DC unit cell is 66% of the entire cell structure.

Q3](b) Define drift current, diffusion current and P-N junction. The electrical conductivity of a pure silicon at room temperature is 4×10^{-4} mho/m . if the mobility of electron is 0.14m^2/V-S and that of hole is 0.04m^2/V-S. calculate the intrinsic carrier density. (7)

Ans:- DRIFT CURRENT :-

Drift current is the electric current, or movement of charge carriers, which is due to the applied electric field, often stated as the electromotive force over a given distance.

DIFFUSION CURRENT:-

Diffusion current is a current in a semiconductor caused by the diffusion of charge carriers. This is the current which is due to the transport of charges occurring because of nonuniform concentration of charged particles in a semiconductor.

P-N JUNCTION:-

A diode is a PN junction with p-type on one side and n-type on the other. When a positive voltage is applied to the p-type side , it shrinks and overcomes the depletion zone, causing the current flow from the p-type to the n-type side.

NUMERICAL:-

Given Data :- $\sigma = 4\times10^{-4}$ *mho/m* , $\mu_e = 0.14m^2$/V-sec , $\mu_h = 0.04m^2$/V-S

Formula :- $\sigma_i = n_i(\mu_e + \mu_h).e$

Calculations :- $n_i = \frac{\sigma_i}{(\mu_e + \mu_h).e}$

$= \frac{4\times10^{-4}}{1.6\times10^{-19}(0.14+0.040)}$

$n_i = 1.388 \times 10^{16}/m^3$

Answer :- carrier concentration = $1.388 \times 10^{16}/m^3$

Q4](a) Distinguish between Type I and Type II superconductor. (5)

Ans:-

TYPE I SUPERCONDUCTOR	TYPE II SUPERCONDUCTOR
1. They exhibit complete Meissner effect .	1.They exhibit partial Meissner effect.
1. These are perfect diamagnetics.	2.These are not perfect diamagnetics.
2. These are known as soft superconductors.	3.These are known as hard superconductors.
3. They have only one critical magnetic field.	4.They have two critical magnetic fields.
4. These materials undergoes a sharp transition from the superconducting state of the normal state at the critical magnetic field.	5.These materials undergoes a gradual transition from the superconducting state to the normal state between the two critical magnetic fields.
5. The highest value of critical magnetic field is 0.1 wb/m^2.	6.The upper critical field can be of the order of 50 wb/ m^2.
6. Applications are very limited.	7.They are used to generate very high magnetic field.
7. Examples:- lead, tin, mercury , etc.	8.Examples:- alloys like Nb-Sn, Nb-Ti, Nb- Zr, etc.

Q4](b) A classroom has dimension $10\times8\times6 m^3$. the reverberation time is 3 sec. calculate the total absorption of surface and average absorption. (5)

Ans:- Given Data :- $V = 10\times8\times6 = 480 m^3$

$S = 2[(10\times8) + (8\times6) + (10\times6)] = 376\ m^3$

$T = 3$ sec.

Formula :- $T = 0.161\frac{V}{A} = 0.161\frac{V}{\alpha_{av}.S}$

Calculations:- $A = \frac{0.161\times V}{T} = \frac{0.161\times 480}{3} = 25.76$ *sabine*-m^2

$$\alpha_{av} = \frac{A}{S} = \frac{25.76}{376} = 0.068 \textit{ sabine.}$$

Answer :- *Total absorption , A = 25.76 sabine*-m^2

Average absorption coefficient, $\alpha_{av} = 0.068$ *sabine.*

Q4](c) Explain the principle, construction and working of a Magnetostriction Oscillator. ***(5)***

Ans:- *This is based on the principle of magnetostriction effect.*

- *A ferromagnetic rod MN is clamped in the middle. Two coils* L_1 and L_2 *are wound round its two halves.*
- *The coil* L_1 *is connected in the plate – cathode circuit and the coil* L_2 *is connected in the grid cathode circuit of a triode valve oscillator.*
- *The capacitor C has a variable capacitance .*
- *As the circuit is switched on the plate current* I_p *starts flowing through coil* L_1 *producing a magnetic field B along the axis of the rod as shown:-*
- *Now the rod is placed in a magnetic field along its length as a result of which its overall length will change by a small amount.*
- *As the length changes the flux linked with* L_1 *and* L_2 *also changes giving rise to an induced emf , e= -d*φ*/dt across* L_2.
- *The induced emf is fed to the grid-cathode circuit and the oscillator valve gives an amplified alternating voltages as output to the plate-cathode circuit causing an alternating plate current.*
- *Due to the alternating current flowing through coil* L_1 *the magnetic field becomes an alternating magnetic field giving rise to the vibration of the rod.*
- *The frequency of mechanical vibration of the rod is given by*

$$f_{rod} = \frac{p}{2L}\sqrt{\frac{Y}{\rho}}$$

Where p = mode of vibration

L = length of the rod.

Y = Young's modulus of the material of the rod and,

density of the material of the rod.

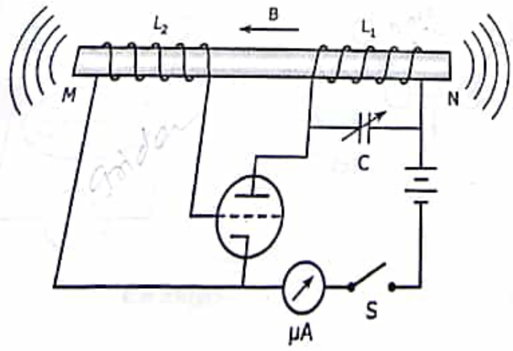


Figure 6.7 : Magnetostriction oscillator

For first harmonic p =1 and the frequency of vibration becomes

$$f_{rod} = \frac{p}{2L}\sqrt{\frac{Y}{\rho}}$$

The frequency of the triode valve oscillator is given by

$$f_{osc} = \frac{1}{2\pi\sqrt{L_1 C}}$$

By varying the capacitance C of the variable capacitor the oscillator frequency , f_{osc} *can be adjusted to the mechanical frequency of the rod* f_{rod}*. In the case*

$$f_{rod} = f_{osc}$$

And resonance takes place.

- *At resonance the rod vibrates vigorously emitting ultrasonic waves from both its ends.*
- *By adjusting the length of the rod and the capacitance of the variable capacitor ultrasonic waves of frequency up to 300KHz can be produced .*

Q5](a) Write Fermi Dirac distribution function. With the help of diagram. Explain the variation of Fermi level with temperature in n-type semiconductor. (5)

Ans:- *Each energy band in a crystal accommodates a large number of electron energy levels. According to Pauli's exclusion principle any energy level can be occupied by two electrons only, one spin up and down . however, all the available energy states are not filled in an energy band. The separation between the consecutive energy level is very small around* 10^{-27} eV *due to which the energy states are not filled in an energy band.*

FERMI DIRAC DISTRIBUTION FUNCTION.

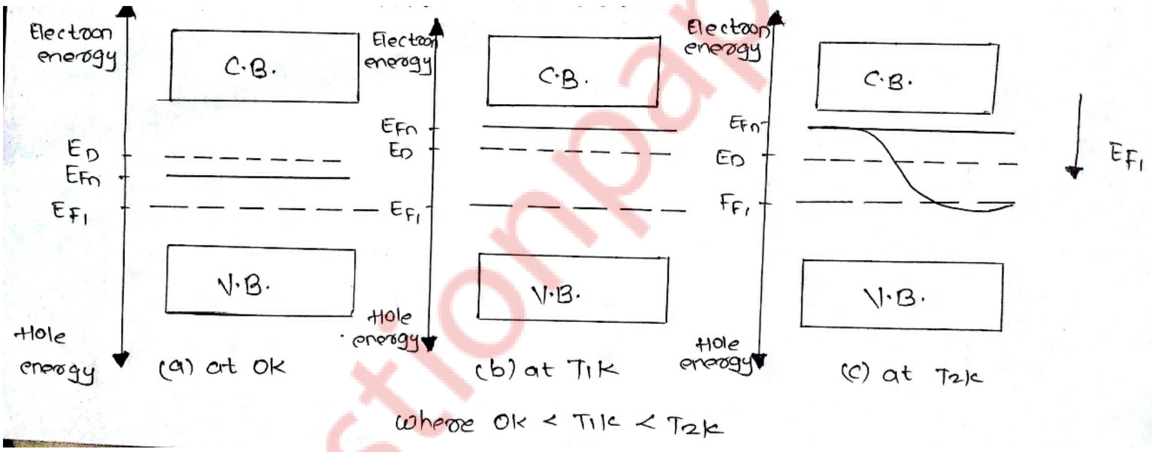
The carrier occupancy of the energy states is represented by a continuous distribution function known as the Fermi-Dirac distribution function, given by

$$f(E) = \frac{1}{1+e^{(E-E_F)/kT}}$$

This indicates the probability that a particular quantum state at the energy level E is occupied by an electron. Here k is Boltzmann's constant and T is absolute temperature of the semiconductor. The energy E_F is called Fermi energy that corresponds to a reference level called Fermi level.

IN n-TYPE SEMICONDUCTOR.

- *At 0K the fermi level E_{Fn} lies between the conduction band and the donor level.*
- *As temperature increases more and more electrons shift to the conduction band leaving behind equal number of holes in the valence band. These electron hole pairs are intrinsic carriers.*
- *With the increase in temperature the intrinsic carriers dominate the donors.*
- *To maintain the balance of the carrier density on both sides the fermi level E_{Fn} gradually shifts downwards.*
- *Finally at high temperature when the donor density is almost negligible E_{Fn} is very close to E_{Fi}.*



Q5](b)Derive Schrodinger time dependent wave equation for matter waves. (5)

Ans:- :- *For one dimensional case, the classical wave is described by the wave equation*

$$\frac{dy^2}{dx^2} = \frac{1}{v^2} \times \frac{d^2y}{dt^2}$$

where y is the displacement and v is the velocity of the wave travelling in a direction. The displacement of the particle at any instant 't', at any point 'x' in space

$$y(x, t) = Ae^{j(kx-\omega t)}$$

where $\omega = 2\pi\vartheta$ *and* $k = 2\pi/\lambda$

in analogy with this the wave function which describes the behaviour of the matter particle at any instant 't', at any point 'x' in space can be written as

$$\Psi(x,t) = Ae^{j(kx-\omega t)}$$

Where , $$\omega = 2\pi\vartheta = 2\pi\frac{E}{h} = \frac{E}{\hbar}$$

And $$k = \frac{2\pi}{\lambda} = \frac{2\pi}{h}\times p = \frac{p}{\hbar}$$

The total energy of the particle is given by

E = kinetic energy + potential energy

$$= \frac{1}{2}mv^2 + V = \frac{(mv)^2}{2m} + V$$

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

Operating this on the wave function Ψ(x, t) it is found that

$$E\Psi(x,t) = \frac{p^2}{2m}\Psi(x,t) + V\Psi(x,t)$$

Differentiating equation with respect to 'x' and 't' it is obtained that

$$\frac{\partial^2\Psi(x,t)}{\partial x^2} = -p^2Ae^{j(kx-\omega t)} = -k^2\Psi(x,t)$$

Hence $$\frac{p^2}{\partial t}\Psi(x,t) = -jA\omega e^{j(kx-\omega t)} = -j\omega\Psi(x,t)$$

Hence the final equation is as follows:-

$$j\hbar\frac{\partial\Psi(x,t)}{\partial t} = -\frac{\hbar}{2m}\times\frac{\partial^2\Psi(x,t)}{\partial x^2} + V\Psi(x,t)$$

Or $$-\frac{\hbar}{2m}\times\frac{\partial^2\Psi(x,t)}{\partial x^2} + V\Psi(x,t) = j\hbar\frac{\partial\Psi(x,t)}{\partial t}$$

The first and the second term on the left hand side represents the kinetic and potential energies respectively of the particle and the right hand side represents the total energy.

This is called as the one dimensional time dependent Schrodinger equation.

Q5](c)Find the depth of sea water from a ship on the sea surface it the time interval of two seconds is required to receive the signal back. Given that: temperature of sea water is 20°C, salinity of sea water is 10gm/lit. (5)

Ans:- *Given Data :- t = 2sec , Temperature = 20°C,*

S = 10 gm/lit = 10 kg/m^3

Formula :- $$d = \frac{\vartheta t}{2}$$

$\vartheta = 1510 + 1.14S + 4.21t - 0.037t^2$

Calculations :- $\vartheta = 1510 + (1.14\times10) + (4.21\times20) - 0.037(20)^2$

$\vartheta =$ *1590.8m/s*

$D = \frac{1590.8\times2}{2}$ *= 1590.8 m*

Answer :- *Depth of sea water = 1590.8m*

Q6](a) Define the critical temperature. Slow that in the superconducting state the material is perfectly diamagnetic. ***(5)***

Ans:- *The critical temperature is the transition temperature at which the normal state of a conductor changes to superconducting state.*

A superconducting material kept in a magnetic field expels the magnetic flux out its body when cooled below the critical temperature and exhibits perfect diamagnetism. This is called MEISSNER EFFECT.

- *It is found that as the temperature of the specimen is lowered to* T_c*, the magnetic flux is suddenly and completely expelled from it. The flux expulsion continues for* $T < T_c$*. The effect is reversible.*
- *When the temperature is raised from below* T_c*. The flux density penetrates the specimen again at* $T = T_c$ *and the material turns to the normal state.*
- *For the normal state the magnetic induction inside the specimen is given by:*

  $B = \mu_o(H+M) = \mu_0(1+\chi)H$……………………………………….*(1)*

Here H is the applied magnetic field , m is the magnetization produced within the specimen , is χ *the susceptibility of the material and* μ_o *is the permeability of free space.*

- *At* $T < T_c$ *as seen above*

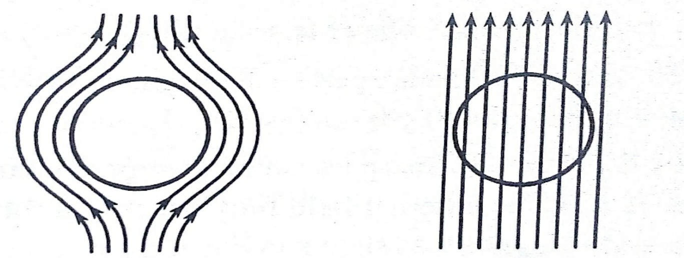
  B = 0

  Hence equation (1) reduced to,

  M = -H

  And thus $\chi = \frac{M}{H}$ *= -1*

- *The specimen is therefore a perfect diamagnetic. The diamagnetism produces strong repulsion to the external magnets.*
- *This effect is used to identify a superconductor , in levitation effect and suspension effect.*



Q6](b) In a solid the energy level is lying 0.012 eV below Fermi level. What is the probability of this level not being occupied by an electron 27°C? (5)

Ans:- *Data* :- $E_F - E = 0.012eV$, $T = 27°C = 300K$

$$K = 1.38 \times 10^{-23} J/K = \frac{1.38\times10^{-23}}{1.6\times10^{-19}} = 86.25\times10^{-6} eV/K$$

Formula :- $f(E_C) = \frac{1}{1+e^{(E_C-E_F)/kT}}$

Calculations :- *Total probability = 1*

Probability of occupying an energy state + Probability of not occupying the energy state = 1.

$f(E)$ + Probability of not occupying the energy state = 1

Probability of not occupying the energy state = 1- $f(E)$

Here $f(E) = \frac{1}{1+e^{(E-E_F)/kT}} = \frac{1}{1+e^{(0.012/86.25\times10^{-6}\times300)}} = 0.386$

Hence, 1- f(E) = 1-0.386 = 0.614

Answer :- Probability of not occupying = 0.614

Q6](c) What is the wavelength of a beam of neutron having:

1. **_An energy of 0.025 eV?_**
2. **_An electron and photon each have wavelength of 2A°. what are their momentum and energy ?_** $m_n = 1.676\times10^{-27}$ ***kg,*** $h = 6.625\times10^{-34}$ ***J-sec. (5)***

Ans:- *1. Given Data* :- *energy of neutron = 0.025eV.*

To find :- *wavelength of a beam.*

Calculation :- $\lambda = \frac{h}{\sqrt{2meV}}$

$$= \frac{6.626\times10^{-34}}{\sqrt{2\times1.676\times10^{-27}\times0.025\times10^{-19}\times1.6}}$$

$= 1.8095\ A°.$

Hence wavelength is equal to = 1.8095 A°.

2.Given Data :- $\lambda = 2A°$, $m_n = 1.676\times10^{-27}$ *kg,* $h = 6.625\times10^{-34}$ *J-sec.*

To find :- *momentum and energy.*

Calculations :- $\lambda = \frac{h}{p}$, *…………………(for momentum)*

$$2\times10^{-10} = \frac{6.625\times10^{-34}}{p}$$

$P = 3.3125\times10^{-24}$ *kg-m/sec.*

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

$$2\times10^{-10} = \frac{6.625\times10^{-34}}{\sqrt{2\times1.676\times10^{-27}\times E}}$$

$E = 5.721\times10^{-11}$ *joules.*

Hence momentum = 3.3125×10^{-24} *kg-m/sec. and energy is =* 5.721×10^{-11} *joules.*
