Civinnovate

Discover, Learn, and Innovate in Civil Engineering

Direct Current

Electric current is the rate of flow of charge in a conductor i.e. $I = \frac{dq}{dt}$. The D.C current does not have frequency and it is scalar density.

Current density: The flow of current per unit area of the conductor is known as current density. It is denoted by J. It is vector quantity.

i.e. $\vec{J} = \frac{I}{A}$ and it's unit is A/m^2

Also, the current is the surface integral of current density.

i.e. $I = \int \vec{J} \cdot \vec{dA}$

Drift velocity (Vd)

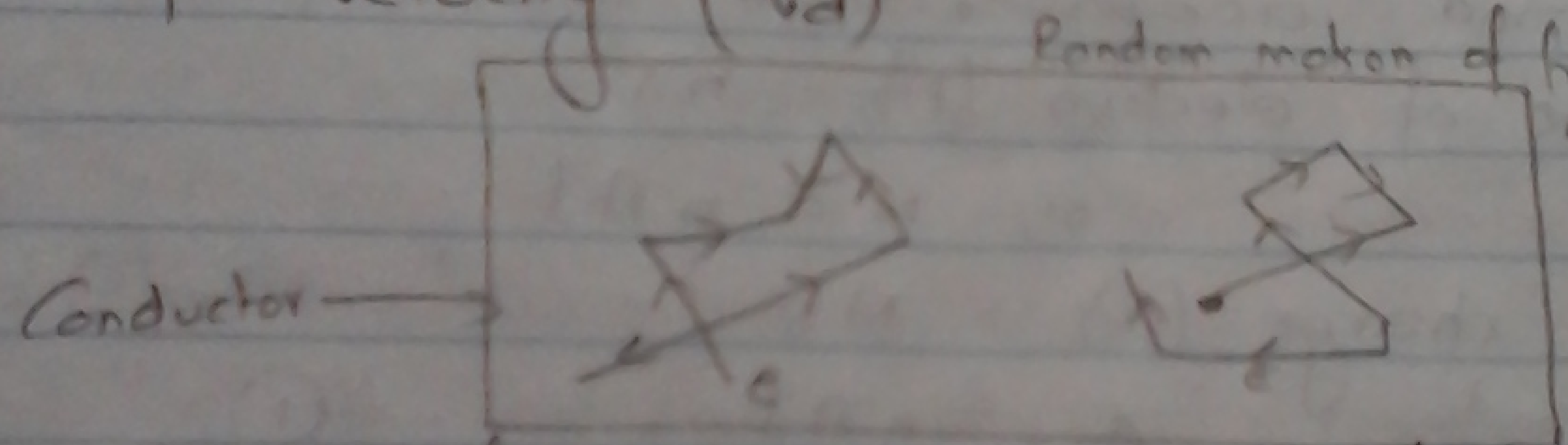


fig ① In the absence of electric field

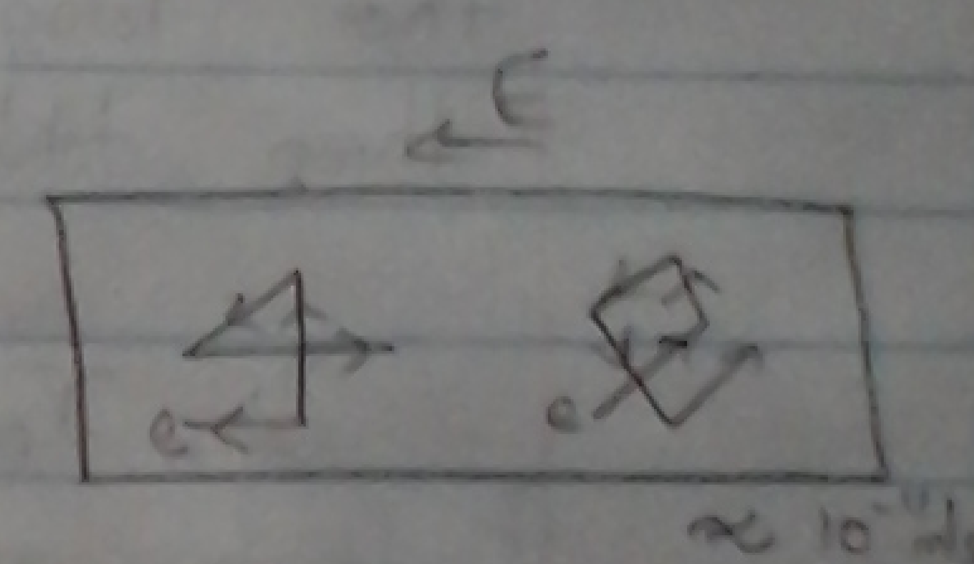
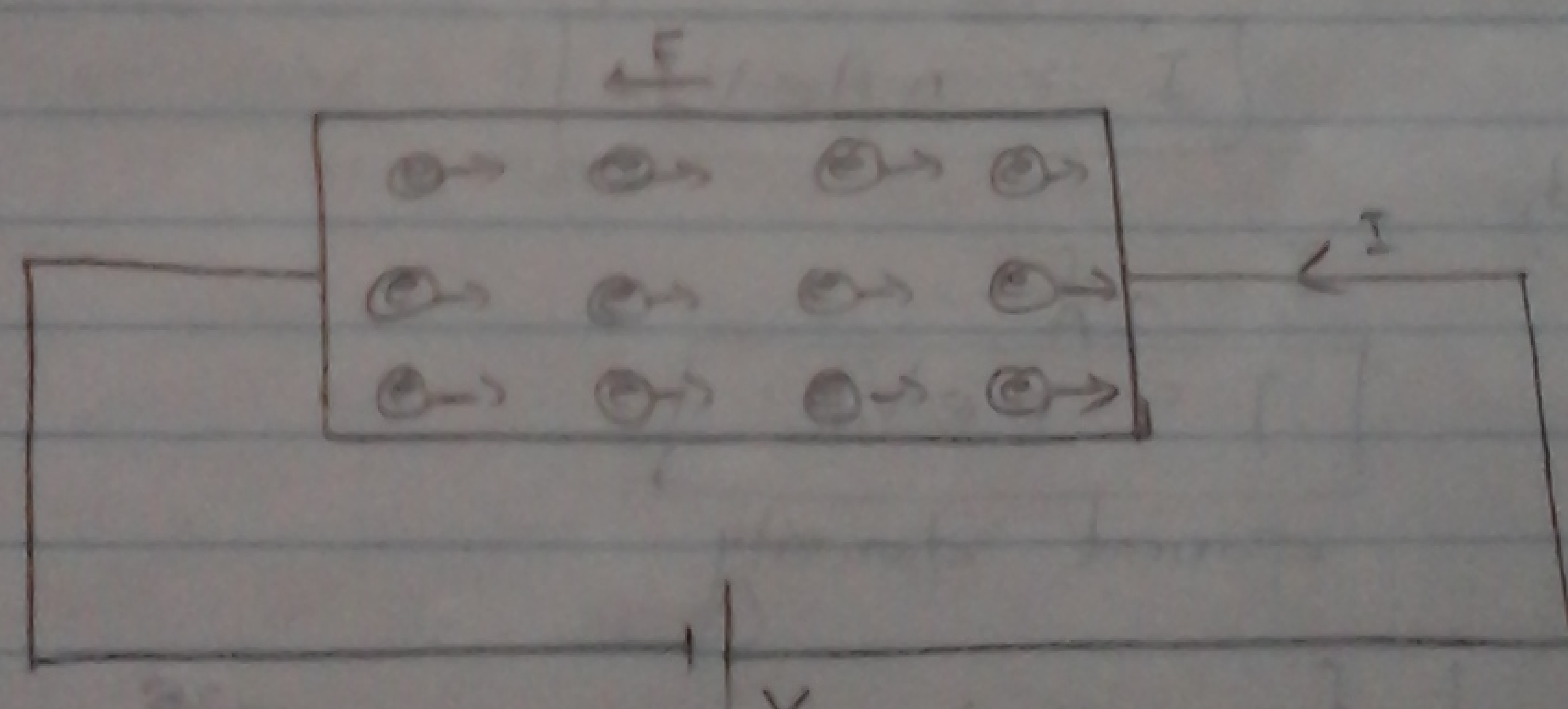


fig ② In the presence of electric field



In the absence of electric field, the large no. of free electrons are present in the conductor with random motion. The speed of free electron is about 10^6 m/s in copper in different direction so there is not current flow in conductor is zero.

If the electric field is applied in the conductor, the free electrons moving unidirection and has less speed is about 10^{-4} m/s. This is due to the increasing of collison with another electrons. Therefore the average velocity attain by the free electron in the presence of electric field is known as drift velocity. It is denoted by V_d. It's direction is opposite of applied electric field.

let 'n' be the no. of electrons present in a conductor per unit volume. If 'l' and 'A' are the length and cross-sectional area of conductor then total no. of electron (N) = nV

or, $N = nAl$

$\therefore$ Total charge (Q) = Ne

$Q = nAle$ ... (1)

Since; $I = \frac{Q}{t} = \frac{nAle}{t}$

$$\boxed{I = nAeV_d}$$

and,

$$J = \frac{I}{A}$$

$$\boxed{J = neV_d}$$

Current density

no. of free e^- in copper $\rightarrow$ 10^{28}

Resistance and Resistivity:

$$R \propto l$$

$$R \propto \frac{1}{A}$$

$$\Rightarrow R \propto \frac{l}{A}$$

$$\Rightarrow R = \frac{\rho l}{A}$$

ρ = resistivity of conductor
it's unit is ohm m

For conductor, $\rho \approx 10^{-8}\ \Omega m$

And, conductivity (σ) = $\frac{1}{\text{Resistivity}}$

$= \frac{1}{\rho}$

$= 10^{8}$ mho/m = Simein/m

Also,

$$R = R_0 (1 + \alpha \Delta\theta)$$

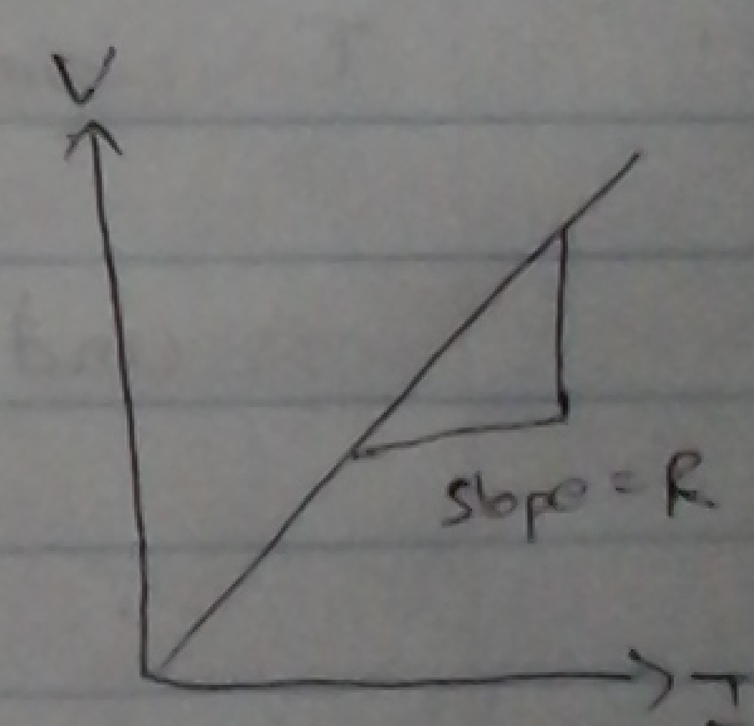
α = coeff of temp.

Ohm's law:

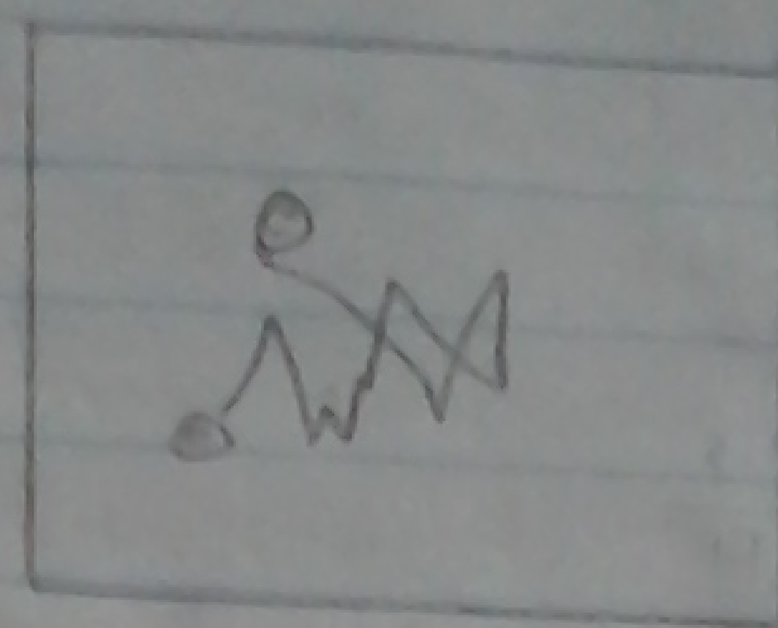
At constant physical condition, the current flow in the conductor is directly proportional to p.d between it's two terminal.

$$V \propto I$$

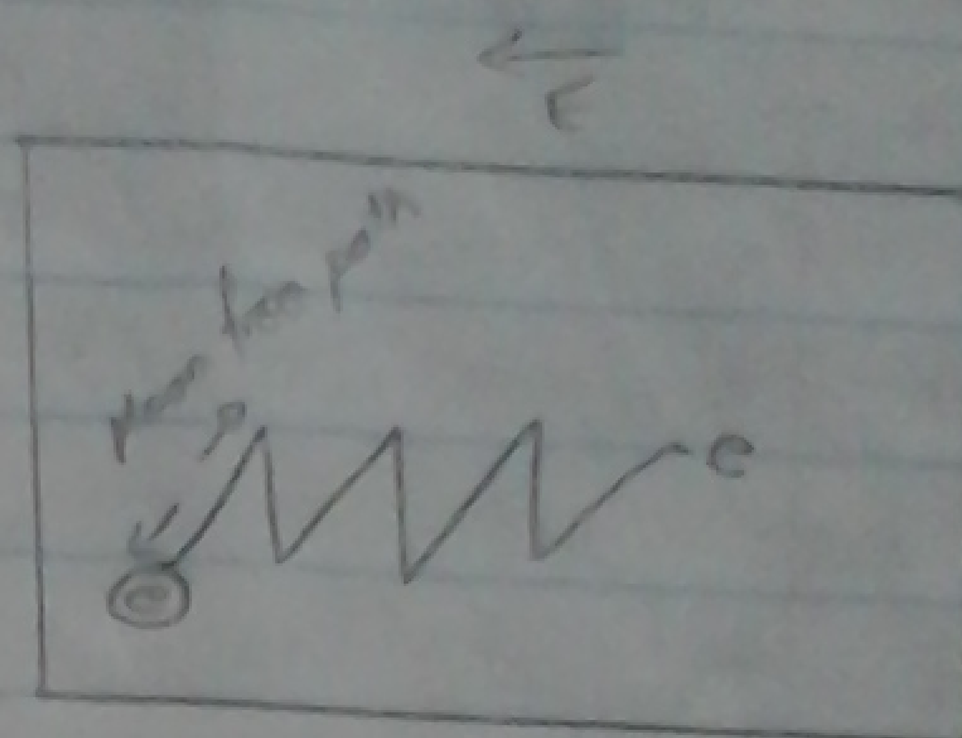
$$V = IR$$



Microscopic View of Ohm's law (Atomic View):



Random Motion (on electron gas in container)



In a unidirectional Motion of free e^{-s} in applied electric field

~~F = eE~~

In the free state, the free electron moves in random motion as like electron gas in container but in applied field the rate of collison is increased of the electron and they achieve sudden average velocity during the collison. The time taken by the free electron during the collison is relaxation time and the average distance travelled by the electron in electric field during the collison is mean free path (λ).

let 'E' electric field be applied in a conductor, it accelerates at first in a time interval τ since it experience an electric force

$$F = eE \quad \ldots (i)$$

and the force $(F) = ma \quad \ldots (ii)$

from eq^n (i) & (ii)

$$eE = ma$$

$$a = \frac{eE}{m} \quad \ldots E\ (iii)$$

Again, it travel a certain distance with the average velocity Vd at a time τ, then

$$a = \frac{V_d}{\tau} \quad \ldots (iv)$$

from (iii) & (iv)

$$\frac{eE}{m} = \frac{V_d}{\tau}$$

$$E = \frac{V_d\, m}{\tau e} \quad \ldots (v)$$

Also, we have,

$$V_d = \frac{J}{ne}$$

$$E = \frac{m}{ne^2 \tau} J$$

Comparing this relation with

$$\vec{J} = \sigma \vec{E}$$

We get, $$\sigma = \frac{ne^2 \tau}{m}$$

This is the conductivity of conductor depends on mass, no. of e per unit volume and relaxation time.

The resistivity of the conductor

$$\rho = \frac{1}{\sigma} = \frac{m}{ne^2 \tau}$$

$$\rho = \frac{m V_d}{ne^2 \lambda}$$

$$\rho = 2.\frac{1}{2}\frac{m V_d^2}{n e^2 \lambda V_d}$$

$$= \frac{\cancel{\frac{1}{2}}\, 2 \cdot \frac{3}{2} kT}{n e^2 \lambda V_d}$$

$$= \left(\frac{3k}{ne^2 \lambda V_d}\right) T$$

Since $v_d \propto \sqrt{T}$, then $\rho \propto \sqrt{T}$

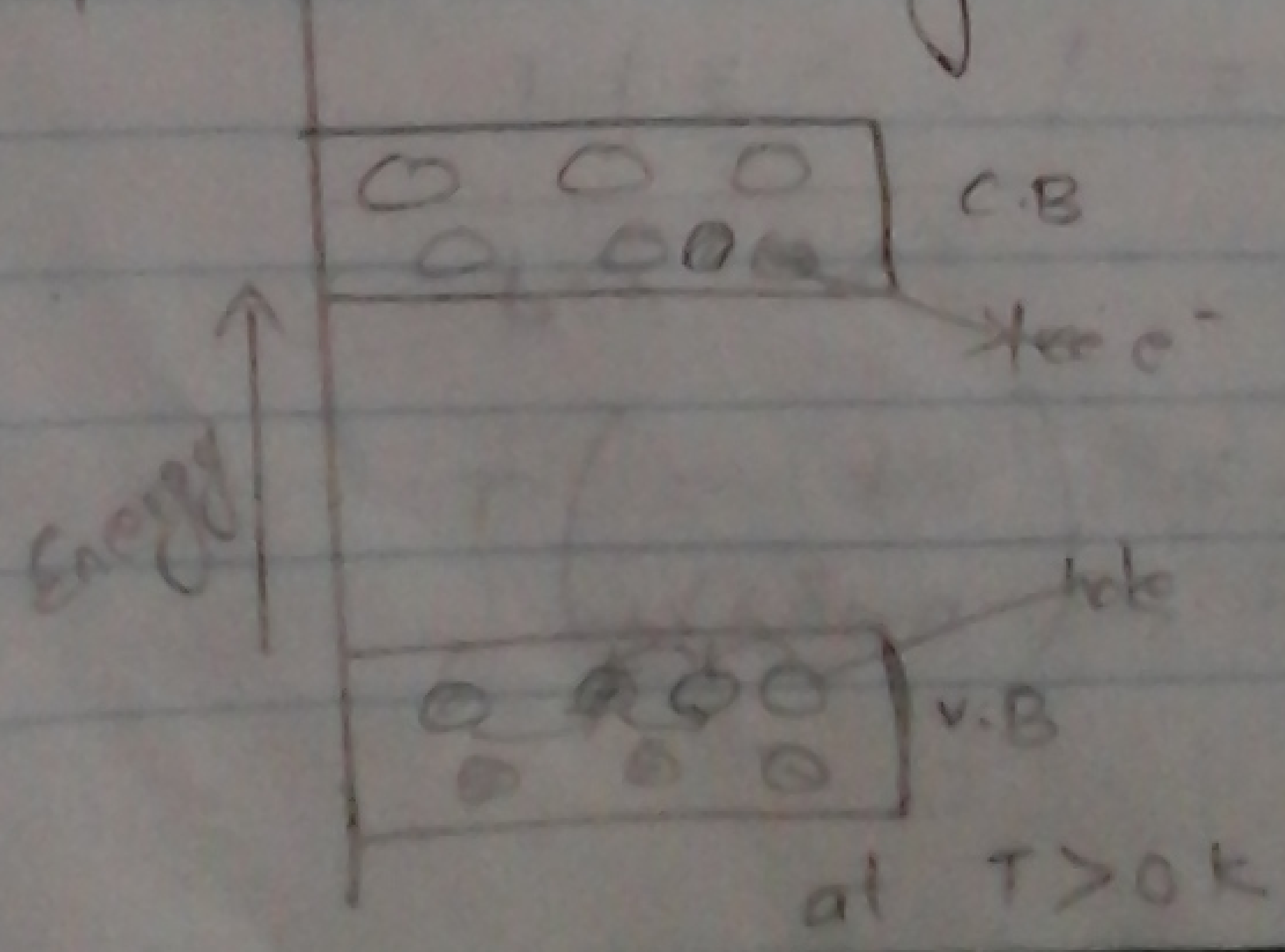
It means the resistivity of conductor depends on temperature. Increase in temperature results increase in the resistivity of conductor, since the rate of collison is increased and the relaxation time is miniumum.

Semiconductor :

The conductor whose resistivity is the negative coefficient of temperature is known as semiconductor. It's resistivity decreases with increase in temp. According to band theory, the forbidden gap is about 0.1 ev of the pure semiconductor. ~~At~~ 0 Kelvin it acts like insulator since valance band is completely filled and conduction band is completely empty. Silicon & Germanium are pure state of semiconductor in nature. There are of two types:

i) Intrinsic Semiconductor (Pure semiconductor)
ii) Extrinsic Semiconductor

In intrinsic semiconductor the majority charge carrier ~~or~~ may be electron or hole which are equal to minority charge carrier.

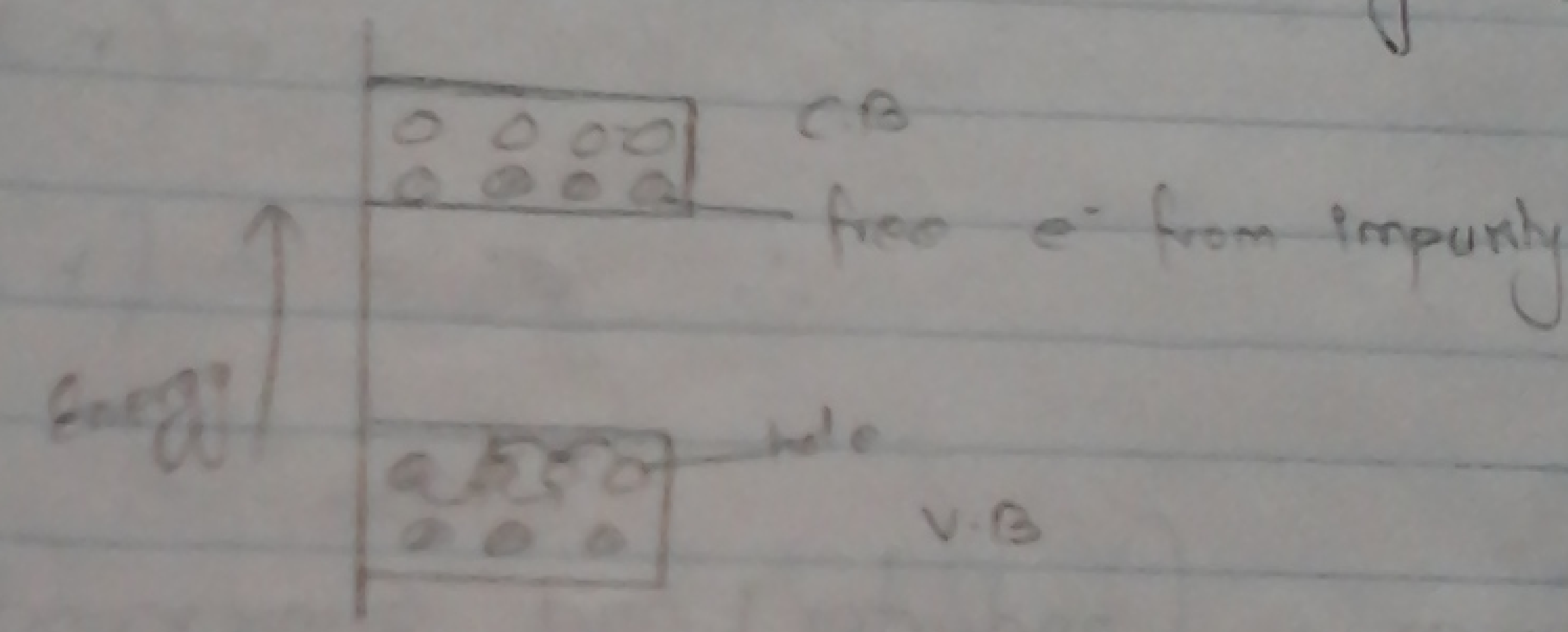


Extrinsic Semiconductor

By doping the suitable impurities in the surface of pure semiconductor, the no. of holes or electrons are changed. This type of semiconductor is extrinsic semiconductor. They are of two types:

1) N-type Semiconductor:

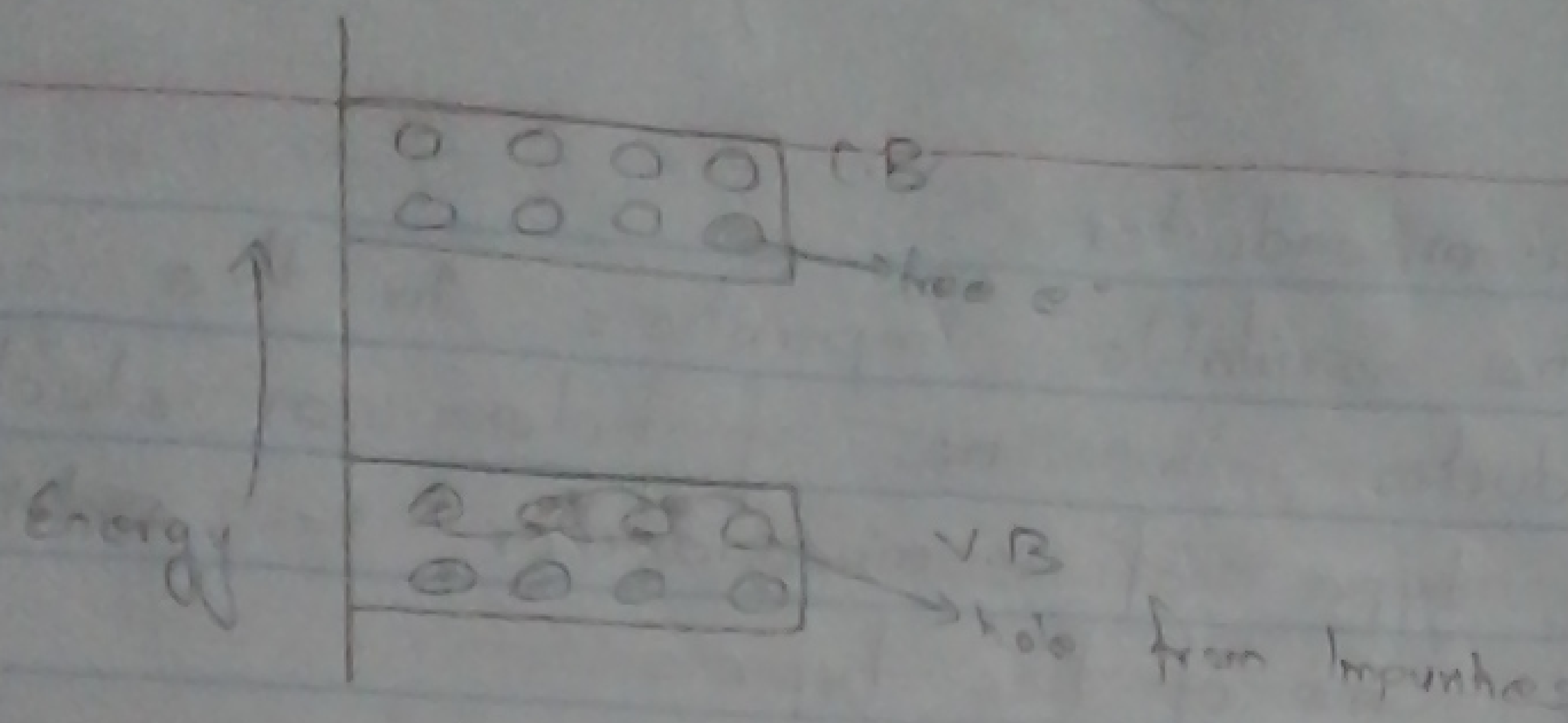
In this semiconductor, the pentavalent impurity is dopped. Among the five valance e^- of the impurities, 4 valance e^- are bound with valance electron of pure semiconductor so one electron get free in a single doped of impurity. Hence the majority charge carrier are electron and minority charge carrier are holes.



at T>0K for N-Type

ii) P-type semiconductor:

In this semicondutor, the trivalent impurity is dopped. During the formation of covalent bond with the pure semiconductor, one electron is insufficient to to form four covalent bond. Due to this deficiency of e^- one position is vacant. This is termed as hole. In a single doped of impurities, one hole is always greater than e^- in valance band so that the majority charge carrier are hole.



at T > 0k for P-Type

Note:

$J = ne\mu_e$

$J = \sigma E$

$neV_d = \sigma E$

$\sigma = ne\left|\frac{V_d}{E}\right|$

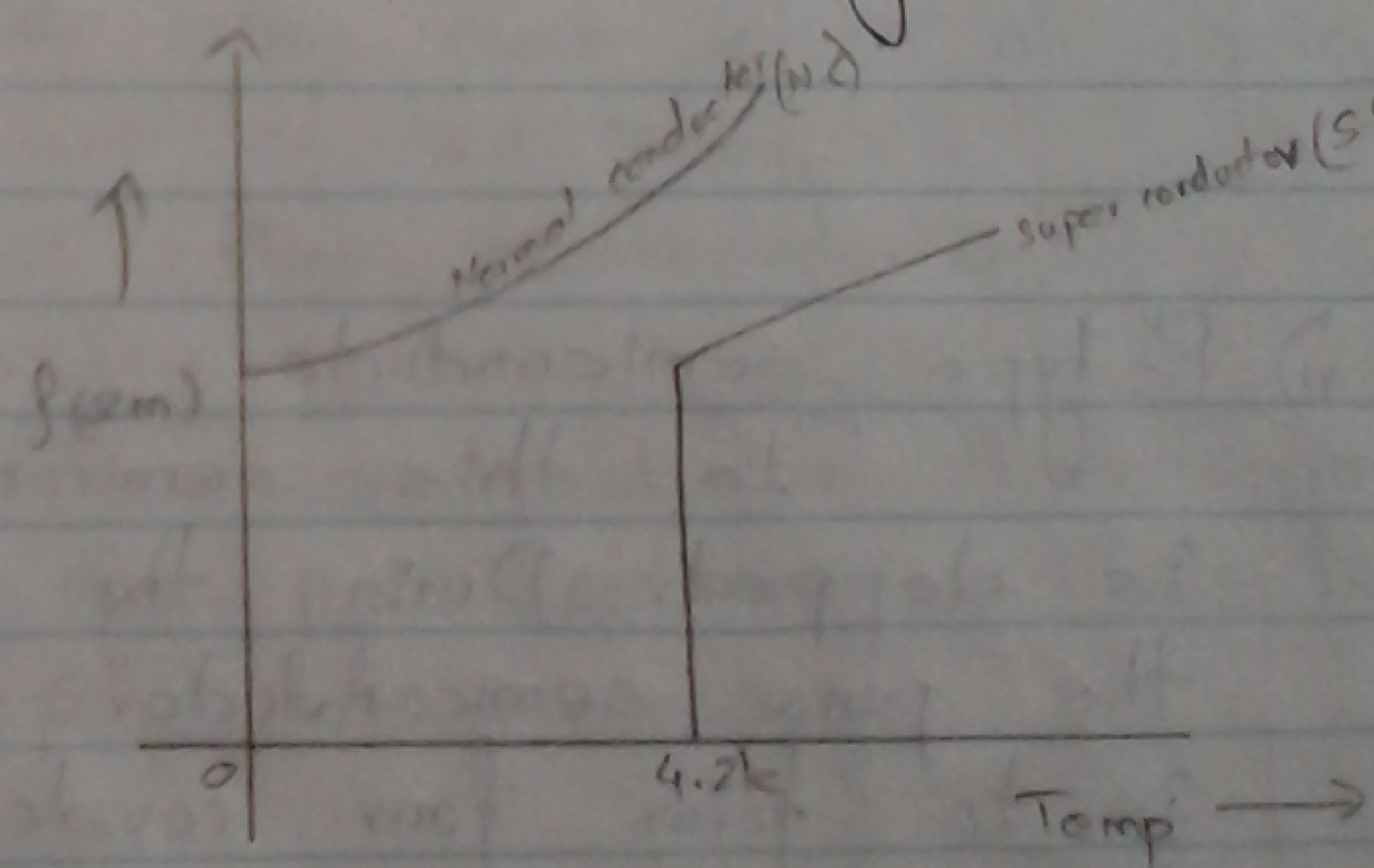
$\mu_e = \left|\frac{V_d}{E}\right|$ = Mobility of e⁻

A semiconductor has electron and holes. let 'n' and 'p' be the no. of electrons and holes resp. Then, charge density $(J) = J_e + J_n$

$$J = ne\mu_e E + pe\mu_p E$$
$$= e(n\mu_e + p\mu_p)E$$

$$\therefore \sigma = e(n\mu_e + p\mu_p)$$

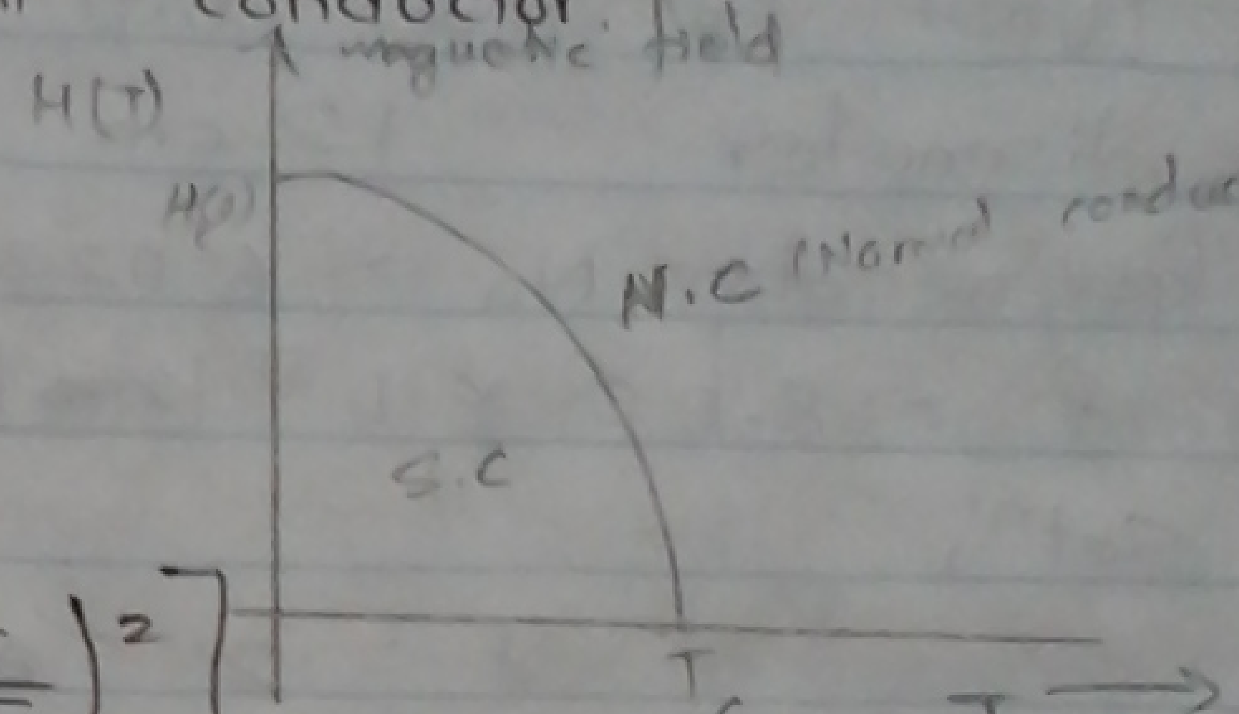
Super-Conductor and Superconductivity:



If the temperature of specimen is gradually decreasin the resistivity is slightly and at a particular temperature it strictly decreased to zero. This type of conductor is super conductor. For a mercury, the transition temp. is 4.2 k.

Destruction of superconductivity:

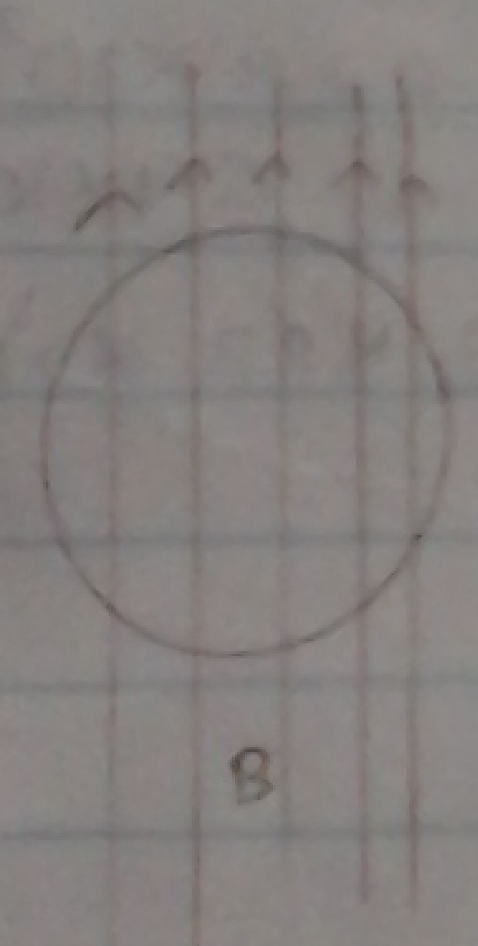
With the strong applied magnetic field, the superconductivity property of material completely destroy and form normal conductor.



$$H_c(T) = H_c(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

↓ magnetic field

Meissner Effect:

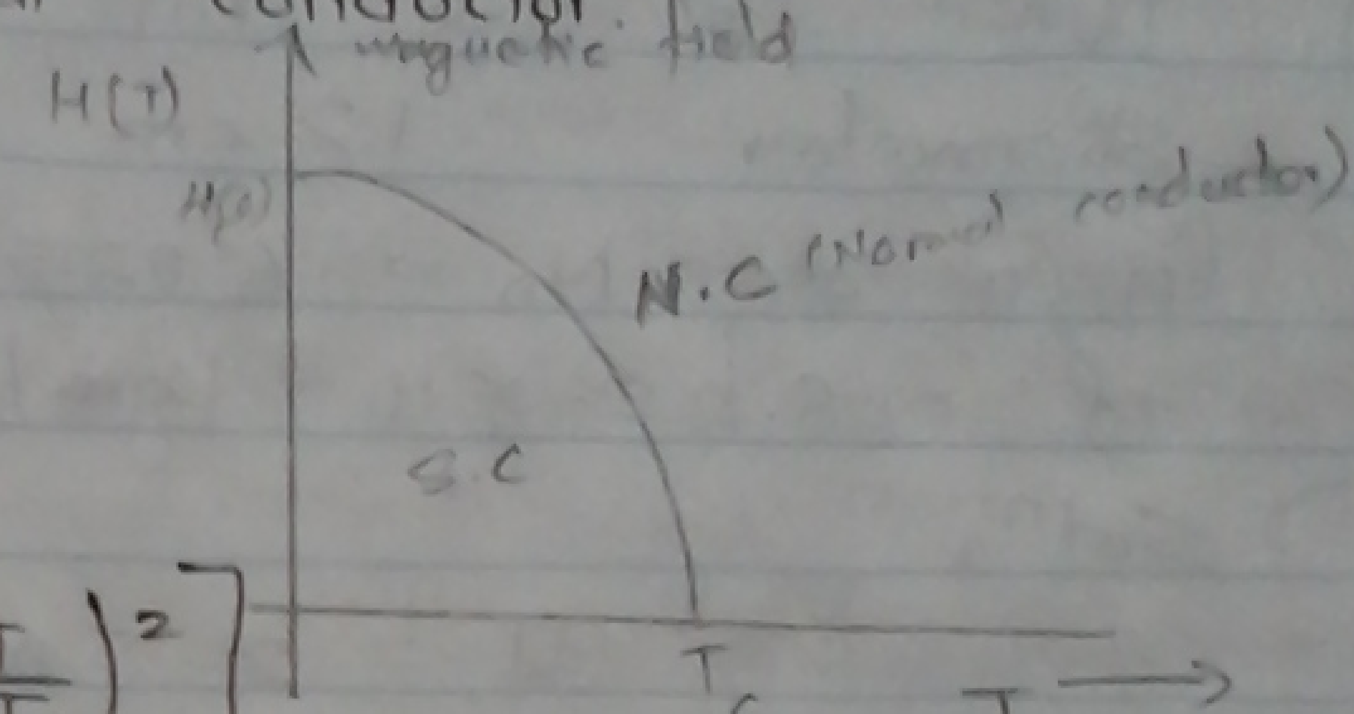


If the temperature of superconductor specimen is decreased below critical temp. the magnetic line of force push out from it's surface. This effect of superconductor on magnetic field is Meissner effect.

conductor is super conductor. For a mercury, the transition temp. is 4.2 k.

Destruction of superconductivity:

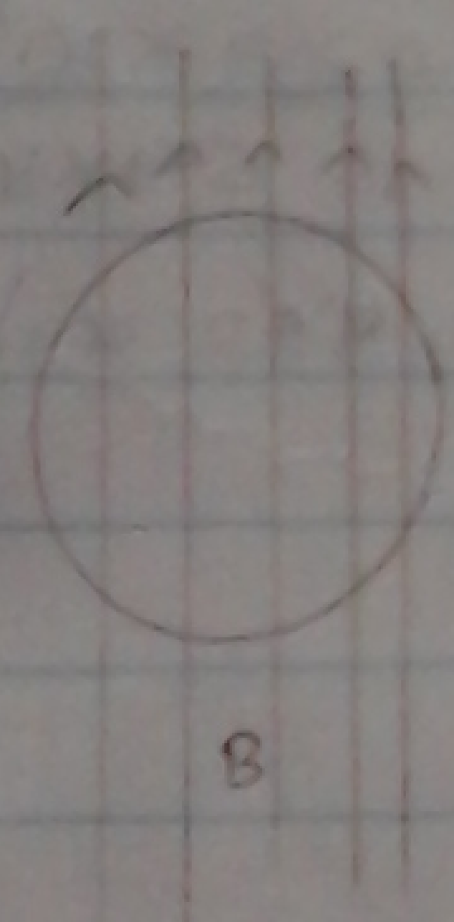
With the strong applied magnetic field, the supercondoctivity property of material completely destroy and form normal conductor.

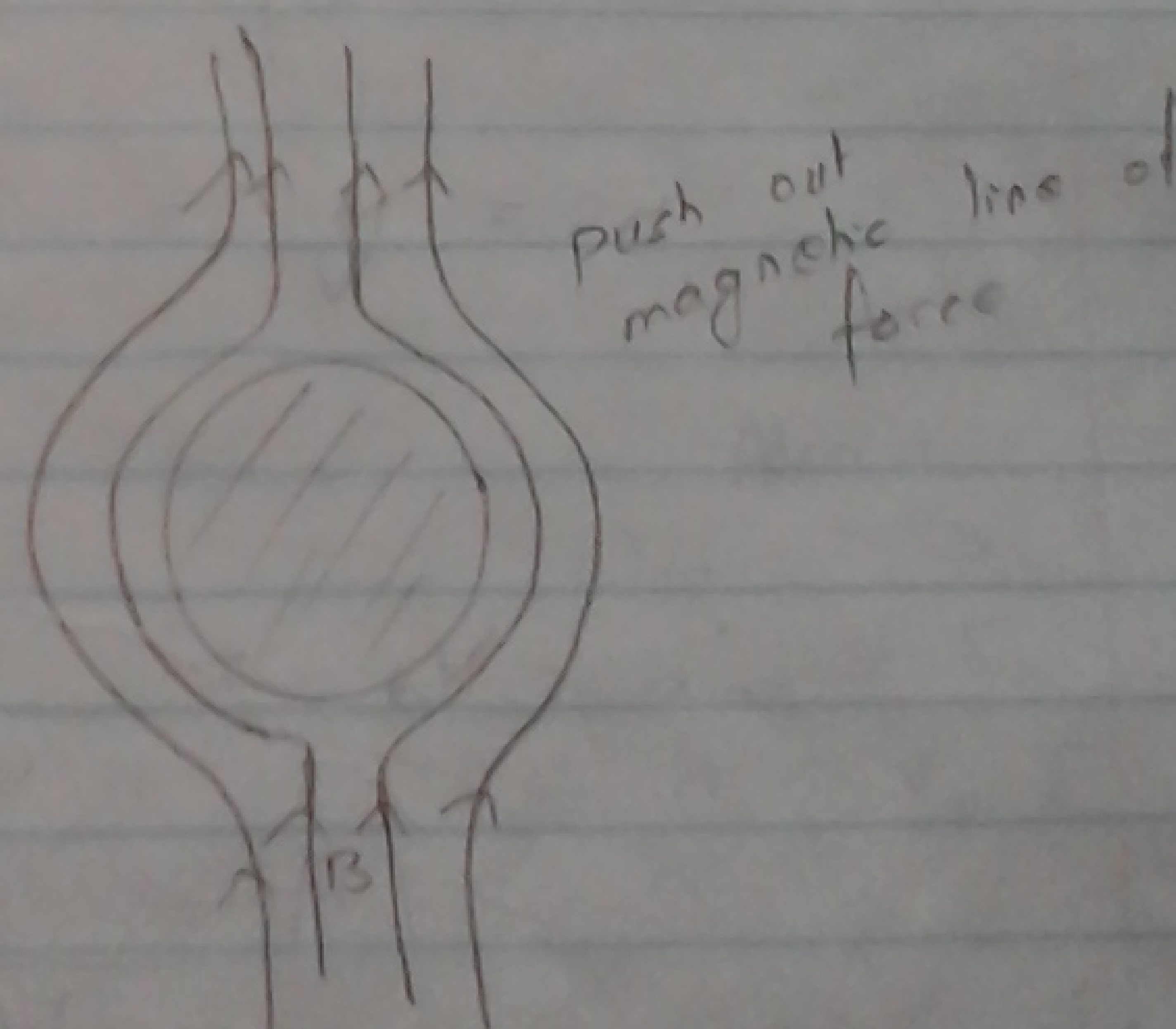


$$H_c(T) = H_c(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

$H_c(T)$ ↓ magnetic field

Meissner Effect:





If the temperature of superconductor specimen is decreased below critical temp. the magnetic line of force push out from it's surface. This effect of superconductor on magnetic field is Meissner effect.

It means the magnetic field doesn't appear in superconductor at temp less than T_c. At a temp. greater than critical temp. (T_c), the magnetic field appear in a specimen

Q. What is the drift velocity for copper wire of diameter 12 cm carrying a current of 2.5 A? Given ~~to~~ $N_A = 6.023 \times 10^{23}$, At. wt of Cu = 64 gm/mole, $\rho = 8.95 \times 10^3$ Kg/m^3

⇒ Soln,

$$I = 2.5A$$

$$\text{diameter } (d) = 12cm = 12 \times 10^{-2} m$$

We have:

$$I = V_d enA$$

$$V_d = \frac{I}{enA}$$

$$n = \frac{N}{V} = \frac{N}{m} \times \rho = \frac{6.023 \times 10^{23}}{64 \times 10^{-3}} \times 8.95 \times 10^3$$

$$= 8.422 \times 10^{22}$$

$$\therefore V_d = \frac{I}{enA}$$

$$= \frac{2.5}{1.6 \times 10^{-19} \times 8.422 \times 10^{22} \times \pi \times (6 \times 10^{-2})^2}$$

$$= \frac{2.5}{1524.622}$$

$$= 1.639 \times 10^{-3} \times 10^{19-22+4}$$

$$= 1.639 \times 10^{-2} \text{ m/s}$$

It means the magnetic field doesn't appear in superconductor at temp less than T_c.

At a temp. greater than critical temp. (T_c), the magnetic field appear in a specimen

Q. What is the drift velocity for copper wire of diameter 12 cm carrying a current of 2.5 A? Given ~~do~~ $N_A = 6.023 \times 10^{23}$, At. wt of Cu = 64 gm/mole, $\rho = 8.95 \times 10^3$ Kg/m^3

⇒ Soln,

$$I = 2.5A$$

$$\text{diameter } (d) = 12\text{cm} = 12 \times 10^{-2} \text{ m}$$

We have:

$$I = V_d enA$$

$$V_d = \frac{I}{enA}$$

$$n = \frac{N}{V} = \frac{N}{m} \times \rho = \frac{6.023 \times 10^{23}}{64 \times 10^{-3}} \times 8.95 \times 10^3$$

$$= 8.422 \times 10^{22}$$

$$\therefore V_d = \frac{I}{enA}$$

$$= \frac{2.5}{1.6 \times 10^{-19} \times 8.422 \times 10^{22} \times \pi \times (6 \times 10^{-2})^2}$$

$$= \frac{2.5}{1524.622}$$

$$= 1.639 \times 10^{-3} \times 10^{19-22+4}$$

$$= 1.639 \times 10^{-2} \text{ m/s}$$

Q.1) Calculate the
(i) mean free time
(ii) mean free path

Given, $n = 8.5 \times 10^{28} / m^3$

$\rho = 1.7 \times 10^{-8}\ \Omega m$

effective speed of e^- $= 1.6 \times 10^6$ m/s

Q.2) What will be the conductivity of sodium metal having e^- density 2.5×10^{28} and relaxation time 3×10^{-14} s

Q.3) The super conducting state of a lead specimen has critical temperature 6.2 kK at zero magnetic field and critical field is 0.064×10^6 A/m at 0K. Estimate the critical field at 5K.

1 ⇒ Soln;

$$\sigma = \frac{ne^2\tau}{m}$$

$$\tau = \frac{m}{ne^2\rho}$$

$$= \frac{}{8.5 \times 10^{28} \times (1.6 \times 10^{-19})^2}$$

Also

$$V_d = \frac{\lambda}{\tau}$$

$$\lambda = V_d\,\tau$$

Civinnovate

Discover, Learn, and Innovate in Civil Engineering

https://civinnovate.com/civil-engineering-notes/