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Semiconductor

Intrinsic Semiconductor →

Semiconductor without any impurities

Ex. Si, Ge, → Pure Crystals.

forbidden gap ≃ 1 eV.

there are two possibilities for transition of e^-s from valence band to Conduction band.

Appling
→ Electric field
→ thermal excitation.

At room temp., the thermal energy that is available can excite a limited no. of electrons across the energy gap.

this limited no. of e^- accounts for Semi-Conduction.

no. of e^- excited given by fermi-Dirac probability distribution →

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

E_F lies midway in forbidden gap for semiconductors.

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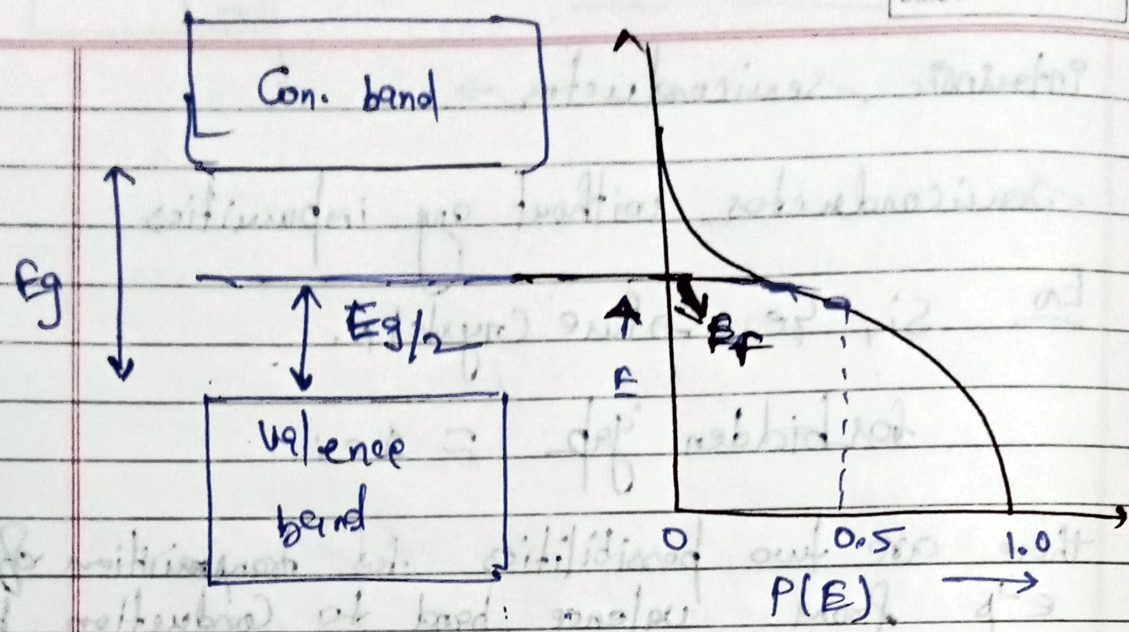

<u>Now</u> we can conclude that

$$E - E_f = E_g/2$$

therefore

$$P(E) = \exp\left[\frac{-E_g}{2kT}\right]$$

{1 can be neglected as it is very v. small in comparision to exp.}

Probability of finding e^-

let

$$P(E) = n$$

<u>then</u>

$$n = N \exp\left[\frac{-E_g}{2kT}\right]$$

N — no. of e^- available for excitation.

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The promotion of some of e⁻ across the gap leaves some vacant e⁻ sites in valence band. these are called holes.

$N_e = N_h$.

$$\text{Mobility} = \frac{\text{drift velocity}}{\text{field gradient}}$$

$$\left.\begin{aligned} \sigma_e &= -n_e e \mu_e \\ \sigma_h &= n_h e \mu_h \end{aligned}\right\} \quad \vec{J} = \sigma \vec{E}$$

$J_e = + n_e e \mu_e E$ → dir of flow of e⁻ opposite to electric field.

$J_h = n_h e \mu_h E$ → dir of hole (+ve charge) same as electric field.

⇒ $J = J_e + J_h$

$\boxed{J = (n_e \mu_e + n_h \mu_h) eE}$ → current density in semi conductor

As $\boxed{n_e = n_h}$ $\boxed{J = (\mu_e + \mu_h) neE}$ → intrinsic semi conductor

- No. of charge carriers (e⁻ & holes) is given the eq ...
- This no. is depends on temp. in an exponential way therefore ↑ very rapidly with ↑ in temp.
- Conduction also ↑ in same manners.
- plot of logarithm of conductivity against the reciprocal of temp. yields straight line.
- slope of this st. line give Energy gap

to make free e^- (→ from Si) we require 0.025 eV energy and at room temp. we have thermal energy (k
= 0.026 eV.

Thus we always have enough energy.

← particle types →

classical particle

quantum particle

fermions

Bosons

↳ used in (p-Si) → semi conductor

Mechanics

classical (real bodies)

quantum (e^-, p)

$\lambda < d$

debroglie wavelength of partical

dis. b/w two particle

$\lambda > d$

debroglie wavelength $(\lambda) = \frac{h}{P}$ → momentum.

distribution function →

$f_{FD}(E) = \frac{1}{1+e^{(E-E_F)/KT}}$ → finding of particle at temp. T

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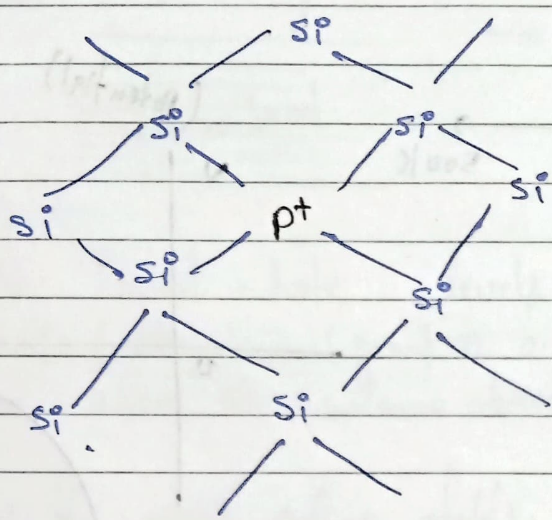
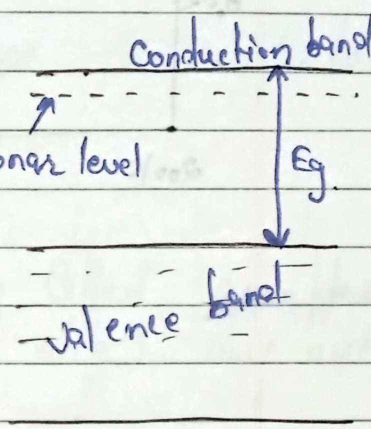
Extrinsic Semiconductor →

the Conduction is due to the presence of extraneous impurities.





$n_e \neq n_h$

$$\boxed{J = (n_e \mu_e + n_h \mu_h) eE}$$

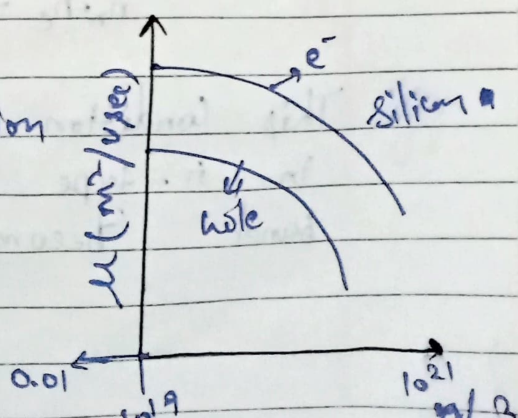
if $n_e > n_h \rightarrow$ n type due to pentavalent

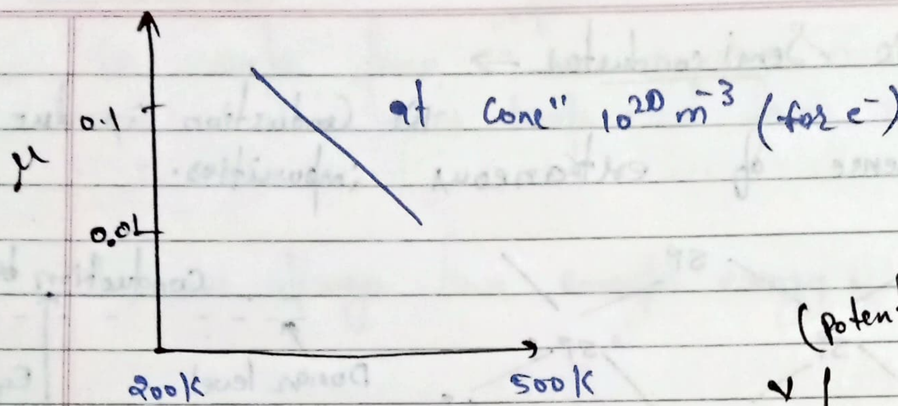
$n_h > n_e \rightarrow$ P type due to trivalent impurity

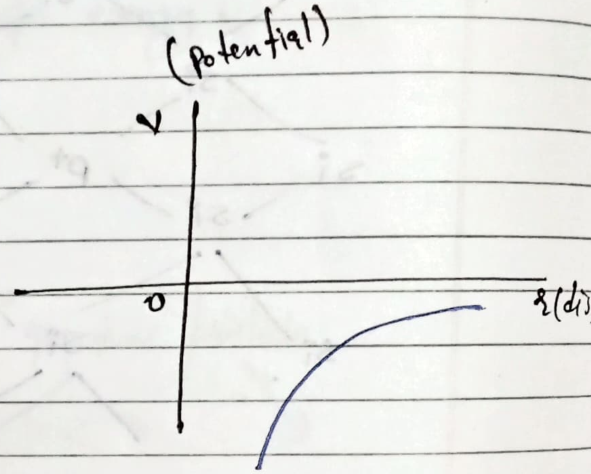
$\mu_I \propto \frac{T^{3/2}}{N_I}$ & $\mu_L \propto T^{-3/2}$

mobility depends upon →

(i) impurity concentration
(ii) temperature.







- Silicon atom in diamond cubic structure. four of five electrons in the outermost orbital of the phosphorus atom take part in the tetrahedral bonding with the four silicon bonding

Acc. to law of mass action, the product of no. of e^- in the conduction band and the no. of holes in the valence band must be constant.

i.e.

$$n_h \cdot n_e = \text{constant}$$

This condition drastically reduces the no. of hole in n-type semiconductor. e^- in conduction band become the majority charge carriers.

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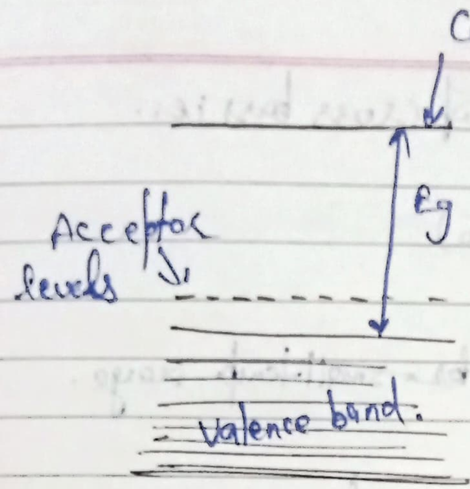
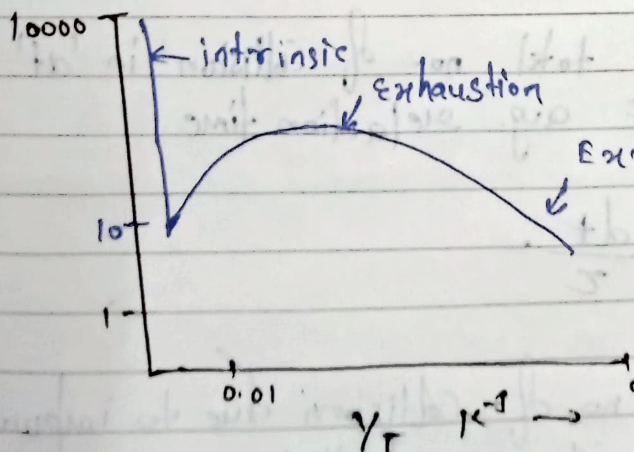


→ P type semiconductor.

The bound - hole levels are called acceptor levels (Aluminium(group 13) accepts an e⁻) are are just above the valence band.

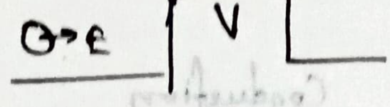
- low of mass action holds good here also.

A typical plot of the logarithm of conductivity against temp.



from the slope of st. lines ionization energy of the impurities can be calculated.

Quantum tunneling



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if $E < V$ then O will not cross barrier.

$$\rho_{(T)} = \rho_0 + \alpha (T - T_0)$$

temp

const.

valid for small temp range.

due to impurity / lattice vibration

additive nature of resistivity →

$$\rho = \rho_I + \rho_L + \rho_D$$

$$\rho = \frac{1}{\sigma} = \frac{1}{ne\mu} = \frac{E}{nev_d}$$

Resistance → Come due to scattering of charge carriers

let n = total no. of collision in 'dt' time:

τ = avg. relaxation time

$$n = \frac{dt}{\tau}.$$

n_I = total no. of collision due to impurity in time

τ_I = avg time (impurity)

$$n_I = \frac{dt}{\tau_I}$$

similarly n_L & τ_I for lattice

$$n_L = \frac{dt}{\tau_L}$$

$n = n_I + n_L$

$$\frac{dt}{\tau} = \frac{dt}{\tau_I} + \frac{dt}{\tau_L} \Rightarrow \frac{1}{\tau} = \frac{1}{\tau_I} + \frac{1}{\tau_L}$$

Extra: other than this class.

force on e^-

$$f = -eE = m_e^* \frac{dv}{dt}$$

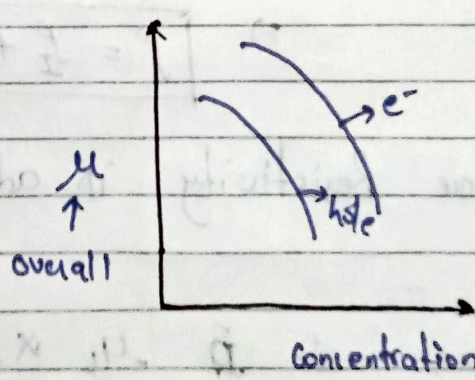
$$\int_0^V dv = \int_0^T \frac{-eE\,dt}{m_e^*} \Rightarrow \boxed{V = \frac{-eE\tau}{m_e^*}}$$

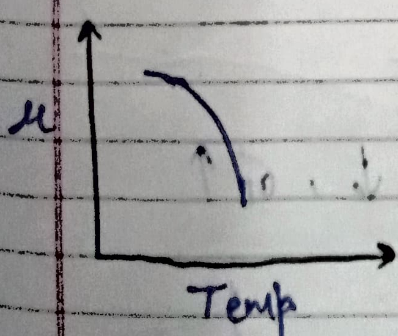
$$\boxed{V_d = \frac{-eE\tau}{m^*}}$$

drift velocity

$$\mu_I \propto \frac{T^{3/2}}{N_I}$$

$$\& \ \mu_L \propto T^{-3/2}$$





$$\frac{1}{\tau} = \frac{1}{\tau_I} + \frac{1}{\tau_L}$$

avg. relo time

$$\frac{1}{\tau} = \frac{1}{\tau_I} + \frac{1}{\tau_L}$$

$$\frac{1}{\mu \frac{m^*}{e}} = \frac{1}{\mu_I\left(\frac{m^*}{e}\right)} + \frac{1}{\mu_L\left(\frac{m^*}{e}\right)}$$

$$\Rightarrow \boxed{\frac{1}{\mu} = \frac{1}{\mu_I} + \frac{1}{\mu_L}}$$

$$\boxed{\mu = \frac{\mu_I \mu_L}{\mu_I + \mu_L}}$$

$$V_d = \frac{-eE\tau}{m^*}$$

$$\tau = \frac{V_d \cdot m^*}{-eE}$$

$$\tau = -\left(\frac{V_d}{E}\right)\cdot\frac{m^*}{e}$$

$$\boxed{\tau = \frac{-\mu m^*}{e}}\ **$$

$$\frac{1}{n\mu e} = \frac{1}{n_I \mu_I e} + \frac{1}{n_L \mu_L e}$$

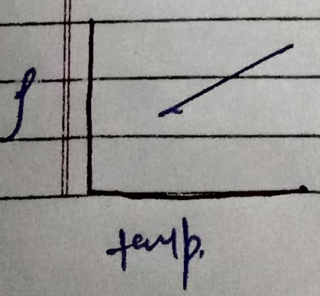
$$\Rightarrow \frac{1}{\sigma} = \frac{1}{\sigma_I} + \frac{1}{\sigma_L} \quad \left(\because \sigma = \mu n e,\ \frac{1}{\rho} = \mu n e\right)$$

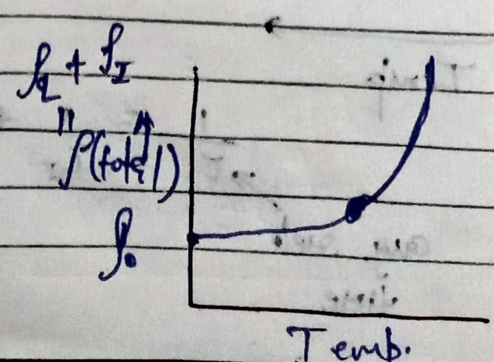
$$\Rightarrow \boxed{\rho = \rho_I + \rho_L}$$

~~Hence~~ Resistivity is additive in nature.

$\rho_L = \frac{1}{ne\mu_L}$ & $\mu_L \propto \frac{1}{T^{3/2}}$

as temp. $\downarrow$ $\mu_L \uparrow$ & $\rho_L \downarrow$, $\sigma_L \uparrow$





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$\mu_I = \frac{T^{3/2}}{N_I}$

it remain almost const. at all temp. or have a minor change can be neglected.

* Velocity of e^- in material (v) $= \sqrt{\frac{3KT}{M_e}}$.

$f = ma$

$-eE = Ma$

$\boxed{a = \frac{-eE}{M}}$

acc. when we apply electric field

u = initial velocity of e^-

v = velocity of e^-

$V = u + at$

$u + \left(\frac{-eE}{M}\right)t$

$\langle v \rangle = \langle u \rangle + \left(\frac{-eE}{M}\right)\langle t \rangle$

$\langle v \rangle \to V_d$, $\langle u \rangle \to 0$

$\Rightarrow \boxed{V_d = \left(\frac{-eE}{M_e^*}\right)\tau}$

ohm's law →

$J = \sigma E$ —(1)

$= -ne\mu E = -neV_d$

$J = -ne\left(\frac{-eE}{M_e^*}\right)\tau = \frac{ne^2 E\tau}{M_e^*}$

$\Rightarrow J = \left(\frac{ne^2\tau}{M_e^*}\right)\tau$ —(ii)

$\sigma = \mu ne$

$= \mu ne$

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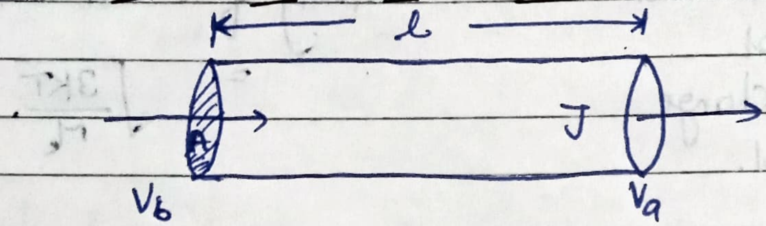
$$\boxed{\sigma = \frac{ne^2\tau}{M_e^*}} \rightarrow \text{drude Model.}$$



$$\Delta V = V_b - V_a = -\int_a^b E \cdot dl = E(l)$$

$$\Rightarrow \boxed{E = \frac{\Delta V}{l}}$$

$$J = \sigma E$$

$$J = \frac{\sigma \cdot \Delta V}{l} \Rightarrow \Delta V = \frac{J l}{\sigma} = \frac{I}{A} \cdot \frac{l}{\sigma} = I\left(\rho \frac{l}{A}\right)$$

$$\Rightarrow \boxed{\Delta V = IR}$$

Conductivity

at microscopic

OR $\boxed{J = \sigma E} \Rightarrow \boxed{J \propto E}$

$$V_d en = \frac{ne^2\tau E}{M}$$

$$\frac{I}{A} = \sigma \frac{\Delta V}{l} \Rightarrow \Delta V = \left(\frac{\rho l}{A}\right) I$$

$$\boxed{\Delta V = IR}$$

$\boxed{J = \sigma E}$

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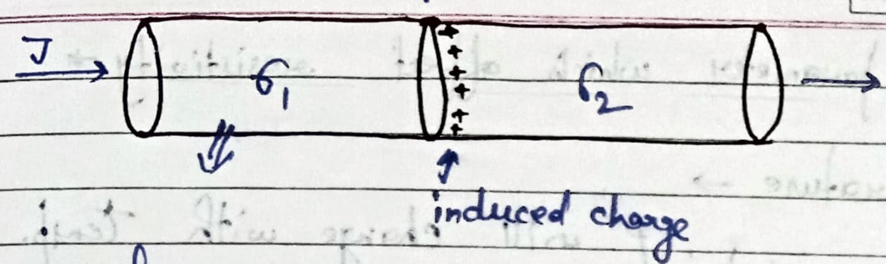
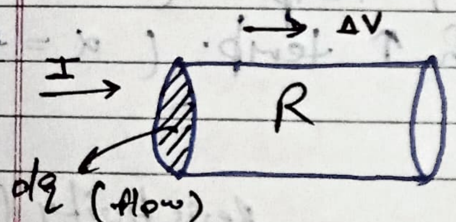
$\sigma_1 > \sigma_2$



will have more no. of charge carriers. i.e. e^-

$J = \sigma_2 E_2 = \sigma_1 E_1$

$\Rightarrow \boxed{E_2 = \frac{\sigma_1 E_1}{\sigma_2}}$



Energy

$\downarrow$

$du = \Delta q \cdot \Delta V$

$P = \frac{du}{dt} = \left(\frac{\Delta q}{dt}\right) \cdot \Delta V = I \cdot \Delta V$

$I \cdot R$

$\Rightarrow P = I \cdot IR$

$\boxed{P = I^2 R}$

$\left(\rho \frac{l}{A}\right)$

** Some values.

$\sigma_{cu} = 5.81 \times 10^7 \; S/m$

$\sigma_{Al} = 3.55 \times 10^7 \; S/m$

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The parameter which affect resistivity →

(1) Temperature →

ρ will change with temp. acc. to given relation.

$$\rho(T) = \rho(T_0)\left[T + \alpha(T - T_0)\right]$$

for Metals → $\rho\uparrow$ with ↑ temp. (α = +ve)
for semiconductor → $\rho\downarrow$ with ↑ temp. (α = +ve)

Metals	temp. coff. (/°c)	Resistivity (Ωm)
Silver	0.0061	1.59×10^{-8}
Copper	0.0068	1.68×10^{-8}
Gold	0.0034	2.44×10^{-8}
Aluminium	0.00429 ← ρ ↑ very fastly.	2.65×10^{-8}
Graphite	−0.0005	
Germinium	−0.05	
Si	−0.07	

(ii) Alloying →

Alloy → Solid solution

$$\rho_i = A(1 - C_i)C_i$$

C_i → % conc^n of impurity added.
(Cu–Ni)

A = Const.

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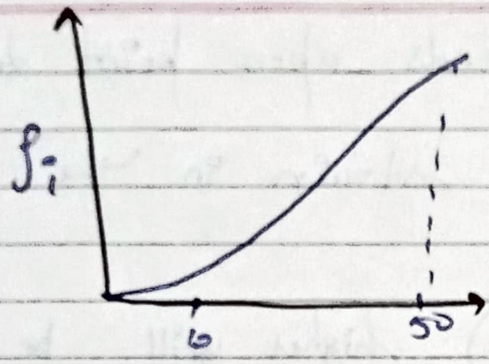


(iii) <u>Volume fraction</u> →

$\rho = \rho_A V_A + \rho_B V_B$ A & B are two phases of same metal. (non metal.)

Volume fraction

$E_n = \left(n+\frac{1}{2}\right)\hbar\omega$ ← discreat energy

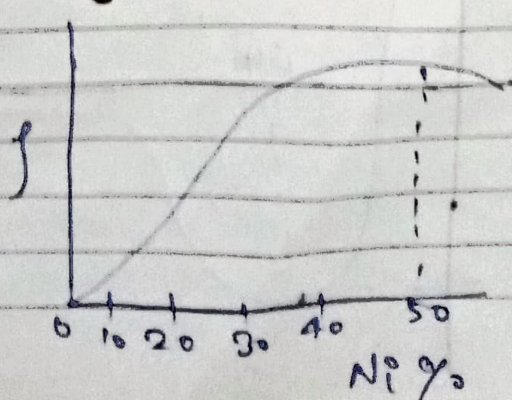
$p = \hbar\omega = \frac{h}{2\pi}\cdot\frac{2\pi}{\lambda} \Rightarrow p = \frac{h}{\lambda}, \quad E = \frac{p^2}{2m}$

$\Rightarrow \boxed{E = \frac{\hbar^2 k^2}{2m}}$

<u>factor affecting Resistivity</u>

(iv) <u>impurities</u> →

Ni in Cu



On adding impurities in metal it ↑ ρ.

1) Stress → (μ depends upon point defect)

↓

(gives rise to strain in the lattice)

More (higher strain) higher will be resistivity
(due to twisting a metal piece)

to solve the this problem

Annealing process →

used for

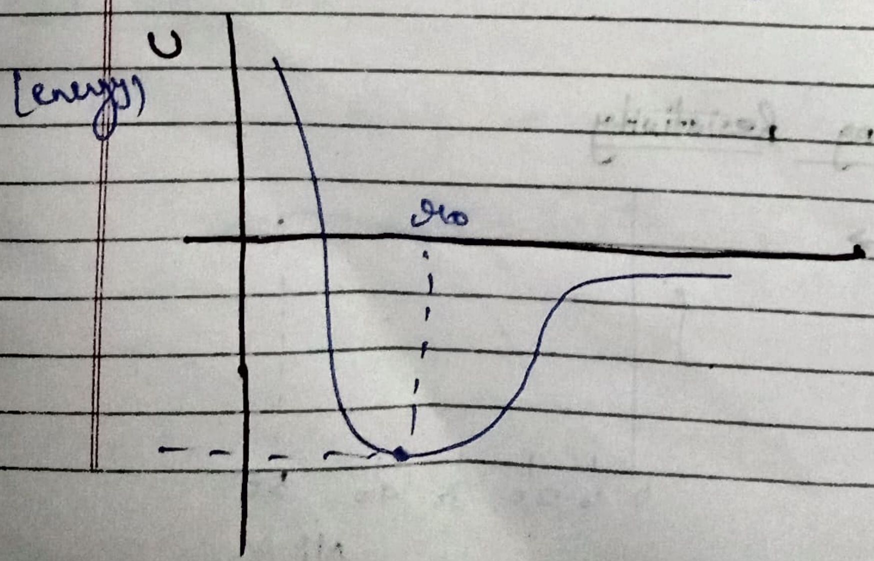
to remove local strain

ρ will decrease as strain is removed

heat twisted metal at higher temp. below melting temp. and then cool it at room temp.

(Note Resistivity will be noted at room temp.)

atom will such that they have lowest energy.



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[VI] **Age hardening →**

after adding small amount of impurity and heating for a long time at lower temp than its melting point.

strength will be more than pure solid.

→ 1st add impurity.
→ heat at higher temp.
→ get a solid sol^n
→ then cool down.

$f \uparrow$ as impurities $\uparrow$

NOTE → in alloys impurities may not homogeneous but here it is.

29/05/23

Gelol

$\rho = \rho_p + \rho_I + \rho_d$ → deformation

ρ_p → phonons

ρ_I → impurities

~~S.No Metals symbol Resistivity ($\mu\Omega$-cm) Temp. coff. (/°C) Thermal conductivity~~

$\rho = \rho_0 [1 + \alpha(T - T_0)]$

S.No.	Metals	Symbol	Resistivity ($\mu\Omega$-cm)	temp. coff. (/°C)	Thermal conductivity (W/mK)	density (gm/cm³)	M.P (°C)
1.	Silver	Ag	1.58	0.0038	429	10.49	962
2.	Copper	Cu	1.68	0.00386	385	8.96	1085
3.	Gold	Au	2.21	0.0034	310	19.3	1064
4.	Aluminium	Al	2.65	0.00429	205	2.7	660

ICs making (vap. deposition).

not used because it vapourised

used in RND (Research field) (Lead time)

Generally used → Can not be soldering.

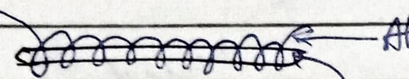
Since on

	Thermal Expansion Coefficient (/°C)
Cu	0.0000167
Al	0.00429

int main( )
{
input
print
}

30/05/23 Ce101

Quiz -2 on 7th June



used for power (electricity) transformation

- Al → ~~used~~ also used in Aircraft (due to light weight)
- Cu (wire) → used in housing item.
- to ↑ strength of wire, impurities are added. → cd-Cdu
- alloy (Si & Cu) so that No Corrosion and ...
- train over head wire (Cd in Cu) ↓ in very low % (0.8 to 1)%

- Silver – Tungsten (good for Mech. strength and Co-organisation.

Good Conductors

Ag, Cu, Au, Al → making wires.