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Comprehensive Course on Electronic Devices

Semiconductor Physics - Part I

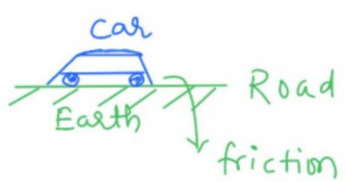
Lesson 1 • July 25, 2020 • Kamesh Shrivastava

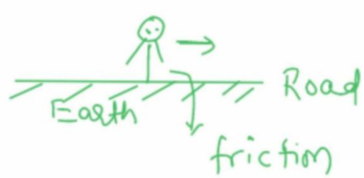
"Syllabus"

1. Semiconductor physics
2. PN junction diode & special diodes.
3. MOS capacitor
4. MOSFET
5. BJT
6. IC Fabrication
7. CMOS Inverter

Books:

1. Streetman & Banerjee
2. Donald A Neaman
3. S.M Sze
4. Taur & Ning
5. Yannis Tsividis
6. Mark Lundstrom (Nano scale)





↳ gravity is responsible for contact of two bodies & then friction is important for motion of object (car).

→ Who is responsible for gravity?
→ Mass

Mass:- Mass is the fundamental property of an object, which is responsible for gravitational force of attraction.

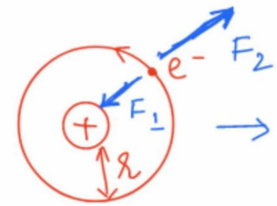
Charge: Charge is the fundamental property of a particle, which is responsible for electric force.
This force may be attractive (or) repulsive depending on nature of other charge present.

(+q) —————— (−q)
"attractive force"

(+q) —————— (+q)
"Repulsive force"

Electronics :- is the study of motion of charge inside a Semiconductor.

Why e^- does not fall in the Nucleus ?



$\Sigma F = 0$ (in radial direction)

$F_2 + F_1 = 0$

→ Centrifugal force + Centripetal force = 0 —— (1)

$$\frac{mv^2}{r} + \frac{e \times (-e)}{4\pi\varepsilon_0 r^2} = 0$$

$$\frac{mv^2}{r} = \frac{e^2}{4\pi\varepsilon_0 r^2} \quad \text{—— (2)}$$

$$mv^2 = e^2/4\pi\varepsilon_0 r$$

Total Energy of e^- (E_T) = K.E + P.E.

$$E_T = \frac{1}{2}mv^2 + \frac{-e^2}{4\pi\varepsilon_0 r}$$

+e (+) ——r—— Potential $= \frac{e}{4\pi\varepsilon_0 r}$

P.E. of e^- = potential × charge $= \left(\frac{e}{4\pi\varepsilon_0 r}\right)(-e)$

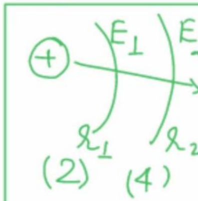
P.E. of e^- $= \frac{-e^2}{4\pi\varepsilon_0 r}$

$$E_T = \frac{1}{2}\left(\frac{e^2}{4\pi\varepsilon_0 r}\right) - \left(\frac{e^2}{4\pi\varepsilon_0 r}\right) = \frac{-e^2}{8\pi\varepsilon_0 r}$$

$$E_T = -\frac{e^2}{8\pi\varepsilon_0 r}$$ "Joules" —— (3)

If we move away from the nucleus Total Energy & P.E of e^- increases.

Ex:



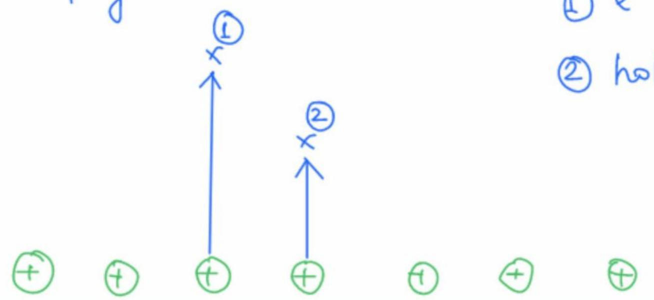
$E_T = \frac{-c}{r} = \frac{-20}{r}$

$E_1 = \frac{-20}{2} = -10$

$E_2 = \frac{-20}{4} = -5$

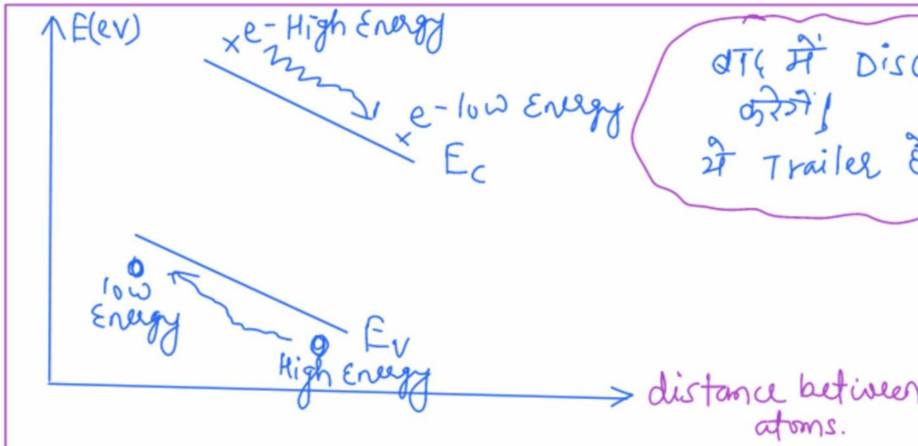
$E_2 > E_1$ $r_2 > r_1$ ⇒ $E_T \propto r$

The Total Energy of e^- and P.E. of electron increases in upward direction. Whereas total Energy of holes & P.E. of holes increases in downward direction. BCZ we have assumed Nucleus at the bottom of the page.



① e^- Energy > ② e^- Energy

② holes Energy > ① holes Energy



बाद में Discuss करेंगे! ये Trailer है!

$$E_T = \frac{-e^2}{8\pi \epsilon_0 r} \text{ 'J'} \quad \text{—— ③}$$

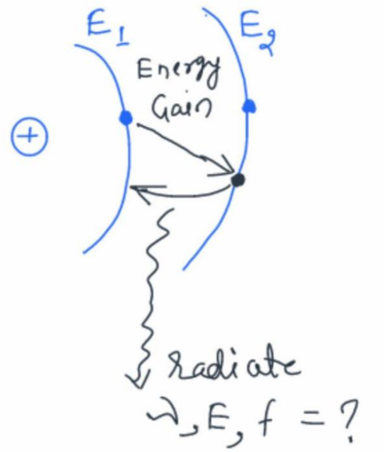
According to classical Electromagnetism, any moving charge must radiate the energy.
Since electron is moving around the Nucleus hence it should radiate the energy.
Hence Electron Energy and therefore radius decreases gradually. And eventually e^- will fall in the nucleus.

Bohr model :-

Above difficulty were resolved by Bohr. He has given 3 basic fundamental Laws.

① Electron does not posseses all the Energies as given by eqn ③. rather it posseses certain sets of Energies (Energy states / Energy levels)
While moving in these Energies e^- does not radiate the Energy. i.e e^- moves in fixed orbitals.

②



$E_{radiate} = E_2 - E_1$
$= \Delta E$

$E = \frac{hc}{\lambda}$

$\lambda = \frac{hc}{E}$

$\boxed{\lambda = \frac{hc}{\Delta E}}$

$\Rightarrow \boxed{\lambda(\text{Å}) = \frac{12400}{(\Delta E)\, eV}}$

h → plank's const. $= 6.626 \times 10^{-34}$ J-sec

c → speed of light $= 3 \times 10^{8}$ m/sec

$1 eV = 1.6 \times 10^{-19}$ J

③

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Semiconductor Physics - Part II

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③ The Angular momentum of electron must be Quantized and it should be integer multiple of $h/2\pi$.

$m v r = n\, h/2\pi$ → $(mv)^2 = \frac{n^2 h^2}{4\pi^2 r^2}$

n → integer $\Rightarrow n = 1, 2, 3 - - - -$

$\Rightarrow$ Eqn (i) → $\frac{mv^2}{r} = \frac{e^2}{4\pi\varepsilon_0 r^2}$

$r = \frac{e^2}{4\pi\varepsilon_0 (mv^2)} = \frac{me^2}{4\pi\varepsilon_0 (mv)^2}$

$$r = \frac{me^2}{4\pi\varepsilon_0 \left(\frac{n^2h^2}{4\pi^2 r^2}\right)} = \frac{me^2 r^2 \pi}{\varepsilon_0 n^2 h^2}$$

$$\boxed{r = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2}}$$ ✓ $n = 1, 2, 3 - - -$

Total Energy of electron eqn③ $E_T = \frac{-e^2}{8\pi\varepsilon_0 r}$

$$E_T = \frac{-e^2}{8\pi\varepsilon_0 \left(\frac{\varepsilon_0 n^2 h^2}{\pi m e^2}\right)} = \frac{-\pi m e^4}{8\pi \varepsilon_0^2 n^2 h^2}$$

$$\boxed{E_T = \frac{-me^4}{8\varepsilon_0^2 h^2} \cdot \frac{1}{n^2}}$$ "Joules"

$m = 9.1 \times 10^{-31}$ kg

$e = 1.6 \times 10^{-19}$ C

$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

$h = 6.626 \times 10^{-34}$ J-sec

$1\,eV = 1.6 \times 10^{-19}$ J

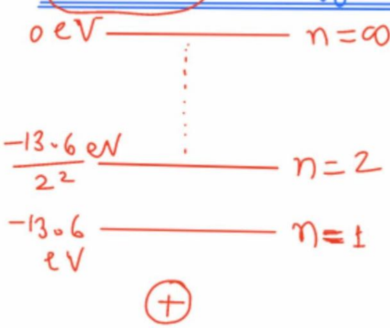
$1\,J = \frac{10^{19}}{1.6}$ eV

$$\boxed{E_T = \frac{-13.6}{n^2}\ eV}$$

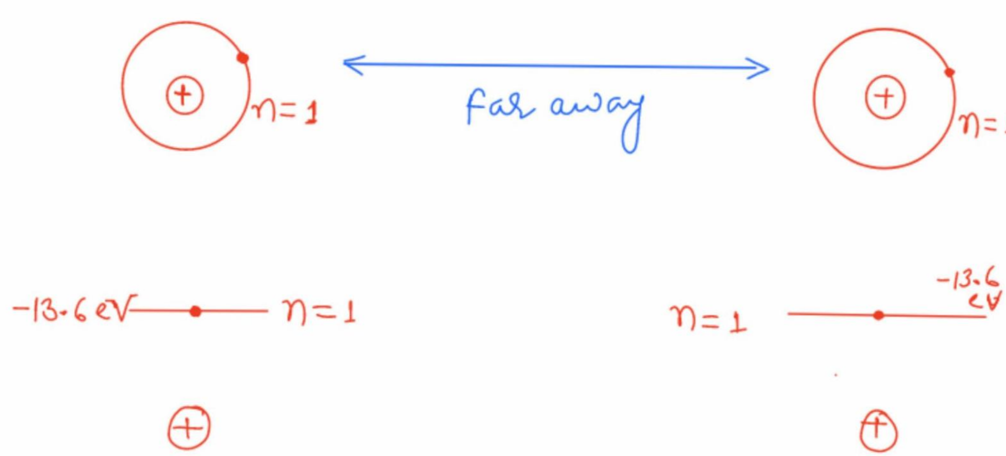
$n = 1, 2, 3 - - - -$

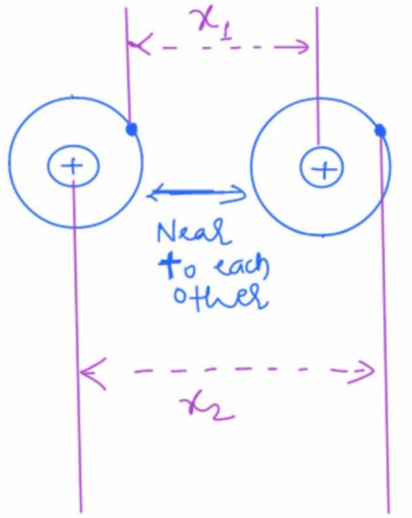
$n \rightarrow$ principle Quantum Number

Atomic Energy level :- (OR) Energy level dig. (Descrete Energy level)

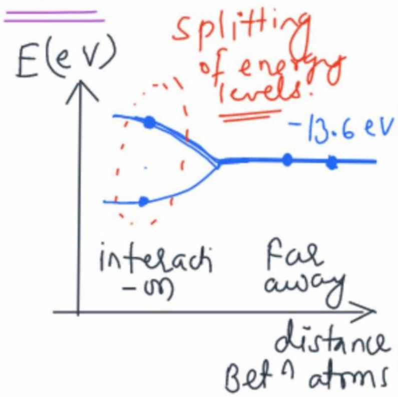


Hydrogen atom



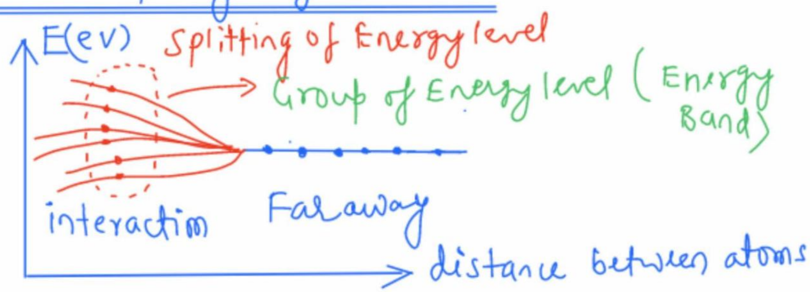


Both e^- are feeling different coulombic force.



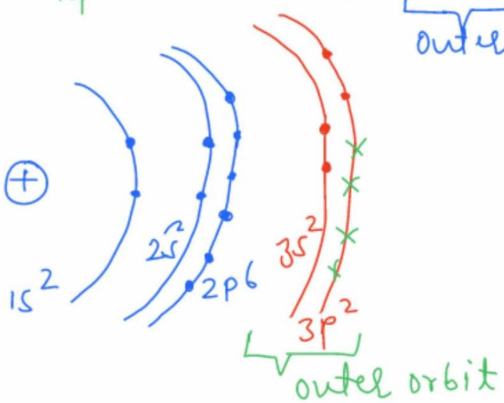
Note: When two atoms come very close to each other, wavefunction of e^- overlap. Hence Energy level splits.

N - number of hydrogen atoms :-



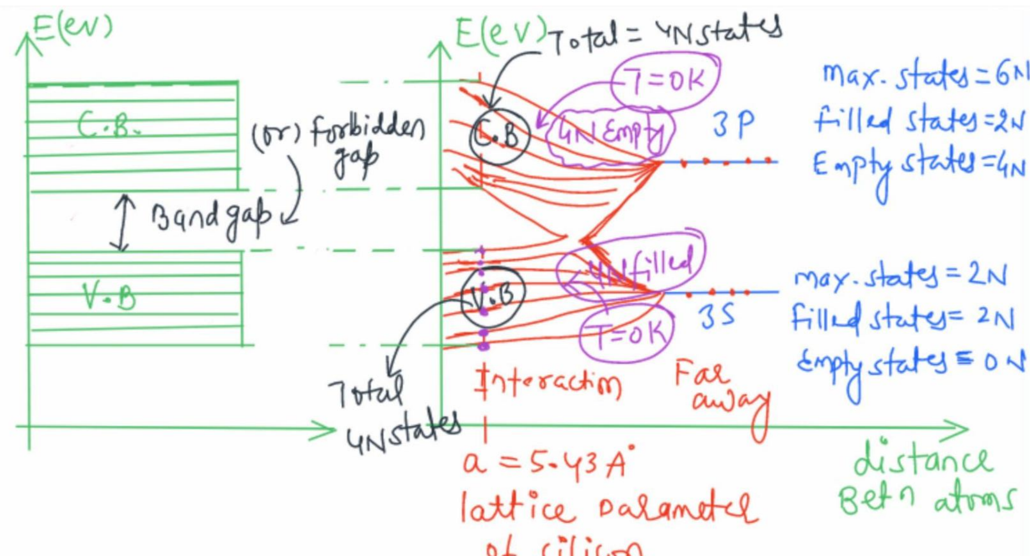
Energy bands in silicon :- ($Ge \rightarrow 32$)

Si_{14} : $1s^2, 2s^2 2p^6, 3s^2 3p^2$ (outer orbit)



3P : Max. states = 6
Filled states = 2
Empty states = 4

3S : Max. states = 2
Filled states = 2
Empty states = 0



Q. Consider Energy band formation in silicon when N number of silicon atoms interact with each other then Number of states in V.B & C.B. respectively are –

Soln ~~4N~~, 4N, 4N

Q. Consider Energy band formation in silicon when N number of silicon atoms interact with each other then at T = 0K number of filled states in C.B & V.B. respectively are – **Ans.** 0, 4N

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Semiconductor Physics - Part III

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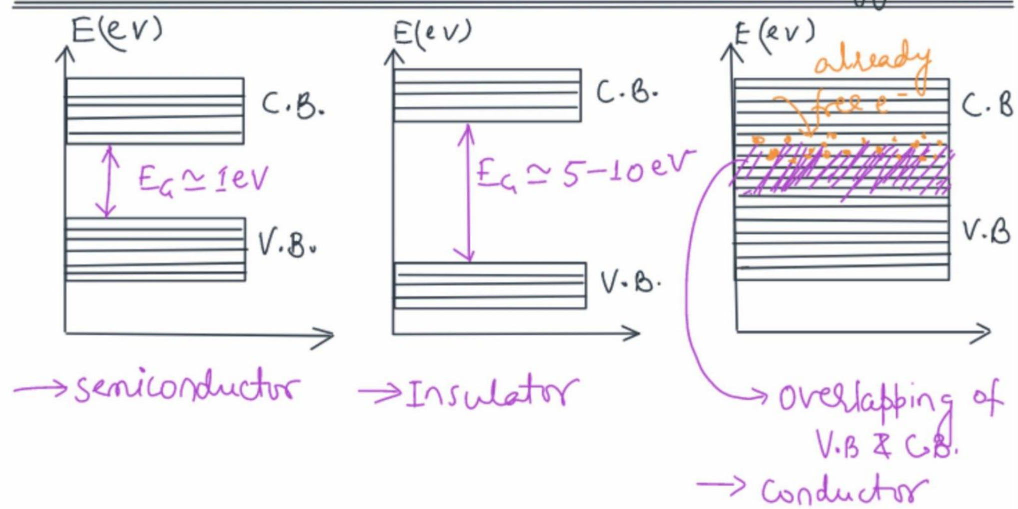
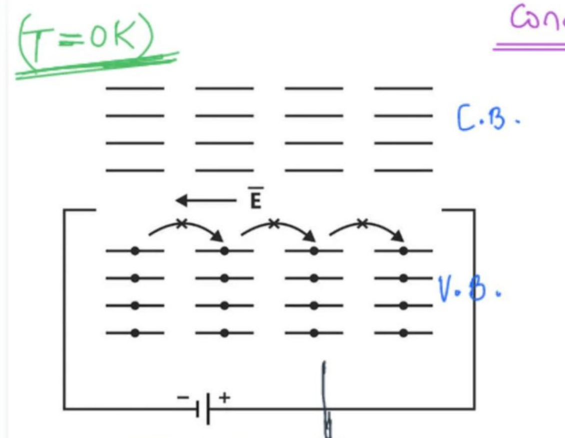
Classification of solids based on Energy bands



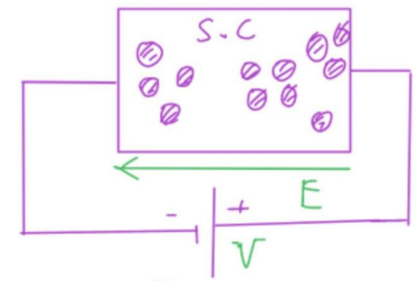
	(0K)	(300K)	
$E_G =$	1.21 eV	1.12 eV	Si
$E_G =$	0.78 eV	0.72 eV	Ge

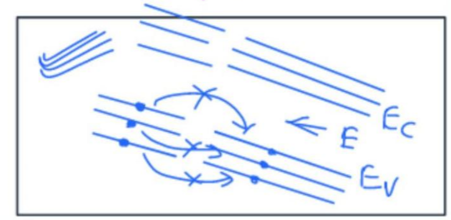
x——x——x —x ——x —x —x—x

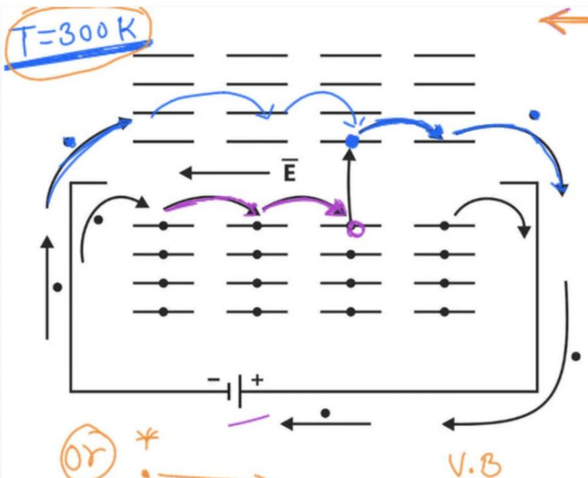
Conduction process in S.C.



$I = 0$
$\sigma = 0$







E

V.B
• ⟶
⟵ I_1

C.B.
• ⟶
⟵ I_2

F = qE

$I_{net} = I_1 + I_2$

$\sigma \neq 0$

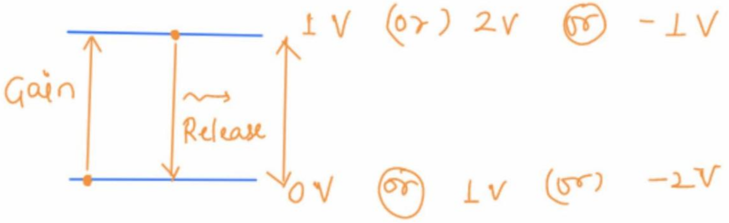
* C.B: • ⟶ , ⟵ I_n

* V.B: ⟵ O , ⟵ I_p ⇒ $I_{net} = I_n + I_p$

Note: at T = 0K all the semiconductors acts as Insulator. B'z no e^- is available in the C.B.

eV : Joules is the unit of Energy in M.K.S. system which is too large a unit. Hence in electronics Engineering problems we define a new unit of Energy that is (eV)

1 eV is the Energy gained / Released by e^- while climbing / falling from a potential difference of 1 V.

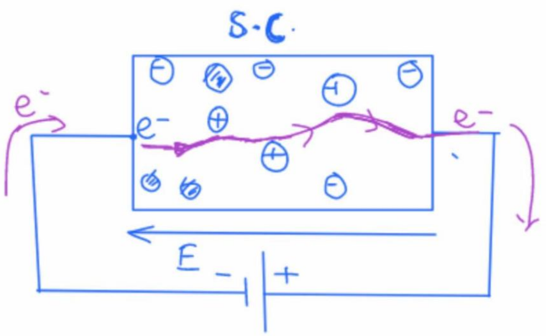


1 eV ⟷ 1 V
2 eV ⟷ 2 V

$$1\,eV = 1.6 \times 10^{-19}\,J$$

$$1\,J = \frac{10^{19}}{1.6}\,eV$$

Define Drift velocity, mobility, collision time, & Relaxation time?



Drift velocity (V_d) :- While moving inside a material e^- collides with atoms & scattered by ions and therefore maintain different velocities. Drift velocity is the avg. velocity maintain by e^-.

$$V_d \propto E$$

$$\boxed{V_d = \mu E}$$

E → Electric field
V_d → Drift velocity
μ → mobility.

mobility (μ): $\mu = \frac{V_d}{E} \rightarrow 1$

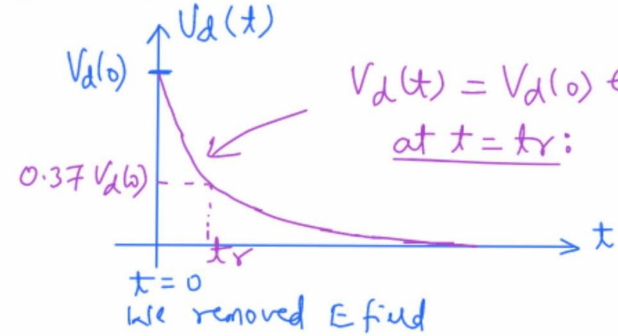
mobility is drift velocity per unit strength of applied electric field.

(OR)

mobility is the measure of how easily a charge particle can drift.

Collision time: Avg. time between two successive collision.

Relaxation (t_r) time:- When electric field is removed we expect $V_d = 0$ But due to inertia e^- takes some time to get Relaxed. Hence V_d takes some time to become zero.



$V_d(t) = V_d(0)\, e^{-t/t_r}$

at $t = t_r$: $V_d(t) = V_d(0)\, e^{-1}$

$V_d(t) = \frac{1}{e} V_d(0)$

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Doubt Clearing Session

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Effect of Temp. on conductivity of semiconductor & Conductors:-

Conductors:- $\sigma = n q \mu_n$

n → Concentration of e^- (or) free e^- concentration → (fixed)

0 K	$T\downarrow$ below 300K	300K	$T\uparrow$ above 300K
σ_{max}, R_{min} → R_0	→ Osc. of atoms at lattice point ↓es → Collision betn e^- and atoms ↓es → $R\downarrow, \sigma\uparrow, \rho\downarrow$		→ Oscillation of atoms at lattice Point ↑es. → Collision betn e^- and atoms per second ↑es → $R\uparrow, \sigma\downarrow, \rho\uparrow$