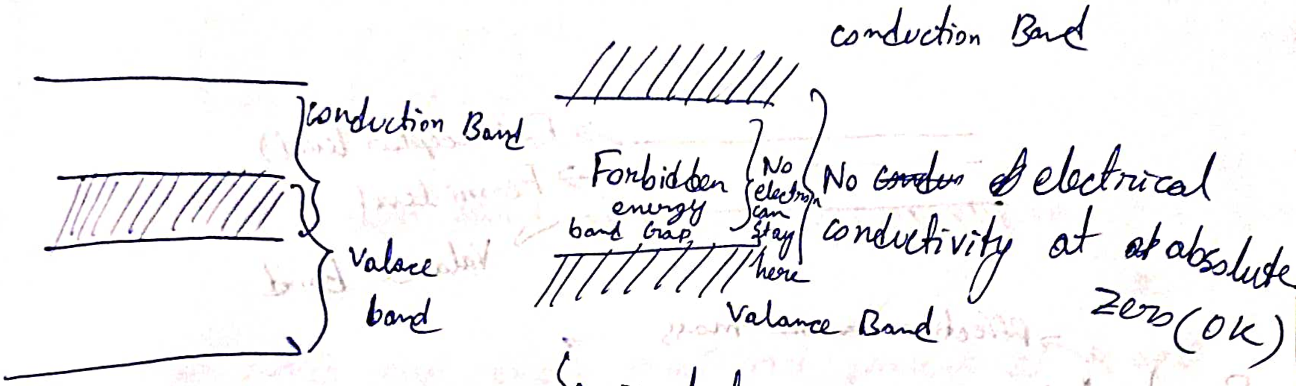
04/08/2022

Semiconductors

- Conduction Band → Free electron (can move under an applied electric field)

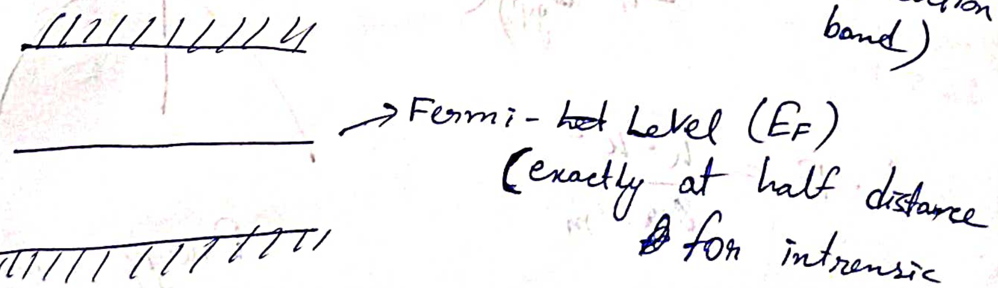
Valance Band → Bounded ~~electons~~ electrons.



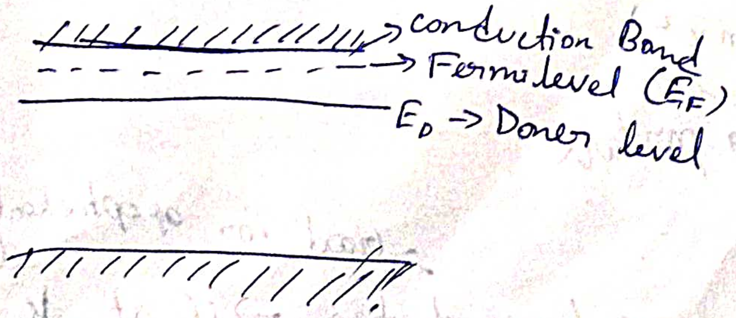
conductor

Semiconductor
- ~~Inten~~ Intrensic
- Extrensic
  - p-type
  - n-type (Si + Arsenic) (valency → 5) (fermi level shifts towards conduction band)

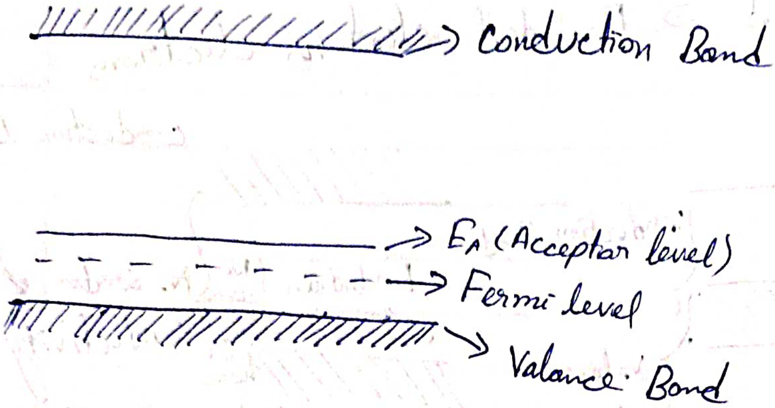
Fermilevel



Si + ~~Arsentic~~ Arsenic (n-type)



For Si + Boron (P-type)
(3 valance electrons)



$$E = \frac{1}{2} m^{*} v^{2}$$

m^{*} → Effective ~~mass~~ mass

$$E = \frac{P^2}{2m} \; ; \; P = \frac{h}{\lambda}$$

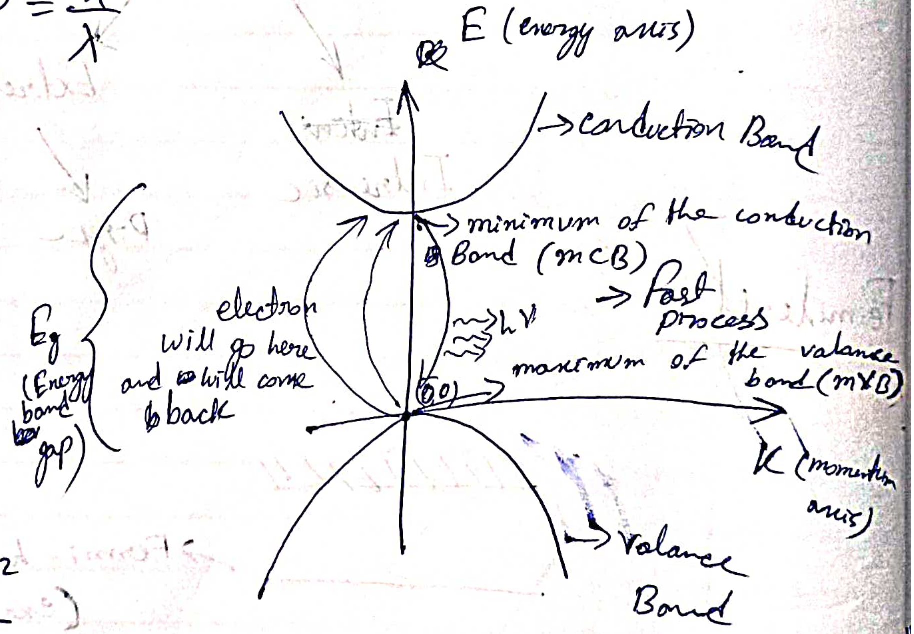
$$\therefore \; \underbrace{K}_{\text{Wave number}} = \frac{2\pi}{\lambda}$$

$$\therefore \; P = \frac{hK}{2\pi}$$

$$\therefore \; E = \frac{h^2 K^2}{8\pi^2 m}$$

$$E = \frac{h^2}{8\pi^2 m} K^2$$

$$\underbrace{(y = m x^2)}_{\text{A parabola}}$$



Energy - moment diagram

$$E_g = h\nu$$

- Direct - Band gap Semiconduction → if at $K = 0$ the mVB and mCB are present (Ex → Gallium Arsenide (GaAs))
  - → Good for optielectronic devices
  - III

$$\frac{dE}{dk} = \frac{h^2 k}{4\pi^2 m^*}$$

$$\frac{d^2E}{dk^2} = \frac{h^2}{4\pi^2 m^*}$$

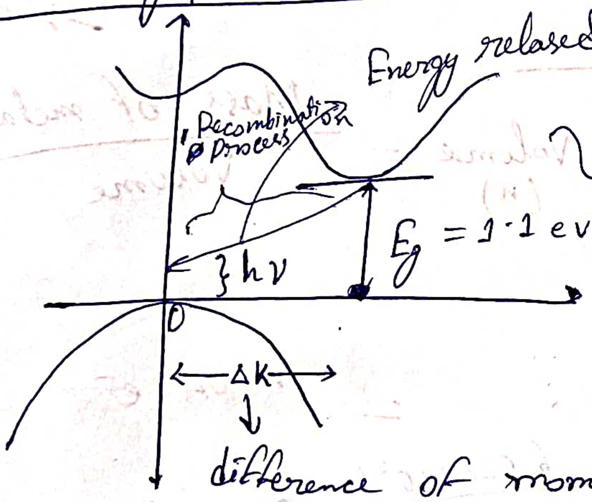
$$\Rightarrow m^* = \frac{h^2}{4\pi^2}\left(\frac{d^2E}{dk^2}\right)^{-1}$$

Another Example of direct Band Semiconductor, ~~Ga~~ GaSB ($\underset{III}{Ga}$, $\underset{V}{Sb}$)

If ~~...~~ mVB and mCB are not present at K = 0

Indirect Band gap Semiconductor (Not ~~go~~ good for optielectronic devices but good for electronic devices)

Energy relased as phonone



slow process

$E_g = 1 \cdot 1$ ev (For Si)

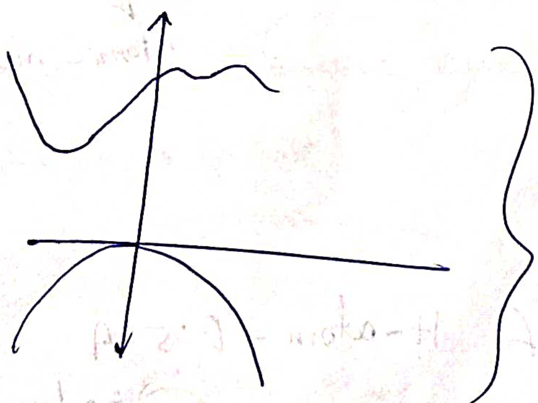
(In Some books $E_g = 1 \cdot 2$ ev)

ΔK → difference of momentum

Si

Ex → Ge → 0·73 eV
Si → 1·1 or 1·2 eV

Phonone ~~⊘~~ ??



For ~~G~~ ~~GE~~ Germanium

Recombination Process

- Radiative → ~~For~~ Responsible for the emission of photons
- Non Radiative → Not " " " " " "

05/08/2022

conductivity $\propto$ Electron density

$\propto$ relaxation time $= \tau$

$\propto \frac{1}{\text{mass of electron}}$

$\propto$ charge of electron

- Model connected macroscopic and microscopic properties

models $\xrightarrow{\text{many}}$ Theories $\xrightarrow{\text{many}}$ Field

Drudes Model

No. of e^- per unit Volume (n) = $\frac{\text{Mass of metal}}{\text{Volume}} \times \frac{\text{no. of atoms}}{\text{mass of metal}} \times \frac{\text{no. of } e^-\text{'s}}{\text{atom}}$

= no. of e^-

ρ → avogadro's no. / atomic mass in grams ↑ no. of atoms

↓ No. of Valance electrons (Z)

$\therefore n = \rho \times \frac{6.022 \times 10^{23}}{A \text{ (in gms)}} \times Z$

A → Atomic mass in grams

- radius of H-atom = 0.5 Å

i.e. radius of the sphere with a single e^- inside it.

- Let $\frac{1}{n} = \frac{4\pi r_s^3}{3}$ → r_s: radius of sphere, volume occupied by a single electron

n → electron density; $\frac{1}{n}$ → volume

$a_0 = 0.5$ Å

Now, $\frac{r_s}{a_0}$ → dimensionless number → For a metal made of pure H, this will b...

$\underbrace{\frac{r_s}{a_0}}_{\text{usually around 2 to 3}}$ ratio

- Average distance between atoms $\rightarrow 1\,\mathring{A}$

- Set up assumptions (First step in creating a model)

Drudes Assumptions

I) Independent electron approximation $\rightarrow$ No $e^- - e^-$ repulsion

~~II~~ Free e^- approximation $\rightarrow$ no e^--ion attraction

- electrons collide with ions some get const current (e^- travels with const v not const acceleration)

II) Electrons collide with ions and not with themselves

~~III~~ III) τ = relaxation time = average time between two collision

~~III~~ ~~IV~~

08/08/2022

IV) Heating of electron $\rightarrow$ Heat transfered to electron by ions.

- Ohm's law $\rightarrow$ $V = IR$ $\rightarrow$ Extensive equation

We want to write as Intensive equation

$$V = \vec{E} \cdot L$$

$$I = \vec{j} A$$

$$R = \rho \frac{L}{A}$$

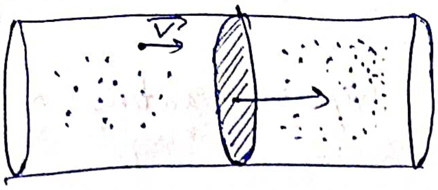
Intensive parameters

$\therefore \vec{E} = \rho \vec{j} \longrightarrow$ Intensive Equation

$\vec{E}$: Electric field

ρ: Resistivity

$\vec{j}$: current density



$\therefore I\,dt$

~~Current (I)~~ $= -(ne\vec{V}dt\,A)$ $\qquad \underbrace{n\cdot(\vec{V}dt)\cdot A}$

~~Charge~~ Current that flows in dt time

No. of electrons flowing through A in time dt.

$\therefore$ At unit time

$$I = -ne\vec{V}A$$

$$\vec{j} = -ne\vec{V} \rightarrow \text{Microscopic property}$$

For No electric field the average $\vec{V}$ is 0.

$\therefore \langle \vec{V} \rangle = 0$ for zero $\vec{E}$

- $\vec{V}(t) = \vec{V_0} + \vec{a}\cdot t$

$$a = \frac{\vec{F}}{m} = \frac{-e\vec{E}}{m}$$

$$\therefore \vec{V}(t) = \underbrace{\vec{V_0}}_{\text{Thermal velocity}} + \left(\frac{-eE}{m}\right)t$$

$$\langle \vec{V}(t) \rangle = \cancelto{0}{\langle \vec{V_0} \rangle} + \left\langle \left(\frac{-eE}{m}\right) t \right\rangle$$

$$\langle \vec{V}(t) \rangle = \frac{-eE}{m}\,\tau \rightarrow \text{Relaxation time}$$

- Now, $\vec{j} = -neV$

$$= -ne\left(\frac{-eE}{m}\tau\right)$$

$$\Rightarrow \boxed{\vec{j} = \underbrace{\frac{ne^2 T}{m}}_{\text{Conductivity } (\sigma)} E}$$

After Drudes calculation

$T = 10^{-14}$ to 10^{-15} sec } Not a function of electric field but an inherent property of the material

Derive an eqvation for Hall effect used today

Point of failure of Drudes theorem

e are not Ideal gases, they are waves
So we cannot apply equipartition theorem to ~~…~~ e^-s

- Equipartition theory (Energy of each degree of freedom $\rightarrow \frac{1}{2} K_B T$) for single atom.

- $\therefore$ For each atom $KE = 3 \times \frac{1}{2} K_B T$

$$\therefore \quad \underbrace{\frac{1}{2} m v_t^2}_{\text{Thermal Velocity}} = \frac{3}{2} \underbrace{K_B}_{\text{Boltzman constant}} T$$

l = mean free path

- $l = \vec{V}_t \cdot T$

l (1 to 10 Å)

$$E_n = \frac{h^2 n^2}{8 m a^2} \qquad n \rightarrow \text{quantum number}$$

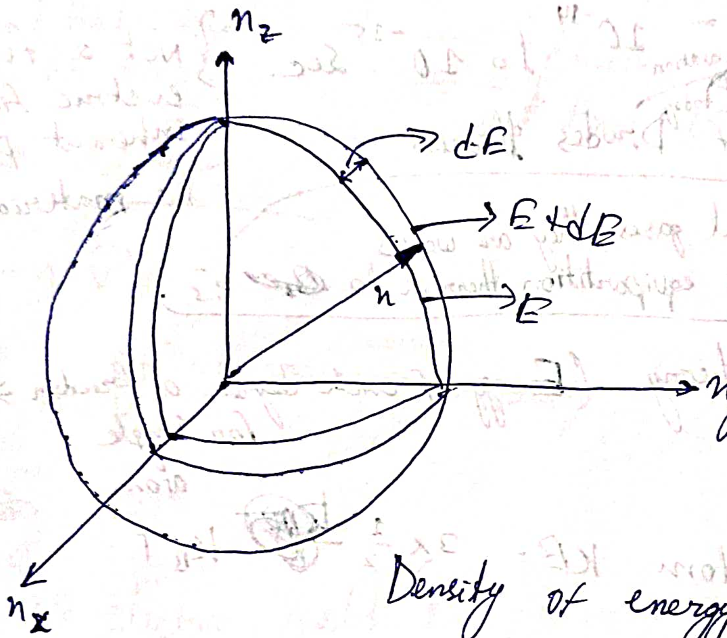
$$n^2 = n_x^2 + n_y^2 + n_z^2$$

$N(E) \rightarrow$ no. of the electrons having the energy E

$Z(E) \rightarrow$ no. of states ~~the~~ of having energy E that the electrons can occupy

Electrons present between energy states E and E+dE is $N(E)dE$

Now, $N(E)dE = \underbrace{Z(E)dE}_{\text{Probability}} \times F(E)$ → ~~Proba~~ Fermi-dirac distribution Probability ↓ Applied to fermions (like e⁻s)



Density of energy state

$n^2 = n_x^2 + n_y^2 + n_z^2$

$$\text{Valence} = \frac{4}{3}\pi n^3 \times \frac{1}{8} \rightarrow E$$

$$\frac{1}{8} \times \frac{4}{3}\pi (n+dn)^3 \rightarrow E+dE$$

$$\therefore Z(E)dE = \frac{1}{8}\frac{4\pi}{3}(n+dn)^3 - \frac{1}{8}\left(\frac{4}{3}\pi\right)n^3$$

$$\Rightarrow \cancel{P}\,\frac{\pi}{2}\,\cancel{n^3 dn}\; n^2 dn$$

$$E = \frac{h^2 n^2}{8ma^2}$$

$$\Rightarrow n^2 = \frac{8ma^2E}{h^2}$$

$$n = \left[\frac{8ma^2}{h^2}\right]^{1/2} E^{1/2}$$

$$\therefore \quad 2n\,dn = \left[\frac{8ma^2}{h^2}\right] dE$$

$$\Rightarrow dn = \frac{1}{2n}\left[\frac{8ma^2}{h^2}\right] dE$$

$$\Rightarrow \cancel{8}\; Z(E)\,dE = \frac{\pi}{2}\, n \times n\, dn$$

$$= \frac{\pi}{2}\left[\frac{8ma^2}{h^2}\right]^{1/2} \times E^{1/2}\left[n \times \frac{1}{2n} \times \frac{8ma^2}{h^2}\, dE\right]$$

a = length

$$Z(E)\,dE = \frac{\pi}{4}\left[\frac{8ma^2}{h^2}\right]^{3/2} E^{1/2}\, dE$$

$e \rightarrow +1/2$

$e \rightarrow -1/2$

$$Z(E)\,dE = 2 \times \frac{\pi}{4} \ldots$$

$$= \frac{\pi}{2} \ldots\ldots$$

The no. of energy states present in unit volume between the energy E and $E+dE$ is $\pi/2 \left[\frac{8m}{h^2}\right]^{3/2} E^{1/2}\, dE$.

→ density of sates between E and E+dE

$$\therefore \; Z(E)\,dE = \frac{\pi}{2}\left[\frac{8m}{h^2}\right]^{3/2} E^{1/2}\, dE$$

$$\therefore \; N(E)\,dE = Z(E)\,dE \times F(E)$$

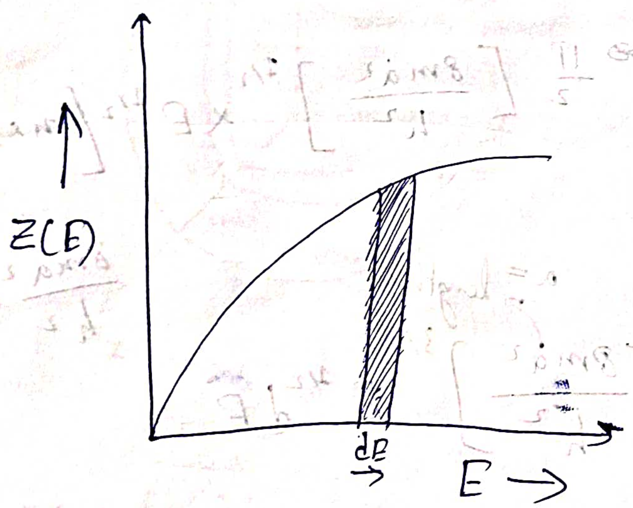
Now, $F(E) = \dfrac{dE}{\underbrace{1 + e^{\frac{E-E_F}{kT}}}_{\text{coming from Pauli excrusion principle}}}$

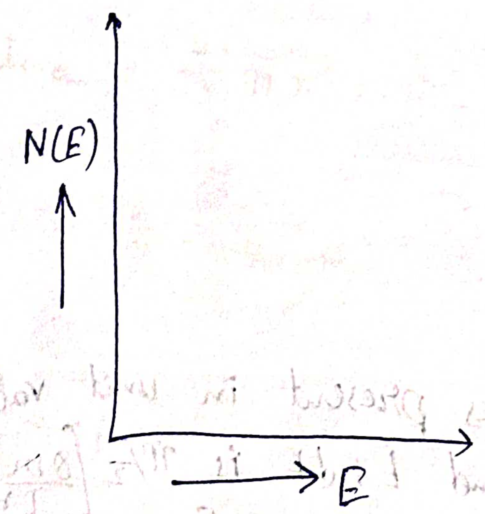
$E_F \rightarrow$ Fermi-level energy

$k \rightarrow$ Boltzmann constant

$$\therefore \quad N(E)dE = \frac{\pi}{2}\left(\frac{8\pi}{h^2}\right)^{3/2} V E^{1/2} \frac{dE}{1+e^{\frac{E-E_F}{kT}}}$$

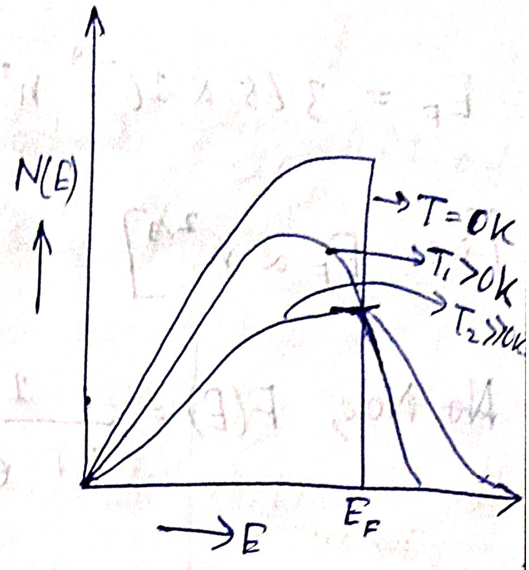
$V \rightarrow a^3$





case I $T=0$

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



At $T=0$

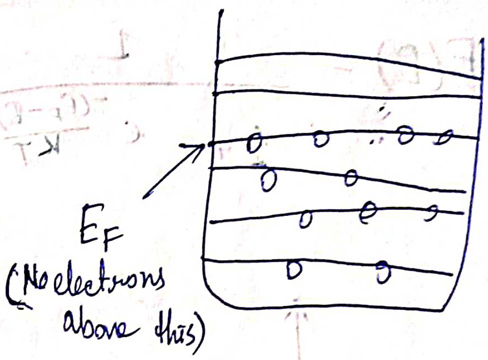
$$F(E) = \frac{1}{1+\underbrace{e^{-\infty}}_{0}}$$

$$\therefore F(E) = 1$$

Now case II

$T_2 >> 0K$

$T_1 > 0K$



Now $N(E)\,dE = \frac{\pi}{2}\left[\frac{8ma^2}{h^2}\right]^{3/2} E^{1/2}\,dE\,F(E)$

at $T=0K$, $F(E)=1$, ~~E<EF~~ $E<E_F$

~~Now~~ Now

$$\int N(E)\,dE = \frac{\pi}{2}\left(\frac{8ma^2}{h^2}\right)^{3/2}\int_0^{E_F} E^{1/2}\,dE$$

$$\Rightarrow N = \frac{\pi}{3}\left(\frac{8m}{h^2}\right) V E_F^{3/2}$$

$$\therefore n = \frac{N}{V} = \frac{\pi}{3}\left(\frac{8m}{h^2}\right) E_F^{3/2}$$

$$\Rightarrow E_F^{3/2} = \left(\frac{3n}{\pi}\right)\left(\frac{h^2}{8m}\right)^{3/2}$$

$$E_F = \left(\frac{h^2}{8m}\right)\left(\frac{3n}{\pi}\right)^{2/3}$$

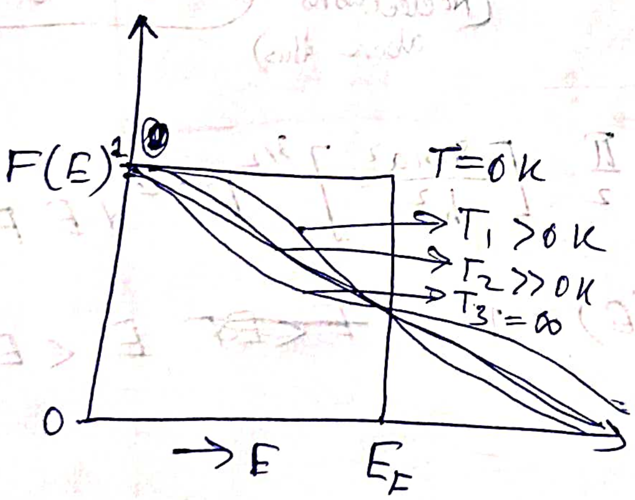
$$E_F = 3.65 \times 10^{-19}\, n^{2/3}$$

$[\text{i.e. } E_F \propto n^{2/3}]$

~~No~~ Now, $F(E) = \dfrac{1}{1 + e^{\frac{E-E_F}{kT}}}$

a) $E < E_F$, $T = 0\,K$

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



$E = E_F$ (Probability will be zero here)

b) $E > E_F$, $T = 0$

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

$$E = E_F$$

$$F(E) = \frac{1}{e^0 + 1} = \frac{1}{1+1} = \frac{1}{2}$$

Q) Let $F(E)$ be the Fermi distribution function characterised by some fermi energy E

calculate the energy range between $F(E) = 0.01$ and $F(E) = 0.99$ for the two different temperature

case a) $T = \cancel{390}$ 300 K (Ans $\Delta E = 0.238 eV$)

case b) $T = 77 K$ (Ans $\Delta E = 0.061 eV$)

At 300 K

$KT = 26 meV$

Ans) $F(E) = \left[1 + e^{\frac{E - E_F}{kT}}\right]^{-1}$

$$\Delta E = E_{0.99} - E_{0.01}$$

Next class problems

So pillai

12/08/2022

- At low temp e^- transfers heat more than ionic vibrations (As then ionic vibrations are low)
- ∴ At low temp the heat conducting material transfers current also
- Weidemann - Franz law → If a material conducts heat then it conducts electricity

ratio of thermal and electrical conductivity is constant