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Assignment # 02 :-

NUMERICALS:-

① One gram of a certain polar substance is dissolved into $1000 cm^3$ of nonpolar liquid. The liquid itself has dielectric constant of 3 at 27°C. whereas solution has dielectric constant of 3.2 at that temperature. Calculate dipole molecules?

Sol:-

Volume is assumed to be constant after dissolving polar substance in liquid.

$$N_1 \alpha_e = 3\varepsilon_0 \left[\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right]$$

$$'' = 3\varepsilon_0 \left[\frac{3-1}{3+2}\right] \text{ for liquid.}$$

$$\alpha_e + N_2\alpha_0 = 3\varepsilon_0 \left[\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right].$$

$$'' = 3\varepsilon_0 \left[\frac{3.2-1}{3.2+2}\right] \text{ for solution.}$$

$$N_2\alpha_0 = 3\varepsilon_0 \left[\frac{2.2}{5.2}\right] - 3\varepsilon_0 \left[2/5\right].$$

$$'' = 3\varepsilon_0 \left[\frac{2.2}{5.2} - \frac{2}{5}\right].$$

$$\alpha_0 = \frac{3\varepsilon_0}{N} \left[0.423 - 0.4\right]$$

$$\alpha_0 = \frac{\mu_0^2}{3k_BT} = \frac{3\varepsilon_0}{N_2} \left[0.43 - 0.4\right].$$

$$\mu_0^2 = \frac{9k_BT\varepsilon_0 \, 0.023}{N_2}$$

$$\mu = \sqrt{\quad ''}$$

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$$\mu_0 = \sqrt{\frac{9 \times 1.38 \times 10^{-23} \times 300 \times 8.85 \times 10^{-12} \times 0.023}{6.02 \times 10^{26}}}$$

$$\boxed{\mu_0 = 0.355 \times 10^{-29} \ C.m}$$

(2) A parallel plate capacitor has area of $8cm^2$ with separation of 0.08mm, the space is filled with Polystyrene. The real part of relative dielectric constant is 2.56 and loss tangent is 0.7×10^{-4} at frequency of 1MHz. Calculate capacitance of equivalent loss resistance?

Sol:- • Area of parallel plate capacitor is
$8cm^2 = 8 \times 10^{-4} m^2$

• separation = d = 0.08mm.

• dielectric constant = K = 2.56.

• loss tanget = $\tan\delta = 0.7 \times 10^{-4}$

• Frequency = 1MHz = 1×10^6 Hz

Capacitance of parallel plate is:

$$C = \frac{K\epsilon_0 A}{d} = \frac{2.56 \times 8.85 \times 10^{-12} \times 8 \times 10^{-4}}{0.08 \times 10^{-3}}$$

$$C = 2.26 \times 10^{-10} F$$

The capacitive reactance of circuit = $X_C = \frac{1}{2\pi f C}$

$\tan\delta = R/X_C$

$R = X_C \tan\delta$

$$R = \frac{\tan\delta}{2\pi f C}$$

$$R = \frac{0.7 \times 10^{-4}}{2 \times 3.14 \times 1 \times 10^6 \times 2.26 \times 10^{-10}}$$

$R = 0.49 \ \Omega$

$$\boxed{R = 49 \times 10^{-3} \ \Omega}$$

equvalent to parallel loss resistence

③ The backelite is found to have real part of its complex relative dielectric constant as 4.36 with loss tangent 2.8×10^{-2} at frequency 1MHz. Calculate complex polarizability of material assuming Lorentz feild Given $N = 4\times10^{28}$

Sol:-

The relation b/w ε_r^* and α^* is similar to Clausis-Mosotti expression and given as

$$\frac{\varepsilon_r^* - 1}{\varepsilon_r^* + 2} = \frac{N\alpha^*}{3\varepsilon_0}$$

where $\varepsilon_r^* = \varepsilon_r' - i\varepsilon_r''$

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'}$$

$$\varepsilon_r'' = \varepsilon_r' \tan\delta$$

Hence $= \varepsilon_r^* = \varepsilon_r' - i\varepsilon_r' \tan\delta$

$= \varepsilon_r'(1 - i\tan\delta)$

$\varepsilon_r' = 4.36$

$\tan\delta = 0.028$

$N = 4\times10^{28}$

$\varepsilon_0 = 8.85\times10^{-12}$

$$\frac{\varepsilon_r^* - 1}{\varepsilon_r^* + 2} = \frac{N\alpha^*}{3\varepsilon_0}$$

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$$\frac{3.36 - 0.122208i}{6.36 - 0.122208i} = \frac{4\times10^{29} \times \alpha^{*}}{3\times 8.85\times10^{-12}}$$

~~21.849~~

$$\frac{(3.36 - 0.122208i)(6.36 + 0.122208i)}{(6.36 + 0.122208i)(6.36 - 0.122208i)} = 150.8\times10^{37}\alpha^{*}$$

$$\frac{21.3845 + i[-0.36624]}{40.465} = 150.79\times10^{37}\alpha^{*}$$

$$\alpha^{*} = \frac{21.3845 - i\,0.36624}{6.1017\times10^{40}}$$

$$= (3.5 - i\,0.06)\times10^{-40}$$

$$\boxed{\alpha^{*} = 10^{-40}\times(3.5 - i\,0.06)}$$

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:- Assignment II :- Problems.

(6) Calculate the probability that a quantum state in conduction band at $E = E_c + kT/2$ is occupied by an electron, Calculate Thermal-equillibrium electron concentration is silicon at $T = 300K$?

Sol:- The Probability that an quantum state at $E = E_c + kT/2$ is occupied by electron is given by:-

$$f_f(F)_f = \frac{1}{1+\exp\left(\frac{E-E_F}{kT}\right)} \approx \exp^{-}\left[\frac{E-E_f}{kT}\right)$$

putting $E = (E_c + kT/2)$

$$f_f(F) = \exp - \left[\frac{E_c + kT/2 - E_f}{kT}\right]$$

$E = 300K$

$N_c = 2.5 \times 10^{19} cm^{-3}$

$$f_f(F) = \exp\left[\frac{-(0.25) + (0.0259)/2}{0.0259}\right]$$

$$" = 3.90 \times 10^{-5}$$

The electron concentration is given by

$$n_o = N_c \exp\left[\frac{-(E_c - E_f)}{kT}\right]$$

$$" = (2.8 \times 10^{19}) \exp\left[\frac{-0.25}{0.0259}\right]$$

$$" = 1.80 \times 10^{15} cm^{-3}$$

(7) Calculate the thermal equillibrium hole concentration in silicon at T=300K. Assume that fermi energy is 0.277eV above valance band energy. The value of N_v for silicon at T=300K is $N_v = 1.04 \times 10^{19}$

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Sol:- we have formula:-

$$\frac{N_{v2}}{N_{v1}} = \left(\frac{T_2}{T_1}\right)^{3/2}$$

$$N_{v2} = N_{v1}\left(T_2/T_1\right)^{3/2}$$

$$" = 1.04 \times 10^{19} cm^{-3} \left(\frac{400K}{300K}\right)^{3/2}$$

$$" = 1.60 \times 10^{19} cm^{-3}$$

The hole concentration is

$$P_o = N_v \exp -\left(\frac{E_F - E_v}{kT}\right)$$

$$E_f - E_v = 0.27eV$$

$$= 0.27 \times 1.6 \times 10^{-19}$$

$$P_o = (1.60 \times 10^{19}) \exp -\left(\frac{0.27 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 400}\right)$$

$$P_o = 6.43 \times 10^{15} cm^{-3}$$

(Q) Calculate the intrinsic carrier concentration in silicon at T = 250K and T = 400K. The values of N_c and N_v for silicon at T = 300K are $2.8 \times 10^{19} cm^{-3}$ and $1.04 \times 10^{19} cm^{-3}$ respectively. Both N_c and N_v vary at $T^{3/2}$. Assume the bandgap energy of silicon is 1.12 eV and does not vary over temperature range?

Sol:- we have formula.

$$n_i^2 = N_c N_v \exp\left[-\left(\frac{E_c - E_v}{kT}\right)\right] = N_c N_v \left[\frac{-E_g}{kT}\right]$$

$$" = (2.8 \times 10^{19})(1.04 \times 10^{19})\left(\frac{250}{300}\right)^3 \exp\left[\frac{-1.12}{(0.0259)\left(\frac{250}{300}\right)}\right]$$

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$n_i^2 = 4.90 \times 10^{15}$

$n_i = 7.0 \times 10^{7} cm^{-3}$

(9) For an intrinsic semiconductor with gap $E_g = 0.7eV$, determine position of fermi level at $T = 300k$ if $m_p^* = 6m_e^*$. Also calculate density of holes and electrons at 300k. How do qualities alter if $E_g = 7eV$?

Sol:- $E_g = 0.7eV$

$n = N_c e^{-(E_c - E_f/KT)}$

$p = N_v e^{-(E_f - E_v/KT)}$

$p = n$

$N_c = e^{-(E_c - E_f/KT)} = N_v e^{-(E_f - E_v)/KT}$

$N_c = \frac{m_e p}{KT}$ $N_v = \frac{m_p P}{KT}$.

$m/e \; e^{-(E_c - E_f/KT)} = \frac{1}{6} m/e \; e^{-E_c - E_v}$

$E_c - E_v = E_g$.

$1/6 = e^{E_g - 2E_f/KT}$

Take ln.

$1.79 = \frac{E_g - 2E_f}{KT}$

$1.79 KT = E_g - 2E_f$

$\frac{1.78 \times 10^{-38} \, 1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}}$

~~$0.04636 eV = E_g - 2E_f$~~

$2E_f = E_g - ''$

$E_f = \frac{1}{2}[E_g - '']$

$E_f = 7eV$.

$E_f = \frac{1}{2}[7 - 0.04636]$

$E_f = 3.52$

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(10) Calculate the intrinsic concentration of charge carriers in germanium at 300K. Eg for germanium is 0.67eV. Given $m_e^*/m_0 = 0.12$ and $m_p^*/m_0 = 0.28$?

Sol:- T = 300K.

$\frac{m_e^*}{m_0} = 0.12$

$\frac{m_p^*}{m_0} = 0.28$.

$E_g = 0.67eV$.

$m_e^* = 0.12 \times 1.6 \times 10^{-19}$

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

$m_p^* = 0.28 \times 1.6 \times 10^{-19}$.

$$n_i = 2\left[\frac{2\pi KT}{h^2}\right]^{3/2} (m_e^* m_p^*)^{3/4} \exp\left[-E_g/2K_BT\right]$$

(1) T = 250

$$f_{250} = \frac{1}{1 + \exp\left(\frac{0.045 - 0.55eV}{8.16 \times 10^{-5} \times 250}\right)}$$

$f_{250} \simeq 1$

(2) $$f_{200} = \frac{1}{1 + \exp\left(\frac{0.45 - 0.5}{8.16 \times 10^{-5} \times 250}\right)}$$

$f_{200} \simeq 1$

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④ The following data refers to a dielectric $\varepsilon_r = 4.94$, $n^2 = 2.69$ where n is index of refraction. Calculate ratio b/w electronic and ionic polarizabilities of this material?

Sol:- $\alpha_e = \dfrac{3}{4\pi\varepsilon_0}\left(\dfrac{\varepsilon_r - 1}{\varepsilon_r + 2}\right) a^3$

$$\alpha_e = \frac{3}{4\pi\varepsilon_0 (0.529\times10^{-10})^3} \cdot \left(\frac{4.94-1}{4.94+2}\right)$$

$$\alpha_e = 1.293\times10^{-30}\ Cm^2/V.$$

ionic polarizability

$$\alpha_i = \frac{1}{4\pi\varepsilon_0} \frac{n_i^2 - 1}{(n^2+2)a^3}.$$

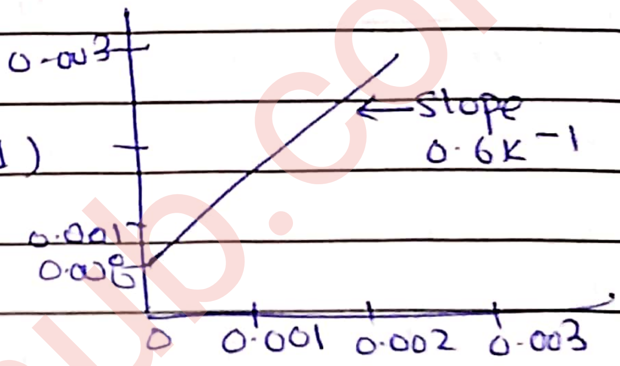
$$\alpha_i = \frac{1}{4\pi\varepsilon_0}\left(\frac{2.69^2 - 1}{2.69^2 + 2}\right)(0.529\times10^{-10})^3$$

$$\alpha_i = 1.112\times10^{-30}\ Cm/V^2$$

$$\frac{\alpha_e}{\alpha_i} = \frac{1.293\times10^{-30}}{1.112\times10^{-30}}$$

$$\boxed{\frac{\alpha_e}{\alpha_i} = 1.162}$$

(5) The variation of dielectric constant of methyl amine CH_5N as a function of temperature plotted as figure(1). Calculate the permanent dipole moment and polarizability of molecules. Number of molecules/m^3 may be assumed to be 2.5×10^{25}?



Sol^n:-

The intercept is 0.008 and slope is 0.6

Now $\varepsilon_0(\varepsilon_r - 1) = N(\alpha_e + \alpha_i)$

$$\alpha_e + \alpha_i = \frac{\varepsilon_0(\varepsilon_r - 1)}{N}$$

$$'' = \frac{8.85 \times 10^{-12}(0.008)}{2.5 \times 10^{25}}$$

$\because \varepsilon_r - 1 = 0.008$

$$\boxed{\alpha_e + \alpha_i = 2.84 \times 10^{-40}\ Fm^2}$$

$$\frac{N\mu_0^2}{3 K_B \varepsilon_0} = \text{slope}.$$

$$\mu_0^2 = \frac{3 \times \text{slope} \times \varepsilon_0 \times K_B}{N}$$

$$'' = \frac{0.6 \times 8.85 \times 10^{-12} \times 3 \times 1.38 \times 10^{-23}}{2.5 \times 10^{25}}$$

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$\mu_o = 2.97 \times 10^{-30}$ C-m

∴ Exam Preparation Questions:-

Assignment # 03:-

Q) Indicate on an energy level diagram the conduct and valance band, donor and acceptor states. What are the positions of Fermi level (i) An intrinsic semiconductor. (ii) n-type (iii) P-type semiconductor?

Ans:-

n-type	P-type
{electrons are in access amount in conduction band}