classmate

Date
Page

Assignment #01
BRANCH : CSE
ID : B120003
NAME : ADITI ROUT

Answers

(1) here, one e^- moves with a velocity of 10^7 cm/s and then the velocity changes by 1 cm/s
We know increase in Kinetic energy is given by.

$$\Delta E = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 = \frac{1}{2}m(v_2^2 - v_1^2)$$

Let $v_2 = v_1 + \Delta v$
Then

$$v_2^2 = (v_1 + \Delta v)^2 = v_1^2 + 2v_1\Delta v + (\Delta v)^2$$

But $\Delta v << v_1$, so we have that

$$\Delta E \approx \frac{1}{2}m(2v_1\Delta v) = mv_1\Delta v.$$

Now
substituting the values we get.

$$\Delta E = (9.11\times10^{-31})(10^5)(0.01)$$
$$= 9.11\times10^{-28}\ J$$

in eV

$$\Delta E = \frac{9.11\times10^{-28}}{1.6\times10^{-19}} = 5.7\times10^{-9}\ eV.$$

From the results, we see a change in velocity of 1cm/s compared with 10^7 cm/s results in a change in energy of 5.7×10^{-9} eV, which is orders of magnitude larger than the change in energy of 10^{-19} eV between energy states in the allowed energy band. This example serves to demonstrate that a difference in adjacent energy states of 10^{-19} eV is indeed very small, so that the discrete energies within an allowed band may be treated as a quasi-continous distribution.

ID: B120003

(2) $P' = 8$

potential width is $a = 4.5 A^0$

$Ka = \pi$

We know,

$$\cos Ka = \frac{P' \sin \alpha a}{\alpha a} + \cos \alpha a$$

So now at one value of $Ka = \pi$ and $P' = 8$, we have $\alpha a = \pi = -\alpha_1 a$

$$-1 = \frac{8 \sin \alpha a}{\alpha a} + \cos \alpha a$$

So net

$$\alpha_1 a = \sqrt{\frac{2mE_1}{\hbar^2}} . a = \pi$$

or

$$E_1 = \frac{\pi^2 \hbar^2}{2ma^2} = \frac{\pi^2 (1.054 \times 10^{-34})^2}{2(9.11 \times 10^{-31})(4.5 \times 10^{-10})^2} = 2.972 \times 10^{-19} J$$

Now we see that, at the other value of $Ka = \pi$, αa is in the range $\pi < \alpha a < 2\pi$.

by trial and error, we find $\alpha a = 5.141 = \alpha_2 a$.

Then

$$\alpha_2 a = \sqrt{\frac{2mE_2}{\hbar^2}} . a = 5.141$$

or

$$E_2 = \frac{(5.141)^2 \hbar^2}{2ma^2} = \frac{(5.141)^2 (1.054 \times 10^{-34})^2}{2(9.11 \times 10^{-31})(4.5 \times 10^{-10})^2}$$

$$= 7.958 \times 10^{-19} J$$

ID: B120003

The bandgap energy is then,

$$E_g = E_2 - E_1 = 7.958 \times 10^{-19} - 2.972 \times 10^{-19}$$

$$= 4.986 \times 10^{-19} J$$

$$E_g = \frac{4.986 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.12 \, eV$$

(3) Photon energy of light with $\lambda = 0.87 \, \mu m$ is

$$h\nu = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} (J.s) \times 3 \times 10^{8} (m/s)}{0.87 \, \mu m}$$

$$= \frac{1.99 \times 10^{-19} (J.\mu m)}{0.87 \, \mu m}$$

$$= \frac{1.99 \times 10^{-19} (eV.\mu m)}{1.6 \times 10^{-19} \times 0.87 \, \mu m}$$

$$= 1.42 \, eV.$$

Therefore the semiconductor is GaAs, with band gap energy 1.42 eV.

The visible spectrum is between 0.5 and 0.7 μm (Si & GaAs have band gaps corresponding to the $h\nu$ of infrared light. Therefore they absorb visible light strongly and are opaque.)

ID : B120003

(4) There are fewer O_2 molecules at higher altitudes because the gravitational potential energy of an O_2 molecule at higher altitude:
E_n is Larger than at sea level, E_0.

$$N_n/N_0 = \frac{e^{-E_n/kt}}{e^{-E_0/kt}} = e^{-(E_n - E_0)/kT}$$

$E_0 - E_n \longrightarrow$ potential difference.

Energy needed to lift an O_2 molecules from sea level to 10 km is

$$E_n - E_0 = \text{altitude} \times \text{weight of } O_2 \text{ molecule} \times g$$
$$= 10^4 \times 32 \times 1.66 \times 10^{-27} \times 9.8$$
$$= 5.2 \times 10^{-21} J$$

$$N_n/N_0 = e^{-5.2 \times 10^{-21} J / (1.38 \times 10^{-10} JK^{-1} \times 273 K)}$$
$$= e^{-1.38}$$
$$= 0.25 \text{ (approx)}$$

So O_2 conc. at 10 km is 25% of the conc. at sea level.

(5) The volume density of quantum states,

$$N = \int_0^{1eV} g(E) dE = \frac{4\pi (2m)^{3/2}}{h^3} \int_0^{1eV} \sqrt{E}\, dE$$

$$N = \frac{4\pi (2m)^{3/2}}{h^3} \left(\frac{2}{3} E^{3/2} \right)$$

ID: B120003

The density of states is

$$N = \frac{4\pi \times [2(9.11 \times 10^{-31})]^{3/2}}{(6.625 \times 10^{-34})^3} \left(\frac{2}{3} \times (1.6 \times 10^{-19})\right)^{3/2}$$

$$= 4.5 \times 10^{27} \ m^{-3}$$

$$= 4.5 \times 10^{21} \text{ states}/cm^3$$

(6) We know,

$$N = \int_{E_c}^{E_c + kT} \frac{4\pi (2m_n^*)^{3/2}}{h^3} \sqrt{E - E_c} \, dE$$

$$= \frac{4\pi (2m_n^*)^{3/2}}{h^3} \left[\left(\frac{2}{3} \cdot (E - E_c)^{3/2}\right)\right]_{E_c}^{E_c + kT}$$

$$= \frac{4\pi [2(1.08)(9.11 \times 10^{-31})]^{3/2}}{(6.625 \times 10^{-34})^3} \cdot \left(\frac{2}{3} \cancel{[(0.0259)(1.6 \times 10^{-19})}\right.$$

$$\times \left(\frac{2}{3} [(0.0259)(1.6 \times 10^{-19})]^{3/2}\right)$$

$$= 2.12 \times 10^{23} \ m^{-3}$$

or

$$N = 2.12 \times 10^{19} \ cm^{-3}$$

(7) $$f_{FD}(E) = \frac{1}{1 + e^{(E - E_F)/k_B T}} = \frac{1}{1 + e^{(3k_B T / k_B T)}}$$

$$= \frac{1}{1 + e^3} = \frac{1}{1 + 20.09} = 0.0474$$

$$= \boxed{4.74\ \%}$$

Probability.

ID : B120003

(8) $f_{MB} - f_{FD} = 5\% \times f_{FD}$

$\Rightarrow e^{-E/k_BT} - \frac{1}{e^{(E-E_F)/k_BT}+1} = \frac{5}{100}\left(\frac{1}{e^{(E-E_F)/k_BT}+1}\right)$

$\Rightarrow e^{-E_F/k_BT} - 1 + e^{-E/k_BT} = \frac{5}{100}$

$\Rightarrow 100\, e^{-E/k_BT} = 5 - 100\, e^{-E_F/k_BT} + 100$

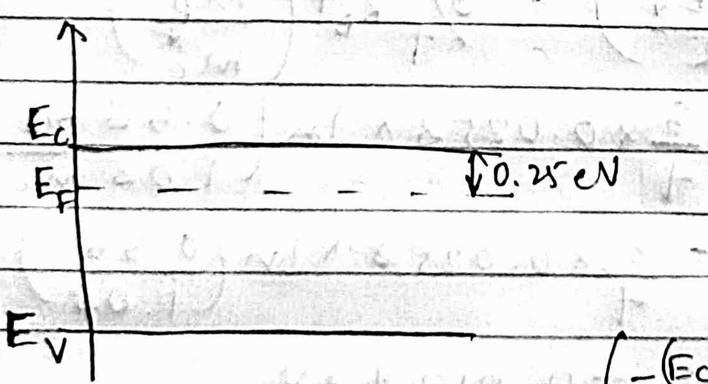
$\Rightarrow e^{-E/k_BT} = \frac{5}{100} - e^{-E_F/k_BT} + 1$

Taking log both sides

$-E = k_BT \ln\left(\frac{5}{100} - e^{-E_F/k_BT} + 1\right)$

$\Rightarrow E = -k_BT \ln\left(\frac{5}{100} - e^{-E_F/k_BT} + 1\right)$

(9)



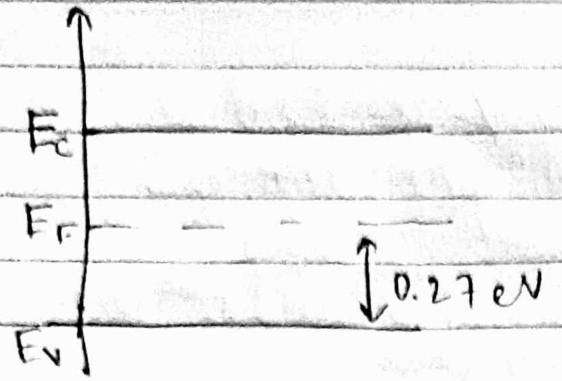
Now, $N = N_c\, e^{\left(\frac{-(E_c - E_F)}{k_BT}\right)}$

$= 2.8 \times 10^{19} \cdot e^{\frac{-(E_c - E_c + 0.25)}{0.0259}}$

$= 1.8 \times 10^{15}\ cm^{-3}$

ID : B120003

(10)



So hole concentration is $= N_V e^{\left(\frac{-(E_F - E_V)}{K_B T}\right)}$

$= 1.04 \times 10^{19} \cdot e^{\frac{-(E_V + 0.27)}{0.0259}}$

$= 3.09 \times 10^{14}\ cm^{-3}$

(11) The intrinsic fermi level, E_f with respect to centre of band gap is

$E_i - E_{midgap} = E_i - E_g/2$

Intrinsic fermilevel is defined in terms of bandgap, temp. and effective carried masses as

$$E_i - \left(\frac{E_C - E_V}{2}\right) = \frac{3}{4} K_B T \left(\frac{m_p^*}{m_e^*}\right)$$

$$= \frac{3}{4} \times 0.0258 \times \ln\left(\frac{0.56\, m_e}{1.08\, m_e}\right)$$

$$= \frac{3}{4} \times 0.0258 \times \ln\left(\frac{0.56}{1.08}\right)$$

$$= -0.0127\ eV$$

(12) a) $E_C - E_F = K_B T \ln\left(N_C/n\right)$

$= 0.026 \ln(2.8 \times 10^9/10^7)$

$= 0.146\ eV.$

ID: B120003

E_F is located at 146 meV below E_c.

b) For $p = 10^{14}\ cm^{-3}$

$$E_F - E_V = K_BT \ln (N_V/p)$$
$$= 0.026 \ln (1.04 \times 10^{19}/10^{14})$$
$$= 0.31\ eV.$$

So E_F is located at 0.31 eV above E_V.

(13) Let P be hole concentration.

In n-type, $N_D = 10^{15}\ cm^{-3}$

and $n_i(Si) = 1.5 \times 10^{10}\ cm^{-3}$.

Now we know

$$np = n_i^2$$

$\Rightarrow$

$$P = \frac{n_i^2}{n} \approx \frac{n_i^2}{N_D} = \frac{(1.5 \times 10^{10})^2}{10^{15}} = 2.25 \times 10^5$$

Now in p-type Ge semiconducter.

$$n_i = 2.4 \times 10^{13}\ cm^{-3}$$
$$P \approx N_A\ (\text{acceptors}) = 10^{17}\ cm^{-3}.$$

So

electron concentration can be found by using.

$$np = n_i^2$$
$$\Rightarrow n = \frac{n_i^2}{P} = \frac{(2.4 \times 10^{13})^2}{10^{17}}$$
$$= 5.76 \times 10^9$$

$n \rightarrow$ electron concentration $= 5.76 \times 10^9$

(14) In Si

$$N_d = 6 \times 10^{16}\ cm^{-3}$$
$$N_a = 2 \times 10^{16}\ cm^{-3}$$

Since $N_d > N_a$ it is n-type semiconductor.

So net doping $= N_D - N_a = 6 \times 10^{16} - 2 \times 10^{16} = 4 \times 10^{16}\ cm^{-2}$

ID : B120003

So $n = 4 \times 10^{16}$

we know $np = 4 \times 10^{16}$

$$p = \frac{n_i^2}{n} = \frac{(10^{10})^2}{4 \times 10^{16}} = 2.5 \times 10^3 \, cm^{-3}$$

or

$$p = \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + n_i^2} \approx 2.5 \times 10^3 \, cm^{-3}$$

If $6 \times 10^{16} \, cm^{-3}$ of acceptors are added.

Net $N_a = (2 + 6) \times 10^{16} = 8 \times 10^{16} \, cm^{-3}$

so $p = N_a - N_d$

$= (8 - 6) \times 10^{16} = 2 \times 10^{16} \, cm^{-3}$

so

$np = n_i^2$

$\Rightarrow n = n_i^2 / p = 5 \times 10^3 \, cm^{-3}$

So $N_a > N_d$ and the semiconductor would be p type as the majority charge carries are holes.