Solutions to Tut 6

P115

$$v = \frac{1}{\hbar}\frac{dE}{dk} \Rightarrow$$

$$\frac{dx}{dt} = \frac{1}{\hbar}\frac{dE}{dk}$$

$$= \frac{1}{\hbar}\frac{dE}{dt}\frac{dt}{dk}$$

$$= \frac{1}{F}\frac{dE}{dt}$$

$$\therefore x - x_o = \frac{1}{F}\left(E(k_o) - E(0)\right)$$

$$J = \frac{E}{\rho}$$

$$E = 100 \times 10^{-8} \times \frac{1}{1 \times 10^{-6}} = 1 \text{ V/m}$$

$$F = \hbar\frac{dk}{dt} \Rightarrow$$

$$t = \frac{\hbar \times \pi \times 10^{10}}{1 \times 1.6 \times 10^{-19}} \approx 2.07 \times 10^{-5} \text{s}$$

Energy at $k = \pi(\text{Å})^{-1}$ is

$$\frac{\hbar^2 k^2}{2m} \approx 37.6 \text{ eV}$$

$$\therefore x_2 - x_1 = 37.6 \text{ m}$$

P116

$$E = A - Bcoska$$

$$v = \frac{1}{\hbar}\frac{dE}{dk} = \frac{1}{\hbar}Basinka$$

$$Therefore, v\ is\ maximum\ when\ k = \frac{\pi}{2a}$$

$$m* = \frac{\hbar^2}{\frac{d^2E}{dk^2}} = \frac{\hbar^2}{Ba^2coska}$$

P117

$$\epsilon = \varepsilon_0(1 - coska)$$

$$\frac{d\varepsilon}{dk} = \epsilon_0 a \sin(ka)\ \ and\ v_g = \frac{1}{\hbar}\frac{d\varepsilon}{dk} = \frac{1}{\hbar}\epsilon_0 \text{a} \sin\,(ka)$$

speed corresponding to $k = \frac{10\pi}{3} \times 10^9 \mathrm{m}^{-1}$ is $2.6 \times 10^5 \frac{\mathrm{m}}{\mathrm{s}}$

This is the speed of the missing electron (hole with the positive charge). That is the current is $I = nev_g = 1 \times 1.6 \times 10^{-19} \times 2.6 \times 10^5 = 4.2 \times 10^{-14} A$, along the $+$ x direction.

effective mass of the electron, $m *= \frac{\hbar^2}{\epsilon_0 a^2 coska} = -3.4 \times 10^{-30} kg.$

Therefore, the effective mass of the hole=$3.4 \times 10^{-30} kg$

Acceleration is a=F/m*

Force on the hole $= 1.6 \times 10^{-19} \times 0.5 = 0.8 \times 10^{-19} N$ along the $-$ ve x axis

Therefore, a of the hole $= -\frac{0.8 \times 10^{-19}}{3.4 \times 10^{-30}} = -2.3 \times 10^{10} m/s^2$

Hence the k value of the hole decreases with time. Or equivalently, the k value of the electron increases. Acceleration is dependent on m*, which depends on the value of k.

Therefore, the speed of the electron becomes zero when $ka = \pi$ $or\ when\ k = \frac{\pi}{a} = \frac{\pi}{2} \times 10^{10}$

Therefore, change in $k, \Delta k = \left(\frac{\pi}{2} - \frac{\pi}{3}\right) \times 10^{10} m^{-1}$

Therefore, $\Delta t = \frac{\hbar \Delta k}{F} = 6.9 \times 10^{-6} s$

P 121

Before the application of B,

$$J_X = \frac{2}{2 \times 10^{-2} \times 10^{-4}} = 10^6 A/m^2$$

$$E_X = \frac{100}{8 \times 10^{-2}} = 1.25 \times 10^3 V/m$$

$\therefore \sigma = \frac{J_X}{E_X} = 800\ (ohm.m)^{-1}$

After the application of the magnetic field, $E_Y = \frac{R_H}{J_X B_Z}$

$$\therefore R_H = \frac{1.5}{2 \times 10^{-2}} \frac{1}{10^6 \times 0.2} = 3.75 \times 10^{-4}$$

$\sigma = ne(\mu_n + \mu_p) with\ n = p$

$R_H = \frac{1}{ne}\frac{\mu_p^2-\mu_n^2}{(\mu_p+\mu_n)^2}=\frac{1}{ne}\frac{\mu_p-\mu_n}{(\mu_p+\mu_n)}$

$$\therefore \sigma R_H = \mu_p - \mu_n = 800 \times 3.75 \times 10^{-4} = \frac{0.3m^2}{V.s}$$

$$\mu_n + \mu_p = \frac{800}{10^{22} \times 1.6 \times 10^{-19}} = 0.5$$

$$\therefore \mu_n = 0.1\frac{m^2}{V.s}\ and\ \mu_p = 0.4\frac{m^2}{V.s}$$

$$\mu = \frac{e\tau}{m} \Longrightarrow \tau = \mu\frac{m}{e} = \mu 5.687 \times 10^{-12}$$

$\tau_p = 2.275 \times 10^{-12}s$ and
$\tau_n = 0.5687 \times 10^{-12}s$

P 122

$$\sigma = ne(\mu_p + \mu_n)$$

$$\sigma = 2\left(\frac{kT}{2\pi\hbar^2}\right)^{\frac{3}{2}}(m_e * m_h *)^{\frac{3}{4}}exp\left(\frac{-E_g}{2kT}\right)e(\mu_p + \mu_n)$$

solving this, E_g=0.68 eV

Using this, the effective mass of the electron can be calculated.

P123

Use the relation

n=$\left(\frac{kT}{2\pi\hbar^2}\right)^{\frac{3}{2}}(m_e * m_h *)^{\frac{3}{4}}exp\left(\frac{-E_g}{2kT}\right)$ to calculate m_h*

P124

n_i=2.5x10^{19}/m^3

n_d=10^{20}

$n_i^2 = np = (p + N_d)p$ .Solve this to get p and n/p.

P 126

$p + N_d = n + N_a$

Using the equation given in problem P 123, calculate n and p (n=p) with the given information.

This works out to be 2.499×10^{25}

$\therefore 2.499 \times 10^{25} exp\{-(E_F - E_V)/kT\} + 5 \times 10^{19} = 2.499 \times 10^{25} exp\{-(E_C - E_F)/kT\} + 10^{20}$

Take E_V=0, E_C=0.7 Ev, Put

$exp\left(\frac{E_F}{kT}\right) = x, which\ will\ give\ a\ quadratic\ equation\ in\ x. Solving\ this\ gives\ E_F = 0.332\ eV$

P 129

From the given intrinsic conductivities at two different temperatures, calculate band gap and n_i values at the two temperatures. Then find $\mu_p + \mu_n$. Taking n=(N_d+p) and n_i^2=np, calculate n. From this, calculate E_F. Use the expression of the extrinsic semiconductor expression for the conductivity, calculate μ_n