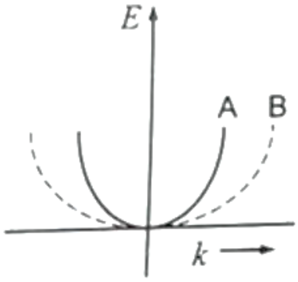
TUTORIAL - 2

1. Two possible conduction bands are shown in the **E** versus **k** diagram given. State which band will result in the heavier electron effective mass.



2. (a) If $E_F = E_C$ find the probability of a state being occupied at $E = E_c + kT$

   (b) If $E_F = E_v$ find the probability of a state being empty at $E = E_v - kt$

3. Determine the probability that an energy level is occupied by an electron if the state is above the Fermi level:

   (a) kT

   (b) 5 kT

   (c) 10 kT.

4. Determine the probability that an energy level is empty of electrons if the state is below the Fermi level by:

   (a) kt

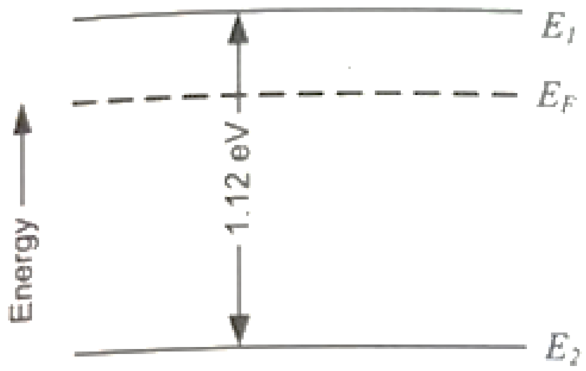
   (b) 5 kT

   (c) 10 kt

5. Consider the energy levels shown in figure below. Let T = 300 k.

   (a) If $E_1 - E_F = 0.30$ eV, determine the probability that an energy state at $E = E_1$ is occupied an electron and the probability that an energy state $E = E_2$ is empty.

   (b) Repeat part (a) if $E_F – E_2 = 0.40$ eV.



6. Assume the Fermi energy is exactly in the center of the band gap energy of a semiconductor at T = 300 k.

   (a) Calculate the probability that an energy state in the bottom of the conduction band is occupied by an electron for Si, Ge and GaAs.

   (b) Calculate the probability that an energy state in the top of the valence band is empty for Si, Ge and GaAs.

7. Calculate the temperature at which there is a 10^{-6} probability that an energy state 0.55 eV above the Fermi energy is occupied by an electron.

Solutions

1. The effective mass is given by,

$$m^* = (\frac{1}{h^2} \cdot \frac{d^2E}{dk^2})^{-1}$$

We have that $\frac{d^2E}{dk^2}$ (curve A) > $\frac{d^2E}{dk^2}$ (curve B). So m^* (curve A) < m^*(curve B).

2. a) $f(E) = \frac{1}{1+ exp^{[\frac{(E_C+ kT)- E_C}{kT}]}}$ = $\frac{1}{1+ exp^{1}}$ = 0.269

b) $1 - f(E) = 1 - \frac{1}{1+ exp^{[\frac{(E_v+ kT)- E_v}{kT}]}}$ = $1 - \frac{1}{1+ exp^{-1}}$ = 0.269

3. $f(E) = \frac{1}{1+ exp^{\left[\frac{E - E_F}{kT}\right]}}$

(a) $E - E_f = kT$, $f(E) = \frac{1}{1+ exp^{1}}$ = 0.269

(b) $E - E_f = 5\, kT$, $f(E) = \frac{1}{1+ exp^{5}}$ = 6.69 x 10^{-3}

(c) $E - E_f = 10\, kT$, $f(E) = \frac{1}{1+ exp^{10}}$ = 4.54 x 10^{-3}

4. $1 - f(E) = 1 - \frac{1}{1+ exp^{\left[\frac{E - E_F}{kT}\right]}}$ or $1 - f(E) = 1 - \frac{1}{1+ exp^{\left[\frac{E_F - E}{kT}\right]}}$

(d) $E - E_f = kT$, $1 - f(E) =$ 0.269

(e) $E - E_f = 5\, kT$, $1 - f(E) =$ 6.69 x 10^{-3}

(f) $E - E_f = 10\, kT$, $1 - f(E) =$ 4.54 x 10^{-3}

5. For $E = E_1$

$$f(E) = \frac{1}{1 + exp^{\left[\frac{E - E_F}{kT}\right]}} = exp^{\left[\frac{-(E_1 - E_F)}{kT}\right]} = \exp\frac{-0.30}{0.0259} = 9.3 \ x \ 10^{-6}$$

For $E = E_2, E_F - E_2 = 1.12 - 0.3 = 0.82 \ eV$

$$1 - f(E) = 1 - \frac{1}{1 + exp^{\left[\frac{-0.82}{0.0259}\right]}} = 1 - \left[1 - exp^{\left[\frac{-0.82}{0.0259}\right]}\right]$$

$$= \exp\frac{-0.82}{0.0259} = 1.78 \ x \ 10^{-14}$$

6. At $E = E_{midgap}$

$$f(E) = \frac{1}{1 + exp^{\left[\frac{E - E_F}{kT}\right]}} = \frac{1}{1 + exp\left[\frac{E_g}{2kT}\right]}$$

For Si, $E_g = 1.12 \ eV$

$$f(E) = \frac{1}{1 + \exp\left[\frac{1.12}{2 \ x \ 0.0259}\right]} = 4.07 \ x \ 10^{-10}$$

For Ge, $E_g = 0.66 \ eV$

$$f(E) = 2.93 \ x \ 10^{-6}$$

For GaAs, $E_g = 1.42 \ eV$

$$f(E) = 1.24 \ x \ 10^{-12}$$

7. $f(E) = 10^{-6} = \frac{1}{1+\exp[\frac{0.55}{kT}]}$

$$kT = \frac{0.55}{\ln 10^6}; T = 461K$$