Chapter 1:Conduction in semiconductors

1.1.Introduction:

The charge of the electron (q) = 1.6 x10^{-19} C

The mass of the electron (M_e) = 9.11 x 10^{-31} Kg

The radius of electron is 10^{-15}m

The number of electrons per second is known as current (I)

The energy of electron (E) is:

$$E = h\nu \qquad (1\text{-}1)$$

Where $\nu = \frac{c}{\lambda}$, h is Blank constant, c is the speed of light, λ is the wavelength.

- The electric field intensity is the force (f) on a unit positive charge (q):

$$E = \frac{dv}{dx} \times \frac{f}{q} \qquad (1\text{-}2)$$

i.e. $$E = f \qquad (1\text{-}3)$$

- The force is directed from the higher potential region to the lower potential region.
- The electron charge is (-q), therefore the force on the electron is:

$$f = -Eq \qquad (1\text{-}4)$$

- Unit of energy is Joule (J) → where, Watt=J/sec.
- The energy that the electron can gain when its voltage increases to 1volt is known as electron-volt (eV).

$$1\ \text{eV} = 1.6\ \times 10^{-19}\ \text{J}$$

- If an electron falls through a potential of 1volt, its kinetic energy will increase by decreasing the potential energy, or:

$$qV = 1.6\ \times 10^{-19}\ (C) \times (1V) = 1.6\ \times 10^{-19}\ J = 1\ eV$$

1.2.The Bohr atom:

In 1913, Bohr has postulated the following 3 laws:

1- The atom can possess only certain discrete energy, and the electron does not emit radiation in states corresponding to these energies, and the electron is said to be in a stationary or non-radiating state.
2- In a transition from one stationary state with energy (W) to another one, radiation will be emitted. The frequency of this radiated energy is :

$$f = \frac{W_2 - W_1}{h} \qquad (1\text{-}5)$$

Where W in (J) and *f* in cycle/sec or hertz.

3- A stationary state is determined by the condition that the angular momentum of the electron in this state is quantized and must be an integral multiple of $h/2\pi$.

$$mvr = \frac{nh}{2\pi} \qquad (1\text{-}6)$$

Where n is an integer. The energy level of each state is:

$$W_n = \frac{mq^2}{8h^2\epsilon_0^2 r^2}\frac{1}{n^2} \qquad (1\text{-}7)$$

$$\lambda = \frac{12{,}400}{E_2 - E_1} \qquad (1\text{-}8)$$

- The lowest energy state is called normal or ground state and other levels are called excited levels.
- As the electron is given more and more energy, it moves into the stationary states which are farther and farther away from the nucleus.
- When its energy is large enough it will detached out of the field of influence of ion, this energy is called ionization energy; is represented as the highest state in the energy level diagram.

1.3.Field intensity, Potential and Energy:

Definition of the electric field intensity: is the force (f) on a unit positive charge in an electric field at a certain point.

Newton's second law determines the motion of a particle with charge "q" in (Coulomb) and mass "m" in (kg), moving with a velocity "v" in (m/sec) in a field "E" in (volt/m).

$$f = qE = m\frac{dv}{dt} \tag{1-9}$$

For 3D field, the potential V (volt) of point B with respect to point A is the work done against the field in taking a unit positive charge from A to B.

For 1D with A at the point x_o and B at an arbitrary distance x

$$V = -\int_{x_o}^{x} Edx \tag{1-10}$$

$$E = -\frac{dV}{dx} \tag{1-11}$$

Where E represents the X component of the field.

The minus sign shows that the electric field is directed from the higher potential region to the lower potential region.

The potential energy "U" (Joules) = Potential (V) x electronic charge (q):

$$U = qV \tag{1-12}$$

If an electron is being considered, q is replaced by –q and U has the same shape as V but is inverted.

The law of conversion of energy states that the total energy (W) which is equals the sum of the potential energy (U) and the kinetic energy ($\frac{1}{2}mv^2$) remains constant, therefore at any point in space:

$$W = U + \frac{1}{2}mv^2 = \text{constant} \tag{1-13}$$

Q: Consider two plates A & B (Fig.1.1(a)) separated by a distance (d); B at a negative potential (V_d) with respect to A. When an electron leaves the surface of A with the velocity (v_o) towards B, how much speed (v) will it have if it reaches B?

Answer: page 3, with Figure 1-1 (the English book).

1.4.Concept of a potential-energy barrier:

Fig.1-1 (b, c) shows a linear relation between Potential (V) and distance (x) and the corresponding potential energy (U) versus (x), respectively.

$\because$ V = U/q   from eq.1-4

- Then Fig.1.1 (c) is obtained by multiplying the each ordinate in the Fig.1.1 (b) curve with q (negative value).
- Since W of electron remains constant, it will be represented as horizontal line.
- From eq.1-6:

$$(\tfrac{1}{2}mv^2)_{\text{at any distance x}} = (W - U)_{\text{at this point}} \qquad (1\text{-}14)$$

$(\frac{1}{2}mv^2)_{\text{electron}}$ is max. at x=0, which means that kinetic energy in the greatest when the electron leaves electrode A.

- At point P: $(\frac{1}{2}mv^2)_{\text{electron}} = 0$, so the particle is at rest at this point (x_o).
- X_o is the max distance that the electron can travel from A.

Q: What is the possibility of traveling the electron from A to reach distance S in Fig.1.1(c)?

This leads to an important conclusion: The electron can never penetrate the shaded part of Fig.1.1(c), and point P is a potential-energy barrier.

1.5.The atomic nature of atom:

In 1911, Rutherford has found that the atom consists of positively charged nucleus and surrounding by negatively charged electrons.

The hydrogen atom, as an example, consists of positively charged nucleus (a proton which is equal in magnitude to the electron charge with opposite sign) and a single electron. Hence, the atom is electrically neutral.

Because the proton has practically all the mass of atom, proton is substantially immobile and the electron moves around it in a closed circular of elliptical orbit, under the force of attraction which follows Coulomb's law.

Now assume the orbit is circle, and the nucleus is fixed, so it is easier to calculate the radius in term of W of electron.

The force of attraction between proton and electron in hydrogen atom is $q^2/4\pi\epsilon_o r^2$. By Newton's 2nd law,

$$\frac{q^2}{4\pi\epsilon_o r^2} = \frac{mv^2}{r} \qquad (1\text{-}15)$$

Where v is the speed of electron in the circle path (m/sec), m is the mass of the electron (kg),r is the separation distance between two particles (m), $\frac{v^2}{r}$ is the acceleration towards the nucleus and ϵ_o is the permittivity of free space.

Moreover, the potential energy at a distance r from nucleus is $-q^2/4\pi\epsilon_o r$, and the kinetic energy is $1/2\, mv^2$. Then, according to the conservation of energy:

$$W = \frac{1}{2}mv^2 - \frac{q^2}{4\pi\epsilon_o r} \qquad (1\text{-}16)$$

From eq. (1-8) and (1-9):

$$W = \frac{1}{2} \times \frac{q^2}{4\pi\epsilon_o r} - \frac{q^2}{4\pi\epsilon_o r}$$

$$W = \frac{q^2}{8\pi\epsilon_o r} - \frac{q^2}{4\pi\epsilon_o r}$$

$$W = \frac{q^2 - 2q^2}{8\pi\epsilon_o r} = -\frac{q^2}{8\pi\epsilon_o r} \qquad (1\text{-}17)$$

This equation gives the desire relation between the radius and the energy of the electron which is always negative.

The negative sign means:

$$W = 0 \; when \; r = \infty.$$

And

$$W \rightarrow smaller\ (more\ negative), when\ r\ \rightarrow close\ to\ neceuls$$

All the accelerated charges must radiate energy with the same frequency (*f*) of the charge oscillation. Therefore, the energy of the emitted radiation is equal to the frequency at which the electron is rotating in its circular orbit.

Therefore, as the atom radiates energy, the electron must move in smaller and smaller orbits, eventually falling into the nucleus.