ECSE-2210 Microelectronics Technology
Class Activity 2 – Solution

1. A voltage of 10V is applied to point B with respect to point A in the figure below. Assume C is in the middle. If an electron at rest is placed at point C and released,

   a. In which direction will the electron move? Towards A or towards B?

   The electron will move towards B. Electrons move towards positive terminal since the electron charge is negative.

   b. Calculate the electron energy in Joules when it reaches B.

   $Energy = q\,V = 1.6 \times 10^{-19}$ C × 5 V = 8.0×10^{-19} J
   (Note: C × V = J; A × V = W; A = C/s. Make sure that you use consistent units.)

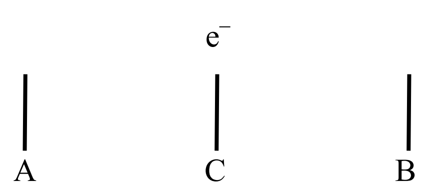
   c. Calculate the electron energy in eV when it reaches B.

   A new unit of energy is electron volt (eV). It is the energy acquired by an electron when subjected to 1V potential difference. Since 1 electron has the charge $q = 1.6 \times 10^{-19}$ C, 1 eV turns out to be $1.6 \times 10^{-19} \times 1$ V, i.e., 1.6×10^{-19} J.
   So, 1 eV = 1.6×10^{-19} J. Therefore: $Energy = 8.0 \times 10^{-19}$ J = 5 eV

   d. What will be the electron velocity in m/s when it reaches B?

   The electron energy at point B is $0.5\, m_o v^2$ where v is the velocity at point B and m_o is the rest mass of electron. So, $(1/2)\, m_o v^2 = 8.0 \times 10^{-19}$ J
   $0.5 \times 9.11 \times 10^{-31}$ kg $\times v^2 = 8.0 \times 10^{-19}$ J results in $v = 1.3 \times 10^6$ m/s

   e. Calculate the electric field $\mathcal{E}$ that exists between point A and point B if the distance between A and B is 5 cm. Indicate the direction of the $\mathcal{E}$ –field by an arrow.



   The electric field is directed from the positive terminal to the negative terminal, i.e., from B to A. If we take the positive *x*-direction as from A to B, then the direction of electric field is in the negative *x* direction. The electric field magnitude is potential difference/distance = 10 V / 5 cm = 2 V/cm.

So, the electric field is –2 V/cm assuming that the positive x direction is from A to B. (Unit of $\mathcal{E}$ is V/cm or V/m. The direction is from +V to –V.)

2. Calculate the energies (in eV) for the first three allowed orbits of the hydrogen atom.

   Use equation 2.1 in text, and plug in the values. Make sure you are consistent with the units. Note that $\hbar = \dfrac{h}{2\pi}$

   Answers should be: – 13.6 eV for $n = 1$
   – 3.4 eV for $n = 2$
   – 1.51 eV for $n = 3$

3. Suppose an electron falls from the $n = 3$ orbit to the $n = 2$ orbit in hydrogen. Calculate the wavelength of radiation emitted during this process. Express this wavelength in Angstroms. Is the emitted light visible?

   When electron falls from $n = 3$ to $n = 2$ orbit, the energy of radiation is
   (– 1.51eV) – (– 3.4eV) = 1.89 eV
   Use $E = h\,c / \lambda$ and
   $\lambda = h\,c / E = (6.63 \times 10^{-34}\text{ J s} \times 3 \times 10^{8}\text{ m/s}) / (1.89\text{ eV} \times 1.6 \times 10^{-19}\text{ J/eV})$
   $= 6.577 \times 10^{-7}\text{ m} = 657.7 \times 10^{-9}\text{ m} = 657.7\text{ nm} = 6577\text{ Å}$
   (This corresponds to red light. Note that the visible spectrum is approximately from 4000 Å to 7500 Å. 4000 Å being the violet color, and 7000 Å being red color.)

4. a. What is the number of Si atoms per cm^3?

   See your class notes:
   There are 8 atoms per unit cell. The unit cell volume is a^3 with $a = 5.42\text{ Å} = 5.42 \times 10^{-8}$ cm.
   So, number of atoms per $cm^3 = 8 / (5.42 \times 10^{-8}\text{ cm})^3 = 5 \times 10^{22}$ atoms/cm^3

   b. What is the **total** <u>number</u> of electrons present in 1 cm^3 of Si?

   Each Si atom has 14 electrons, so total number of electrons per cm^3 is given by $14 \times 5\times10^{22}\text{ cm}^{-3}$

   c. What is the total number of electrons present in the valence band of Si at 0 K?

   There are 4 electrons per atom in the valence band or $4 \times 5 \times 10^{22}$ valence electrons/cm^3.

   d. How many electrons are free to conduct electricity at 0 K?

   None, since the valence band is full, i.e., every state in the valence band is filled with electrons. Note that there are 4 states per atom or $4 \times 5 \times 10^{22}$ states/cm^3 in the valence band, and there are 4 valence electrons per atom $4 \times 5 \times 10^{22}$ valence electrons/cm^3. A full band cannot conduct current because for every electron moving from one state to another state in one direction, there must be another electron moving in the opposite direction.

e. Is Si an insulator or a conductor at 0 K?

Si will be an insulator at 0 K. At 0 K the valence band is full and cannot conduct current. The conduction band is empty and cannot conduct current either. If you think in terms of the bond model, each and every electron is used up in making the bond. So, no current conduction is possible unless you break the bond. There is no energy available to break the bond at 0K.

5. Suppose you have some electrons to spare and you want to put them in the conduction band of Si. What is the total number of electrons/cm^3 that you can put in the conduction band ? (This is the number of states/cm^3 available in the band.)

You can put up to $4 \times 5 \times 10^{22}$ electrons in the conduction band since there are that many states available in the conduction band. Of course, it is a very hypothetical question.

6. Using the bond model for a semiconductor, indicate how one visualizes (a) a missing atom, (b) an electron (c) a hole (This is problem 2.2 in the textbook)

See figure 2.7 in text