Name:

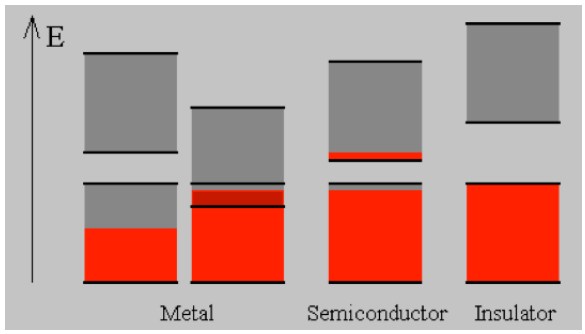
Student Number:

Quiz 2 ELEC 4705

Wed Oct 15, 2014

1. (10 marks) Crystals

   Draw the band structures of a metal, semiconductor and insulator and explain how the band structure determines their conductivity.



- **Metals have effectively half-filled bands so any energy will easily create an electron/hole pair for conduction.**
  - **Semiconductors have filled bands with a small band gap that electrons can be easily excited over**
  - **Insulators have filled bands with large band gap that is not easy to get over**

(a) What is effective mass?

In a crystal the $E-k$ relationship shows that the Bloch electrons respond to forces as if the mass is altered. This mass is called the effective mass.

(b) For an electron, why is it different from the actual mass?

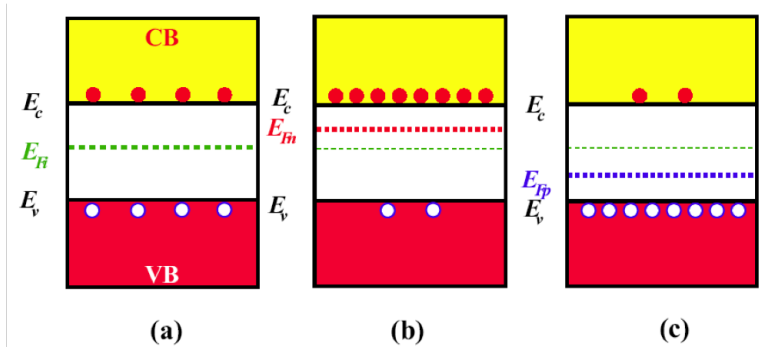
The +ve ions of the crystal also affect the force on the electron so it will not be the same as a free electron.

(c) What is the concept of a "hole". Does it also have an effective mass? If so explain how this effective mass arises.

Yes. A hole is just the absence of an electron in the valence band. Holes will respond to forces as if they were a +ve particle and will also be affected by the +ve ions and will have their own effective mass

2. (8 marks) Semiconductors

(a) Draw the energy band diagrams for intrinsic, n-type, and p-type semiconductors at equilibrium. Indicate the doping levels (relative to n_i). Briefly explain the difference.



- **Intrinsic: undoped,** $n = p = n_i$
- **n-type:** $N_d - N_a \gg n_i$
- **p-type:** $N_a - N_d \gg n_i$

(b) What is the Fermi Energy? Show it for each semiconductor.

Free energy per electron

(c) How would we make the n-type semiconductor degenerate?

Add more donar dopant atoms (heavily doped)

3. (7 marks) Carrier Transport

(a) If a single electron is subject to a force and given that $F = ma$ what would you expect the velocity to do?

Increase without bound in the direction of the force.

(b) What is the drift velocity for electrons in a metal or semiconductor? Why does the drift velocity differ from the velocity of single electrons?

i. **Average velocity of all electrons (usually in one direction, the direction of the applied electric field).**

ii. **Scattering.**

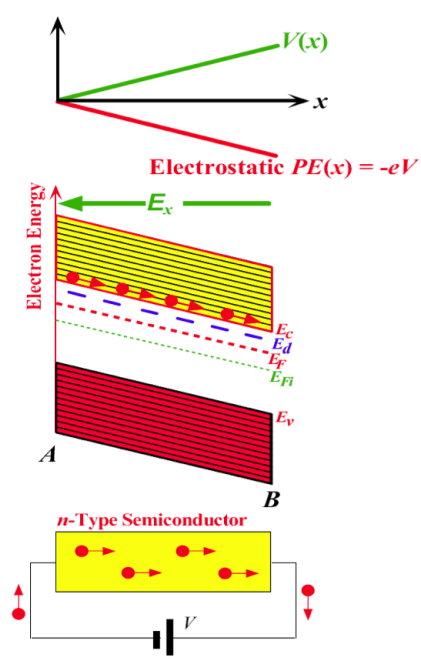
(c) How does the current density relate to the drift velocity?

$$J = env$$

(d) Identify two different types of scattering processes for electrons?

Scattering from impurities and from thermal vibrations

(e) If we connect the ends of the n-type semiconductor to a voltage supply of V volts what happens to the energy band diagram? Show the diagram before and after the voltage is applied.



Without the voltage applied the bands are flat. When the voltage is applied the bands tilt.