Duke University
Department of Physics

Physics 271 Spring Term 2017

WUN2K FOR LECTURE 11

These are notes summarizing the main concepts you need to understand and be able to apply.

- Based on quantum mechanics, we have a model of quantized electronic energy levels in atoms, in which electrons fill up "shells" of increasing energy (two allowed per state according to the Pauli Principle). Electrons outside "closed" (filled) shells, called *valence* electrons, are relatively free to participate in inter-atomic interactions.

- In a crystalline solid, an effective model is one in which positive nuclei and inner shell electrons are fixed and valence electrons can participate in inter-atomic bonds or act as mobile charge carriers. Inter-atomic interactions break the degeneracy of single-atom energy levels, so that valence electrons can occupy a continuum of energy levels within allowed "bands". Materials can be classified according to their band structures:

  - *Conductors* have overlapping valence and conduction bands, so that valence electrons can move around easily in conduction band states.
  - *Insulators* have well-separated valence and conduction bands; electrons need to be excited to relatively high energy before they can occupy a conduction band state.
  - *Semiconductors* have valence and conduction bands separated by only a small gap (typically around an eV) so that thermally-excited electrons can easily get into the conduction band. Examples of semiconductors are silicon and germanium.

- *Dopants* are elements added to a semiconductor with more or fewer valence electrons than semiconductor atoms, so that extra electrons or *holes* (absences of electrons) can be easily excited into the conduction band. The materials are electrically neutral but have more charge carriers so have higher conductivity.
  - An *n-type* semiconductor has a dopant which provides extra conduction electrons.
  - A *p-type* semiconductor has a dopant which provides extra conduction holes.
- A *p-n junction* is formed when p-type and n-type semiconductors are placed next to each other. By thermal diffusion, positive charges drift from the p-type to the n-type and negative charges drift the other way, until an electric field (and potential difference) opposing the drift forms and the system comes to equilibrium. The junction region over which this occurs is called the *depletion region* and has low conductivity.
- The simplest p-n-junction device is a *diode*.
  - A *reverse-biased* diode has an external potential difference applied across it such that the n-side is more positive. The depletion region grows and the diode acts as a poor conductor.
  - A *forward-biased* diode has an external potential difference applied across it such that the p-side is more positive. The depletion region narrows, and can disappear for sufficiently high external voltage, such that the diode acts as a good conductor (with a small intrinsic potential difference across it).
- The current-voltage relation across a diode can be modeled $I = I_0(e^{eV/kT} - 1)$, where I_0 is a constant which tends to be small (e is the electron charge, k is Boltzmann's constant, and T is the temperature). A simplified, but useful, model of a diode is of a device that does not conduct (acts like open circuit) when reverse-biased, but conducts (with a 0.6 V drop for Si diodes) when forward-biased. (Better models describe the diode as resistive in both forward and reverse biased regimes, with lower resistance when forward-biased.)