How Things Work II
(Lecture #20)

Instructor: Gordon D. Cates
Office: Physics 106a, Phone: (434) 924-4792
email: cates@virginia.edu

Course web site available through COD and Toolkit
or at http://people.virginia.edu/~gdc4k/phys106/spring08

March 14, 2008
We were talking about diodes ...

But before understanding diodes, I want to discuss the concept of an energy level...
Atoms have things called energy levels

Neon has 10 electrons, which exactly fills both the n=1 and n=2 shells.
Atoms have things called energy levels

Neon has 10 electrons, which exactly fills both the n=1 and n=2 shells.

Can I somehow make this a more real idea for you??
Okay, start with a question ...

Is light a particle or a wave?

A. Particle
B. Wave
Light is usually thought of as an electromagnetic wave

- The speed of electromagnetic waves in a vacuum is always the same: $c = 3 \times 10^8 \text{ m/s}$
- The wavelength and frequency are related by a simple equation: $c = \text{frequency} \times \text{wavelength}$
The range of wavelengths of electromagnetic waves associated with phenomena that are important to us is huge.
Light can also be thought of a being made up of photons

- Each photon has a well defined amount of energy.
- When atoms absorb or emit light, they always absorb or emit one or more photons.
- The amount of energy depends on the frequency of the light and is given by: $\text{Energy} = \text{Frequency} \times \text{Planck's constant}$
- Planck's constant $= 6.626 \times 10^{-34}$ J-s
Energy levels in atoms and photons

- In atoms, electrons cannot have just any orbital, they must be in one of a number of discrete “energy levels”.
- In the atom above, I am imagining that there are just two energy levels.
  - The level in which the electron sits is shown with a solid line.
  - The unoccupied energy level is shown with a dotted line.
- When a photon of the right energy is absorbed, the electron can make a transition from one energy level to the other.

To be readily absorbed, the photon’s energy needs to be quite close to the energy difference between the two energy levels.
Energy levels in atoms and photons

- If an atom is in an excited state to begin with, it will eventually emit a photon and make a transition to the ground state.
- The energy of the photon will correspond to the energy difference between the two levels.
- A photon's energy is directly related to the photon's frequency, and hence its color.
- Thus, a gas of a particular type of atoms, when excited by a discharge, will produce light of a characteristic color.
How neon makes its characteristic red light

- First an electrical discharge is run through the gas, exciting electrons to various excited states.
- The familiar red light comes from a transition between the 3p and 3s levels.
There are also energy levels in solids

- Unlike atoms where the energy levels are well separated, they tend to cluster into “bands”.
- The electrical properties of a substance are greatly influenced by which levels are filled and unfilled.
- Halfway between the highest filled level and the lowest unfilled level is a point we refer to as the “Fermi level” which defines the top of the so-called Fermi-sea of electrons.
In a metal, the fermi surface fall right in the middle of a band.

• Thus, there are plenty of unoccupied energy levels within the same band.
• We can think of this as the orchestra section being only part filled.
• If we want more people to come in from the right, the other people can accommodate by shifting one seat over toward the left.
• Thus, a partially filled orchestra section is a good people conductor.
In an insulator, the Fermi surface falls at a “band gap”, a region with no energy levels.

- In this case, if we want people to come in from the right, the people already in the orchestra have no place to go.
- It is true that if you yelled really loudly to the person on the far left-hand side to get out of their seat, and they did, then everyone could move over one. But you can only yell so loudly!
In a photoconductor the band gap is small enough that a photon can knock an electron up to the conduction band.

- Imagine that you have a gorilla roaming around the theater throwing people up into the balcony, thereby making more room in the orchestra section.
- This would cause our theater to be a kind of “gorilla conductor”. That is, in the presence of gorillas, it conducts people.
P-N junctions

- With doped semiconductors you have an excess of either holes (p-type) or electrons (n-type).
- At a junction of p-type and n-type semiconductors, electrons drop down to fill the holes until Coulombic repulsion stops the process.
- In the depletion region, the orchestra is once again filled, and no one can move.
Diodes

- If you add electrons from the right and pull them off from the left, (forward bias the diode), you replenish the electrons in the n-type semiconductor, replenish the holes in the p-type semi-conductor, and eliminate the depletion region. Now electrons can flow.
- If, on the other hand, you pull electrons from the right and push them in from the left, the depletion region grows and no current can flow.