Chapter 5

Diodes
Semi-conductors

Quantum Mechanics tells us that there are "magic" numbers in which electrons populate atomic shells: 2, 8, 8, ...

A full shell is inert (Noble gases) because outer electrons are tightly bound to the atom.

- Insulators are close to having full shells (outer)
- Conductors have nearly empty outer shells
- Semi-conductors have 1/2 full shells

Note that non-ionized atoms are electrically neutral. However, one can approximate (simplify) a multi-electron atom as an equal number of protons and outer shell electrons → this is a good approximation for chemical covalent bonding.

Si has 1/2 full outer shells. Si or Ge form crystals by bonding (in 3D)

This creates a solid crystal.

Current flows in a conductor when loosely bound electrons move from atom to atom under an electric field.\[V_{eq}\]
So Si or Ga crystal would not have any current flow since e\(^{-}\) are all bound.

If one adds impurities of P (5 outer shell e\(^{-}\)s) into the crystal structure, the Si lattice becomes a semiconductor. Called "doping".

Note that the crystal is still electrically neutral (same number of protons and electrons), but P-doping yields 1 "free" electron N-type
B-doping yields 1 "free" hole P-type

The "free" electron in an N-type semiconductor

P-N Junction

When an N-type and P-type semiconductor are produced adjacent to each other, N-type "free" electrons will migrate across the junction to fill the "free" holes. Whereas before the migration, or "diffusion", began, both sides of the semiconductor were electrically neutral, the diffusion of charges causes charging of both sides of the junction. N-type has net + charge P-type has net - charge

This diffusion will occur and form a "depletion" layer at the junction (where the diffusion occurred). Across the depletion layer will be a potential
difference which suppresses further diffusion of charges.

1) Junction formed $\Sigma q = 0$  

2) Diffusion begins $\Sigma E = 0$  

3) Depletion layer formed $\Sigma \mathcal{E} = 0$  

Note that the $\mathcal{E}$ field produced in the depletion layer produces a potential barrier (a voltage).

**Diode**

If one applies a voltage across the semiconductor such that:

\[ V = V_0 \]

then the applied $V$ will increase width of depletion layer and potential across junction will increase -> inhibiting current flow. This is reverse bias.

If power leads are reversed, potential barrier is reduced, and current flows easily. This is forward bias.
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The P-N junction is a diode. It is a non-linear device which allows current flow in only one direction.

\[ \text{anode} \quad \text{P-type} \rightarrow \quad \text{N-type} \quad \text{cathode} \]

\[ I \rightarrow \quad \text{symbol} \]

The I-V characteristic curve will look like:

\[ \text{Note } I_F \text{ in mA} \]
\[ I_R \text{ in mA} \]

Unlike L, R, C, these devices are clearly non-linear and do NOT follow Ohm's law.

So, a diode acts as a switch: in one direction, I flows, in the other it doesn't.

Of course, if device is operated out of specs, it will break down.

Note that we have discussed ideal diodes, there.
Actually, there is a small voltage drop and leakage current in diodes; the magnitude of these depends on materials and manufacturing of device.
Rectifiers

Recall \( V \rightarrow AC \rightarrow +V \rightarrow -V \)

One can use a diode to get

\[ +V \rightarrow -V \rightarrow +V \rightarrow -V \]

since I only flows one way. (One can reverse this and get only -V)

This is a half-wave rectifier. To get the full wave, a center-tap transformer is required.

\[ V_i \rightarrow \text{Rectifier} \rightarrow V_o \]

Note, that \( V = V(t) \), it is technically a DC voltage because current only flows in one direction. Not useful however; in most applications one desires \( V \neq V(t) \)

To get \( V \neq V(t) \):

Recall filters from previous chapters.
One can use a bridge rectifier to get 
$+V$ and $-V$ from the same AC source.

Here $C$ acts as a filter.

Zener Diode

Zener diodes are designed to run in reverse bias mode. At breakdown voltage, $e-$ in crystal will become ionized and will have energies large enough that they will collide with other atomic electrons to ionize them also. These electrons will also have collisions with other atoms, liberating more electrons. One then has an “avalanche” of electrons.

$\text{Note that } I_R \text{ is almost independent of } V_Z \text{ as long as } V > V_Z, \text{ where } V_Z \text{ is Zener diode voltage}$
Zener diodes serve well as regulators, keeping output voltage steady independent of current draw (within specs).

There exist devices known as voltage regulators which alleviate problems from the present setup:

- $V_0$ is fixed by transformer
- Ripple $\propto$ current drawn
- $V_0$ is dependent on $V_{AC}$

**Summary**

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V: 120V Ac
transformer rectifier filter

Signal
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V0
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Notice ripple

HWS: 1.7