Diodes:

"Characterize and use diodes in rectifier and wave shaping circuits."

2 labs

1 - Characteristic curve + clipping circuits.

2 - Rectifiers

6 lectures

1 - basics (Lab) - what is it? simple use.

2 - more simple use.

3 - Rectifiers

4 - Filters. (Lab)

5 - Examples - Logic gates.

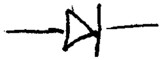
6 = Examples.

web/text:

http://www.kettering.edu/~bguru/DIODE/

Lab: Diode characteristics

What is a diode?

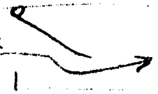


A device that allows current to flow one way, but not the other.

No Flow

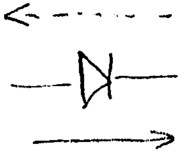
← Pressure closes valve

Pressure opens valve



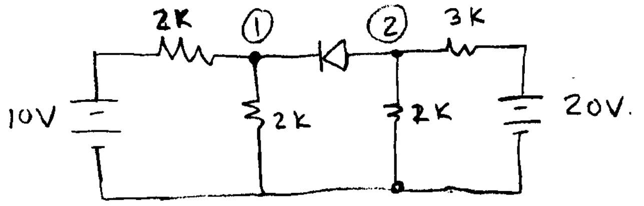
water flows.

No current this way



Direction of current flow

Basic diode circuits:

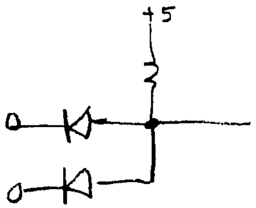


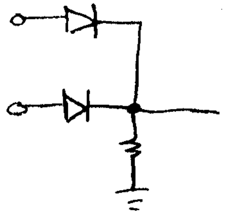
What are voltages at ① and ② ?

as shown?

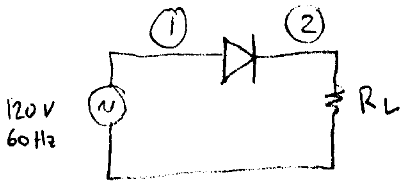
when the diode is reversed?

Logic circuits:



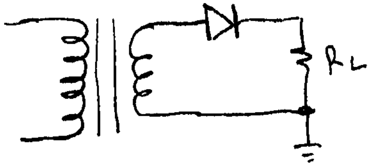


Rectifier circuits

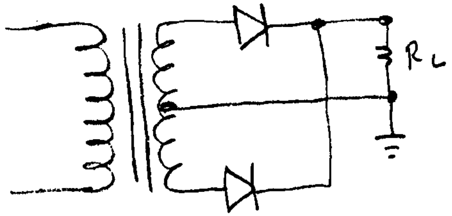


"Half wave"

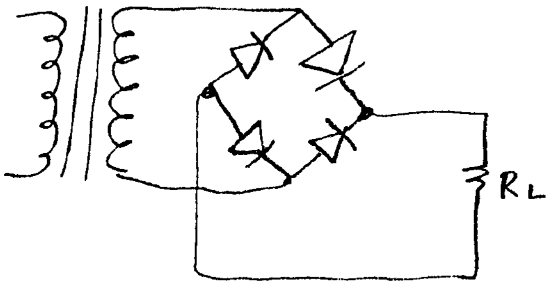
Half wave with transformer:



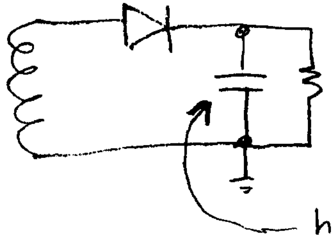
"Full wave"



"Full wave bridge"

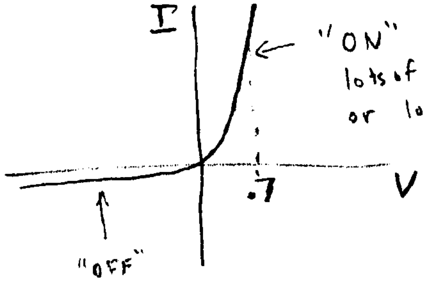


Filters for rectifier circuits --



Real™ diodes

Actually, it isn't "on" or "off"



"ON" lots of current, or low voltage.

"OFF" very low current

$$i_D = I_s\left[e^{\frac{V}{nV_T}} - 1\right]$$

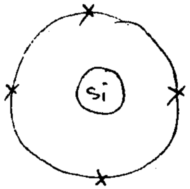
Basic semiconductor theory.

(will cover very shallow).
(more detail in device physics course)

"Intrinsic semiconductors" (1.1.1)

they are pure

Usually column 4 of periodic table.



4 electrons in outer ring.
(valence electrons)

8 is full,
so they share
Form a crystal.

Poor conductor

(not really an insulator, but...)

"Extrinsic semiconductors" (1.1.2)

Add impurities — either column 3 or column 5 elements.

3	5
Boron	Phosphorus
Aluminum	Arsenic.
Gallium	

This is called "doping".

Col. 3 — missing electron - a hole
"acceptor impurity" "P" type

Col. 5 — extra electron
"donor impurities" "N" type

Drift and diffusion currents (1.1.3)

These holes or free electrons move in presence of electric field. → Drift currents

They also move due to variations in the impurities → Diffusion currents

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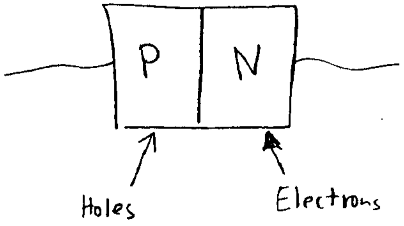
Excess carriers (1.1.4)

When heated, more electrons break loose from their crystal structure.
→ excess electrons

They leave a space
→ excess holes.

This increases the conductivity

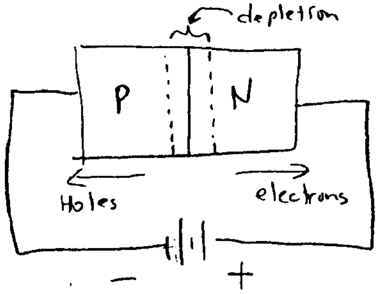
The P-N junction (1.2)



At equilibrium —
(0 volts)
It doesn't conduct
at the junction
(will see why later)

Reverse biased (1.2.2)

Apply a voltage:



This causes holes and electrons to move away from the junction.

Forming a depletion region.

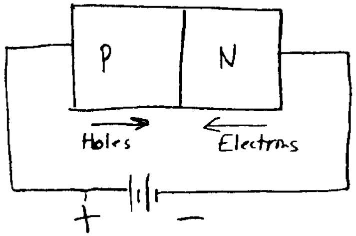
This is a region in which there are no carriers. — Does not conduct.

Increase the negative bias — increases thickness of depletion region.

→ It acts like a capacitor that varies with voltage.

(Actually ... it does conduct a little -- "reverse saturation current", $\simeq 10^{-15}$ A

Forward biased (1.2.3)

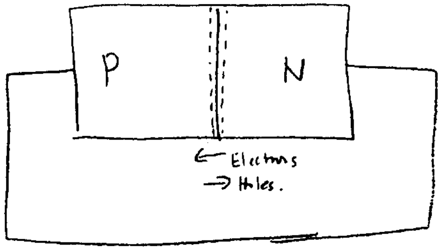


Holes and electrons both move toward the junction.

Lots of carriers near the junction causes it to conduct.

At equilibrium (1.2.1)

(zero volts).



Diffusion current causes some migration —

Electrons move into P region, filling holes

→ This too makes a depletion region —

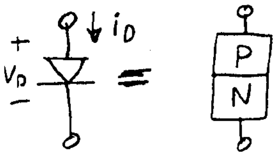
Does not conduct.

The book shows some math — so you can calculate how much.

You should be able to make the calculations, but they may not appear to be useful.

Ideal current-voltage relationships (1,2,4).

$$i_D = I_S\left[e^{\frac{V_D}{nV_T}} - 1\right]$$



I_S = "reverse saturation current"

Typical value -- 10^{-15} to 10^{-13} amps.

Depends on — doping concentration

area.

V_T = "thermal voltage" ≈ .026 at room temperature

Actually — $V_T = \frac{KT}{Q}$

K = Boltzmann's Constant
1.38×10^{-23}

Q = Charge of an electron
1.6×10^{-19} coulombs

T = Temperature Kelvin

n = "emission coefficient" — Typical 1 to 2

"ideality factor"

Adjusts for recombination in depletion (space charge) region.

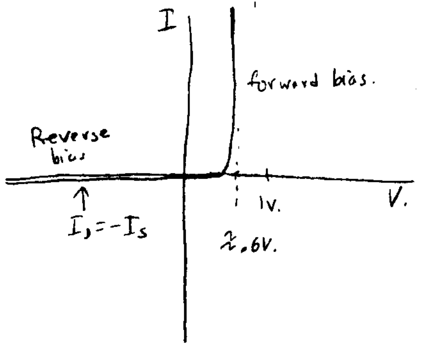
Depends on current —

usually — assume $= 1$.

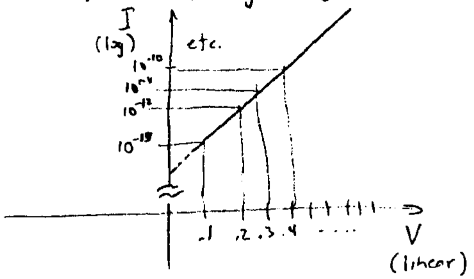
Diode characteristics (1,2,5)

Plot that formula --

Looks like this:



Plot on log scale



Other effects

Temperature — V_T is a function of temperature

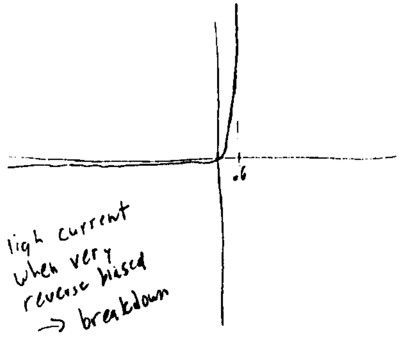
$$\frac{\Delta V_T}{\Delta T} \approx 2\ \frac{\text{mV}}{^\circ\text{C}}$$

I_S — function of intrinsic carrier concentration.

Doubles for 5°C rise in temp.

Breakdown

Actual I/V:



Breakdown voltage --

most diodes — 50 to 1000 V.
("PIV" rating peak inverse voltage)

"Zener" diodes — 3 to ____ volts

designed to operate in breakdown.

→ Non-destructive —

The diode equation —

1C 1

Remembering the formula.

① It's exponential (rapid growth in forward region, flat in reverse region)

$$\Rightarrow e^{X}$$

X is related to voltage

② Crosses through **zero** at $V=0$

e^{x} is always positive

approaches zero for negative x.

is 1 for $x=0$

what is like e^{x} but $=0$ for $x=0$?

$$\Rightarrow e^{x}-1$$

③ Now, scale it for "reverse saturation current"

so that is the value for negative x.

(above formula is $=-1$)

$$\Rightarrow I_S(e^{x}-1)$$

④ X is related to voltage, but how?

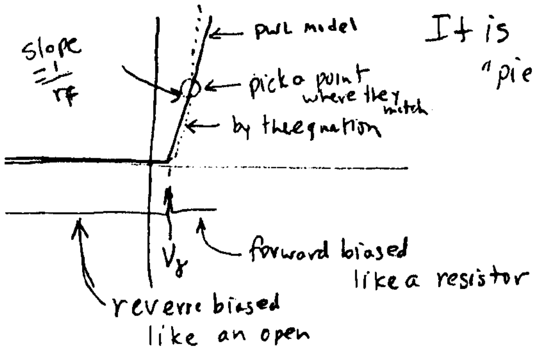
$$X = f(V) = \frac{V}{\text{Some\_V\_reference}}$$

call the reference V_T (thermal voltage)
(and use n as a fudge factor)

$$\Rightarrow I = I_S\left(e^{\frac{V}{nV_T}}-1\right)$$

Approximate model of a diode (1,3,2)

1C 2



It is close to this "piecewise linear model"

V_γ = turn-on voltage

r_f = forward resistance

↑ It varies, so measure at some point.

$$I = \begin{cases} 0 & V_D < V_\gamma \\ \frac{V_D - V_\gamma}{r_f} & V_D > V_\gamma \end{cases}$$