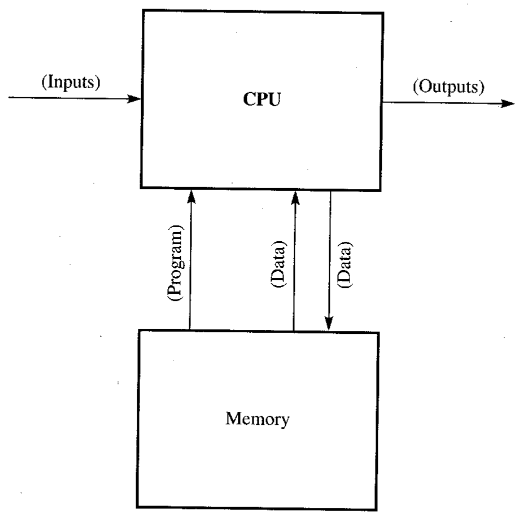
Semiconductor/Diodes

Today: (12.4, 13.1, 13.2)

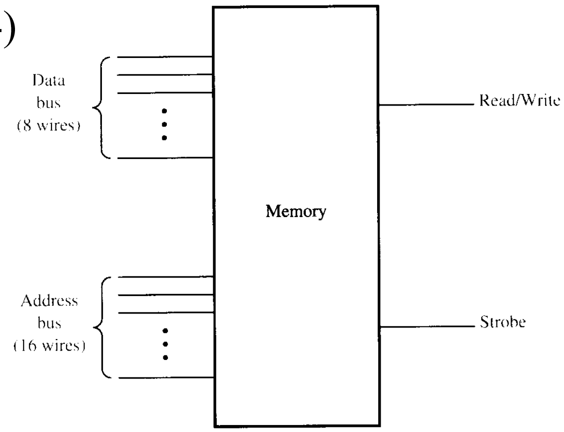
- Introduction to computer architecture
- Semiconductor devices
- Diodes

Typical outline of a computer



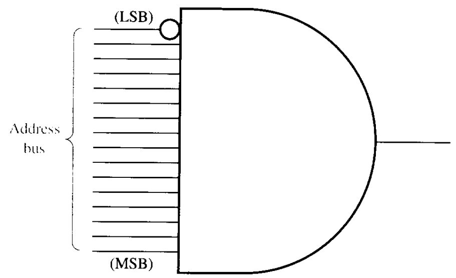
Memory

- 64K (64X1024)



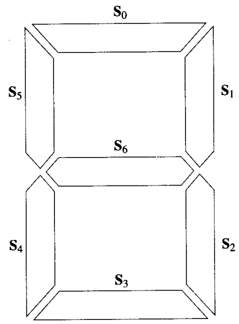
Memory Mapped Address

- Why?
- How?



Display

- Seven segment display



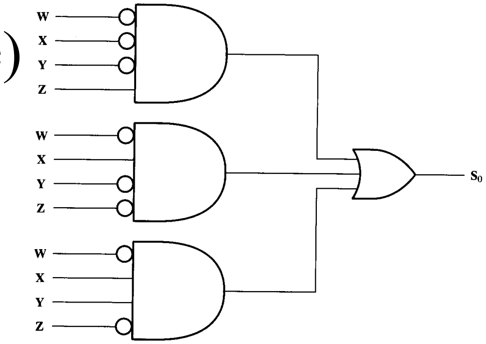
(a)

Decimal integer	W	X	Y	Z	S_0	S_1	S_2	S_3	S_4	S_5	S_6
0	0	0	0	0	0	0	0	0	0	0	1
1	0	0	0	1	1	0	0	1	1	1	1
2	0	0	1	0	0	0	1	0	0	1	0
3	0	0	1	1	0	0	0	0	1	1	0
4	0	1	0	0	1	0	0	1	1	0	0
5	0	1	0	1	0	1	0	0	1	0	0
6	0	1	1	0	1	1	0	0	0	0	0
7	0	1	1	1	0	0	0	1	1	1	1
8	1	0	0	0	0	0	0	0	0	0	0
9	1	0	0	1	0	0	0	1	1	0	0

(b)

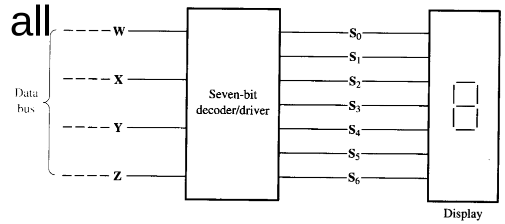
Display (continue)

- Decoder circuit fo
segment S_0.



(a)

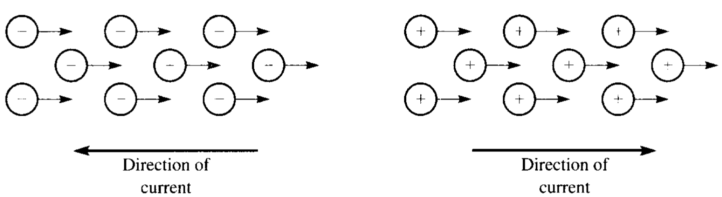
- Decoders/driver for all 7 segment.



(b)

Semiconductors

- Materials - silicon crystal
- Electrical conduction in semiconductors can take place when negative charged electrons or positive charged holes (absent of electrons) move through the crystal.

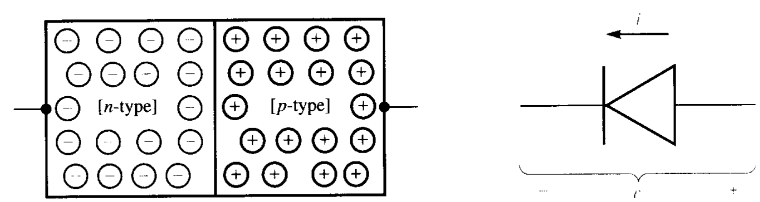


(a) (b)

- Material contain primarily free electrons is known as n-type semiconductor
- Material contain primarily holes is known as p-type semiconductor

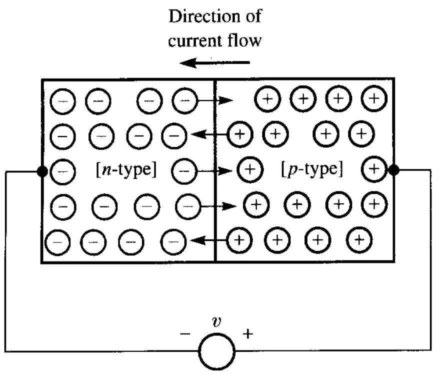
Diodes

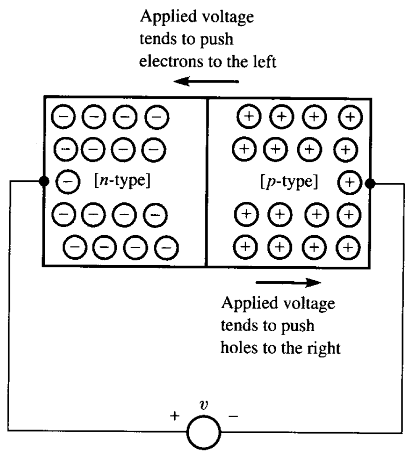
- When p-type and n-type materials are placed in contact, the result structure is called pn junction.



- In p-type material, holes are the majority carriers, electrons are minority carriers.
- In n-type material, electron are the majority carriers, holes are minority carriers.
- Three phenomena: (1) one way conduction; (2) injection of
- minority carriers when forward biased; (3) collection of
- minority carriers when zero or reverse biased.

Forward Bias/Reverse Bias

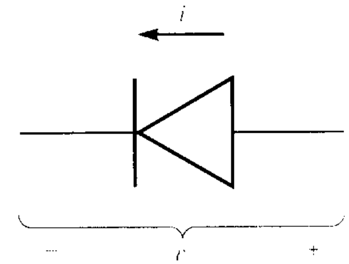




I-V characteristic of pn junction

- Ideal pn junction obeys the equation

$$i = I_s\left(e^{qv/kT} - 1\right)$$



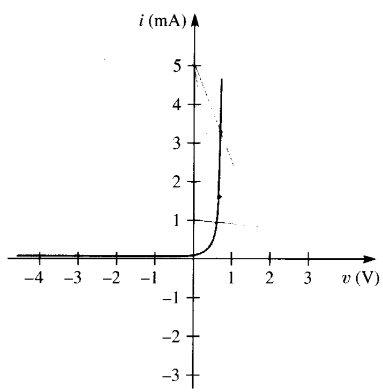
Where i and v are defined as shown in the diagram on the right
q is the electronic charge,
k is Boltzmann's constant
T is temperature in degree Kelvin
kT/q has a dimension of voltage, Vto (thermal voltage) =kT/q
Vto (300K or room temperature) is 0.026V.
I_s is saturation current constant (but depends on the size of the junction, impurity concentration, and temperature)

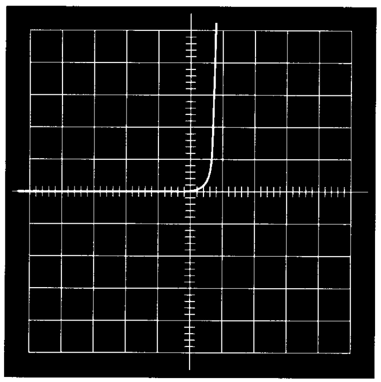
I-V characteristic of pn junctions

$$i = I_s\left(e^{qv/kT} - 1\right)$$

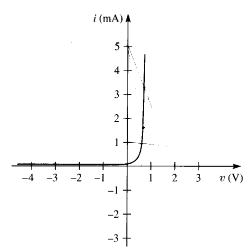
With $I_s = 10^{-13}$A

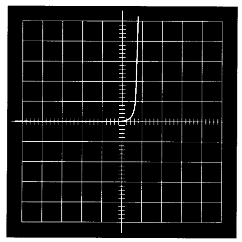
Vertical scale: 1mA per large division
Horizontal scale: 1V per large division





I-V Characteristic (Continue)

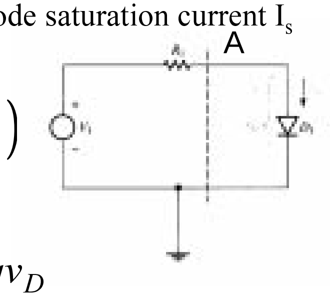




- When V is positive, the pn junction is forward bias
- qv/kT = v/Vto = v/0.026 = 38.5v
- If v = 0.7volt, 38.5v = 26.95, $e^{v/vto}$

Example

- Obtain the current i_D thru the diode in the ckt. using graphical load-line method. Let R_1=1kΩ, V_1=5V, Diode saturation current I_s is 10^{-12}A.



$$i_D = I_s\left(e^{qv_D/kT}-1\right) \Rightarrow \frac{i_D}{I_s}+1=\left(e^{qv_D/kT}\right)$$

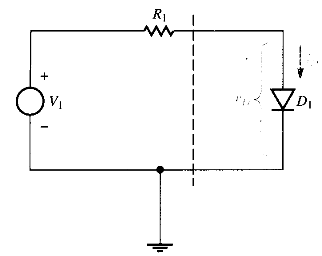
$$\Downarrow$$

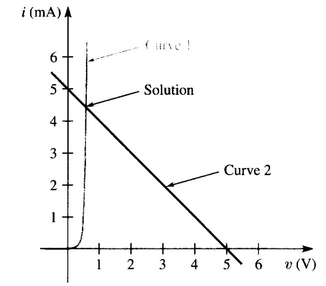
$$\ln\left(\frac{i_D}{I_s}+1\right)=\frac{qv_D}{kT}$$

Apply KCL at node A:

$$\frac{v_D-V_1}{R_1}+i_D=0 \Rightarrow \frac{\frac{kT}{q}\ln\left(\frac{i_D}{I_s}+1\right)-V_1}{R_1}+i_D=0$$

Example (continue)





- Using graphical load-line method

Curve 1(the right of the dash-line) $i_D = I_s\left(e^{qv_D/kT}-1\right)$

Curve 2 (the left of the dash-line) $v_D = V_1 - i_D R_1$

The solution is at the intersection between the two curves.

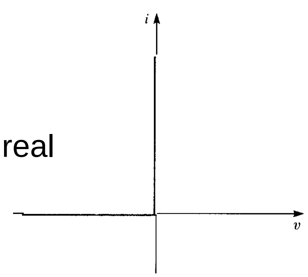
Models for the Diode

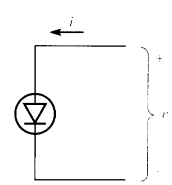
- Simplifying the diode into a ideal diode.

Rectifier - device that pass current in one direction only.
(pn junction diode is a kind of rectifier)

Perfect rectifier has 2 properties:
1. When i > 0, v = 0 (conduction in forward direction can occur with no voltage drop across diode)
2. When v < 0, i = 0 (when in reverse direction, no current flow)

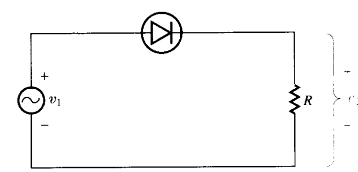
I-V characteristic of a perfect rectifier and symbol (as oppose to a real diode)





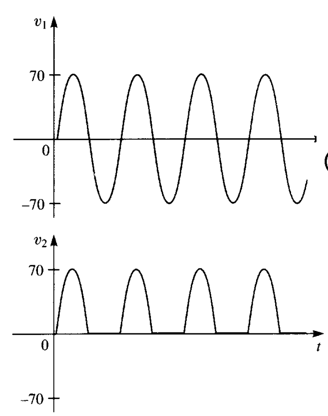
Perfect rectifier example

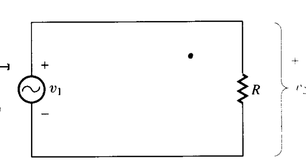
- Find V_2 vs time.



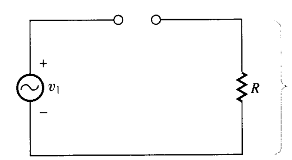
v_1 = 70 sin (ωt) volts R = 1000 Ω

(a)





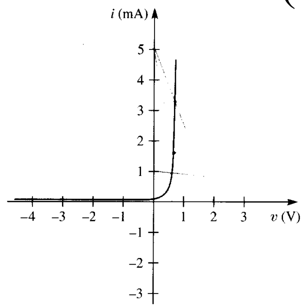
Positive v_1

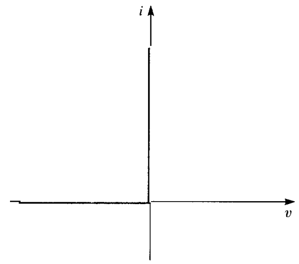


Negative v_1

(b)

Modified Model (Large-signal diode model)





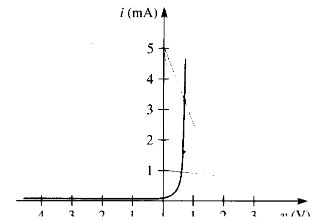
Real diode I-V characteristic Perfect rectifier I-V characteristic

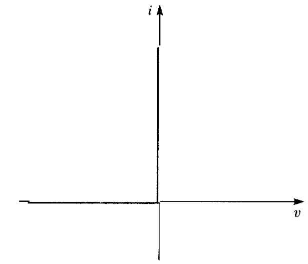
How do we reduce the error?
- we introduce a modified model (large signal diode model)

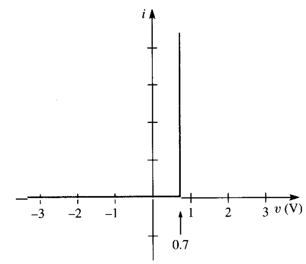
Rule 1: When current flow thru the diode in forward direction (i >0) voltage drop across the diode, v, is 0.7V.

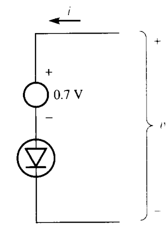
Rule 2: When v < 0.7V, i = 0A.

Large-signal diode model





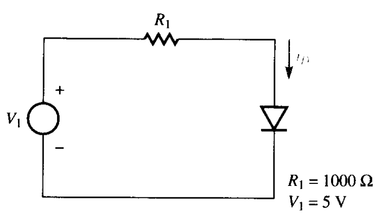


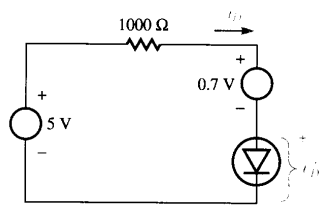


Large-signal diode model

Large-signal diode model (example)

Find the current i_D using the large-signal diode model.





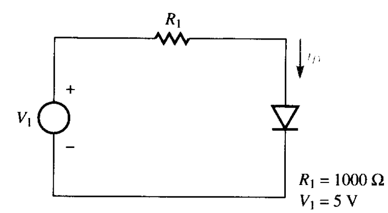
Apply KVL at the large signal diode model on the right.

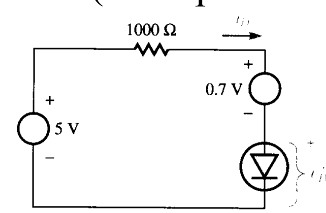
$$-5 + 1000 i_D + 0.7 + v'_D = 0$$

Voltage drop across the resistor & perfect rectifier is 4.3V (but voltage drop across perfect rectifier = 0V, so 4.3V is dropped across the resistor)

$i_D = 4.3/1000 = 4.3mA$ ≈ The value we got thru graphic method of 4.5mA

Large-signal diode model (example cont.)



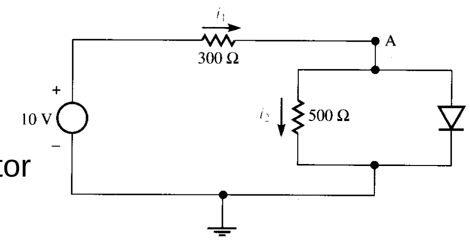


The example shows that the large signal diode model is a good approximation to the real diode. But its limitation is that it incorrectly implies that the current is zero whenever the forward bias is less than 0.7V. The actual change is gradual rather than as abrupt as stated in the previous slide.

Rule: If a silicon diode conducts significant forward current, the forward voltage is approximately 0.7V.

Example

- Find the approximate values i_1 and i_2. Approx. the voltage across a forward biased diode to be 0.7V.



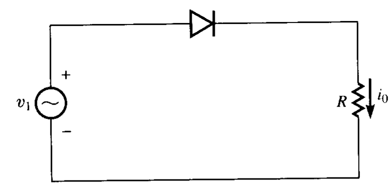
Voltage dropped across diode = 0.7V, then voltage dropped across 300Ω resistor is 10 - 0.7V

$$i_1 \cong \frac{10-0.7}{300} = 31mA$$

$$i_2 \cong \frac{0.7}{500} = 1.4mA$$

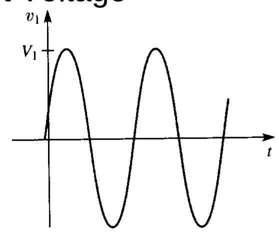
By KCL:
31-1.4mA = 29.6mA
current flow through the diode.

Rectifier circuits



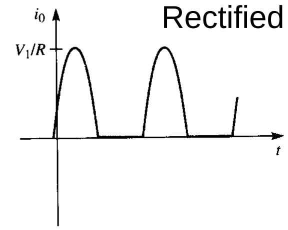
(a)

Input Voltage



(b)

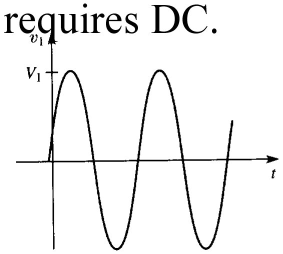
Rectified voltage

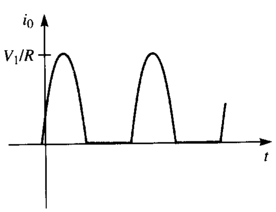


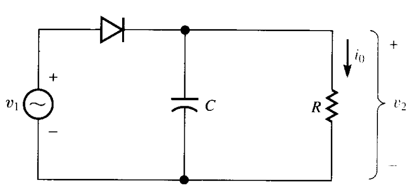
(c)

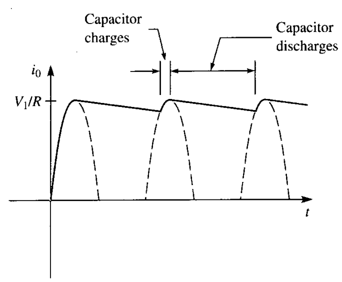
Rectifier circuits (continue)

- Practical circuits (e.g. power adapter for notebook) often requires DC.

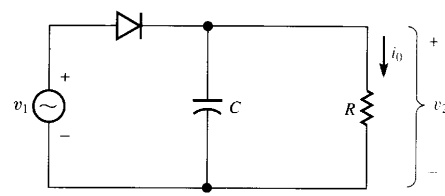




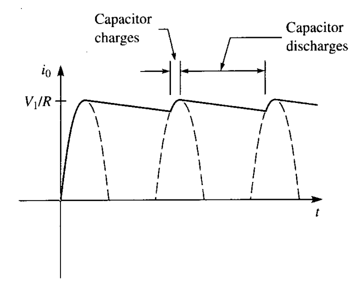


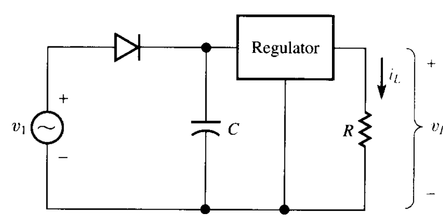


Continue



(a)

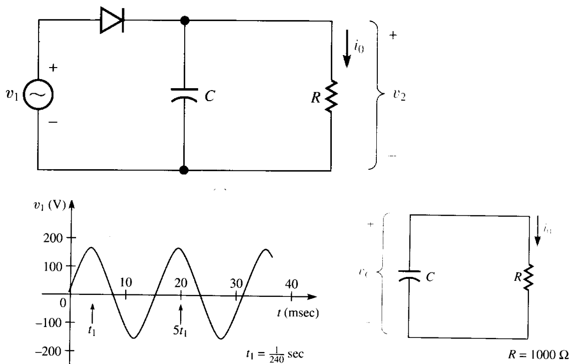




(b)

Example

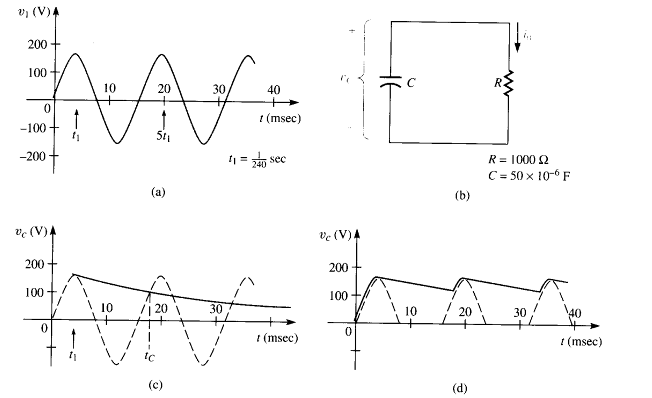
- Sketch the load current for the rectifier circuit for $C = 50\times10^{-6}$F, $R=1k\Omega$, $v_1=165\sin377t$, assuming the diode is a perfect rectifier.



0 < t < t_1, the voltage supply is charging the capacitor

t_1 < t < $5t_1$, the voltage supply is disconnected thru the diode, only the cap. & resistor remain. The capacitor discharges into the load.

(continue)



From 8.1, we learned that the voltage in FOC dropped exponentially with time constant RC.

$V_c = 165 \exp(-(t-t_1)/RC)$ $t_1 < t < 5t_1$

Summary

- Semiconductor devices are nonlinear, active circuit element.
- The most important semiconductor material is silicon.
- Currents in semiconductors arise from motions of negatively charged electrons and/or motion of positively charged “holes”.
- Materials containing primarily holes is known as p-type semiconductor
- Materials containing primarily free electrons is known as n-type semiconductor.
- Semiconductors can be made n-type or p-type by “doping” them with impurity.
- A pn junction is obtained by placing a p- and n-type materials in contact. Three properties of pn junctions are (1) one way conduction (2) injection of minority carriers when forward bias; (3) collection of minority carriers when zero or reverse biased.
- The voltage across a forward-biased silicon pn junction is approx. 0.7V