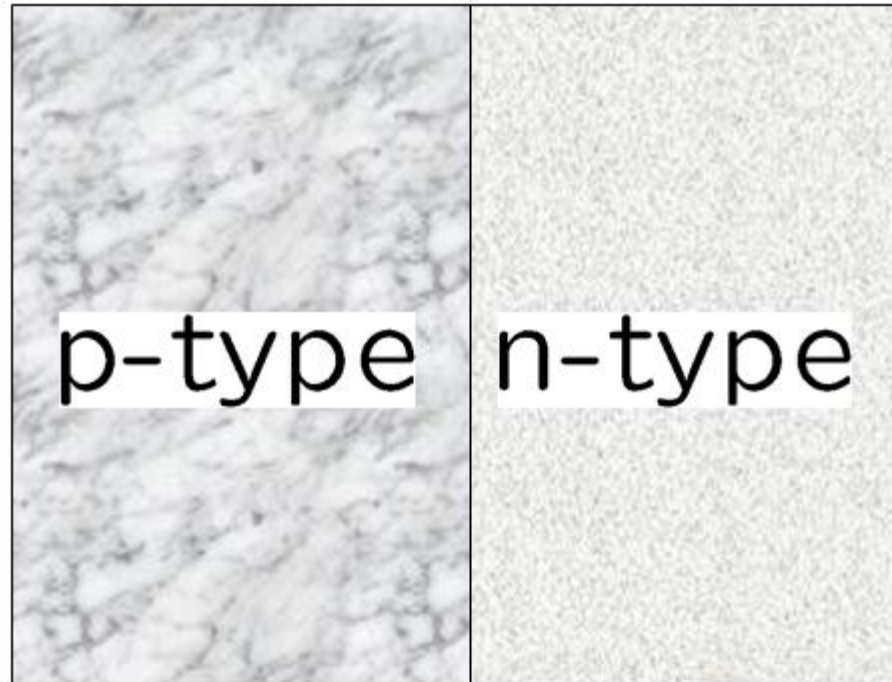
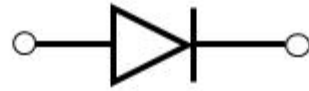


# ELG3336: Diodes

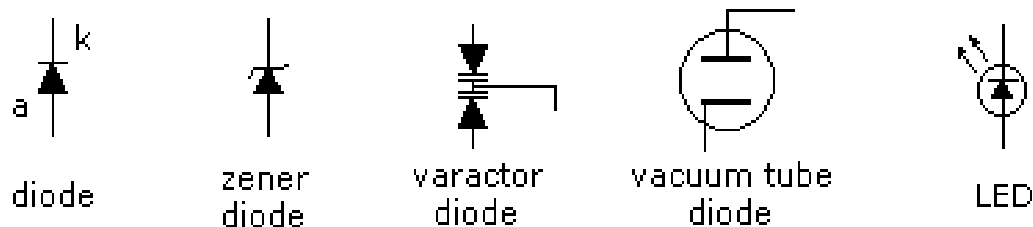


**ANODE**

**CATHODE**

# What are Diodes?

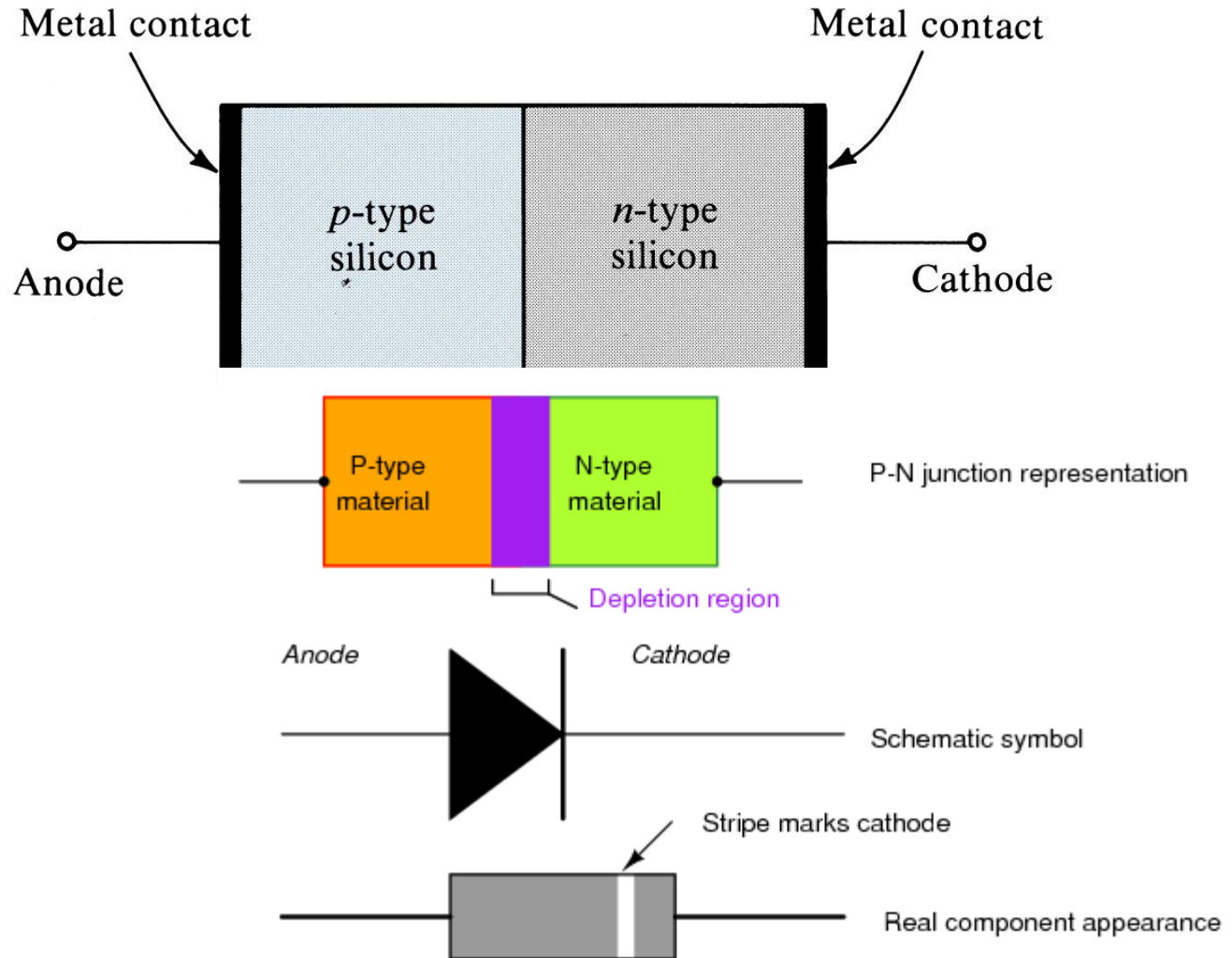
- Diodes are semiconductor devices which might be described as passing current in one direction only. Diodes however are far more versatile devices than that.
- Diodes may be used as voltage regulators, tuning devices in RF tuned circuits, frequency multiplying devices in RF circuits, mixing devices in RF circuits, switching applications or can be used to make logic decisions in digital circuits.
- There are also diodes which emit “light”, of course these are known as light-emitting-diodes or LED’s.



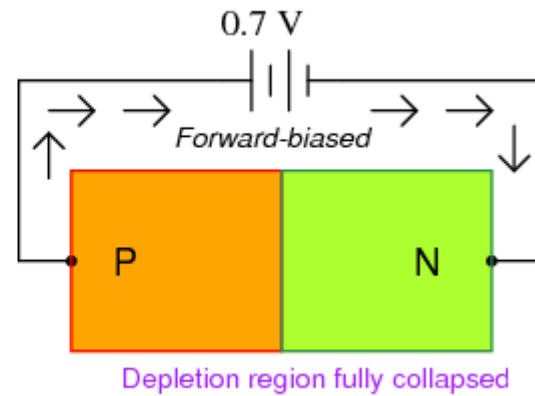
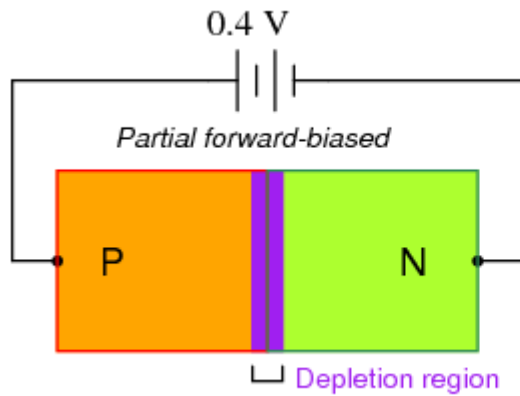
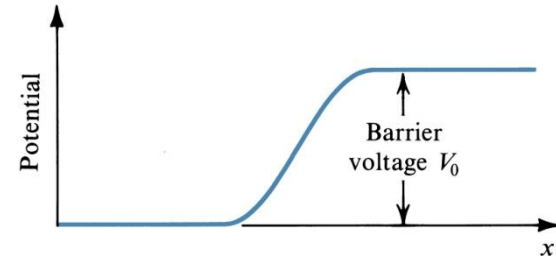
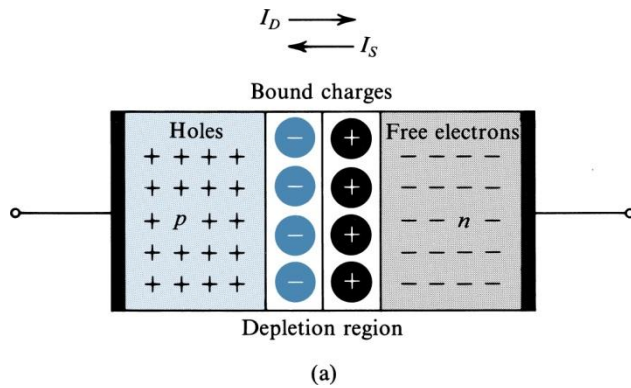
# Common Diode

- The first diode in the previous Figure is a semiconductor diode which could be a small signal diode. Notice the straight bar end has the letter “k”, this denotes the “cathode” while the “a” denotes anode.
- Current only flows from anode to cathode and not in the reverse direction, hence the “arrow” appearance. This is one very important property of diodes.
- The anode terminal must be positive and the cathode terminal negative for a current to flow.
- In an ideal diode, there is no voltage drop across a diode when current is flowing.

# Physical Structure of the Junction Diode

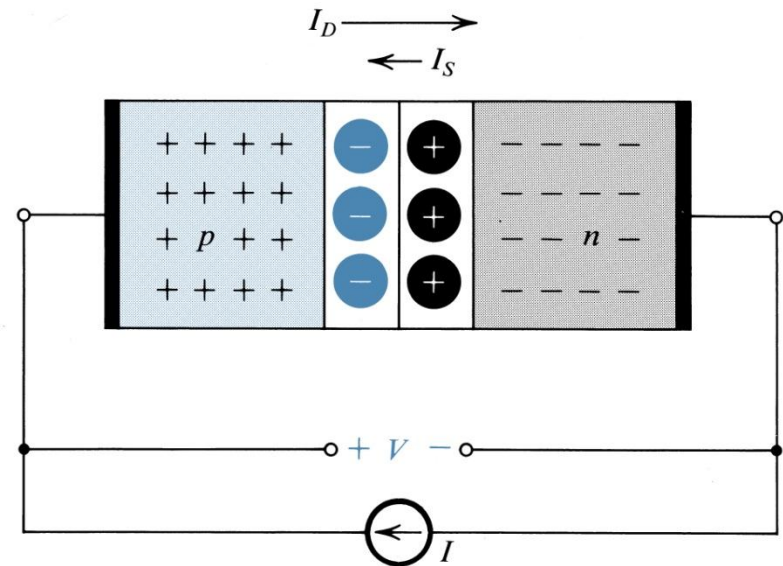


# The *pn* Junction



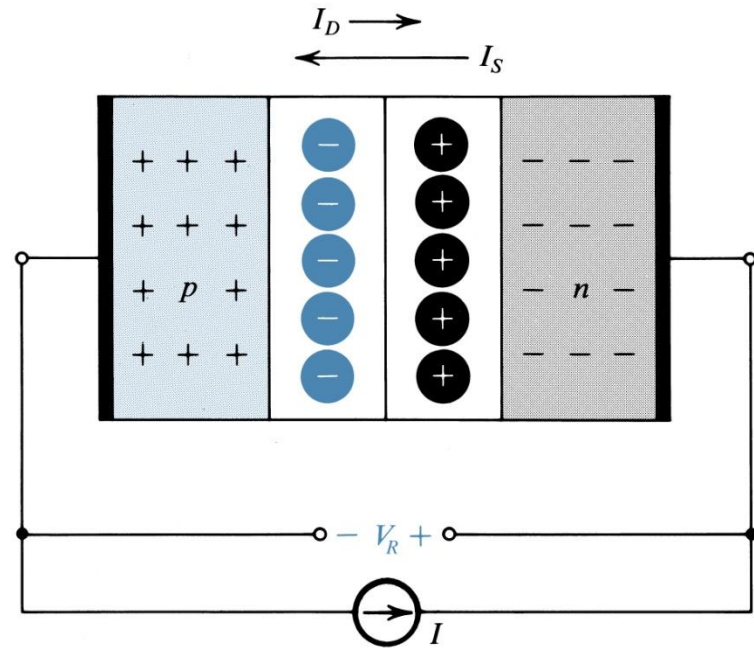
# Forward Biasing the Junction

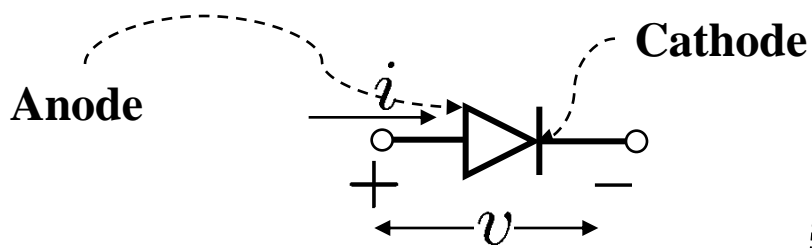
- Electrons in the p-type material, near the positive terminal of the supply, break their electron pair bonds and enter the supply, thereby producing new holes. Also electrons from the negative terminal of the supply enter the n-type material and migrate towards the junction.
- Free electrons from the n-type then flow across the junction and move into the holes which have migrated from the positive terminal. This current flow will continue as long as the external supply is connected and is called forward current flow.



# Reverse Biasing the Junction

- When the polarity of the supply is reversed, the potential within the device is effectively reinforced and the depletion layer becomes wider. This is because the free electrons in the n-type are attracted towards the positive terminal, away from the junction, while the electrons from the negative terminal of the supply enter the p-type and migrate towards the junction. Current flow is extremely small and is called reverse current. Note that this current is produced by minority carriers and the device is said to be reverse biased.

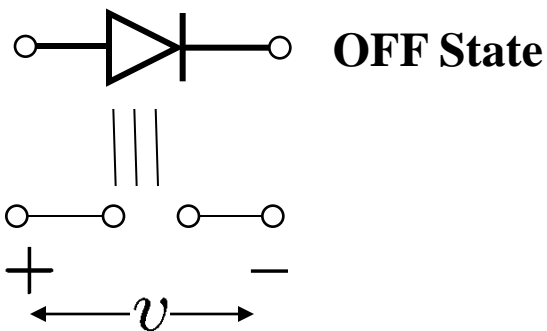
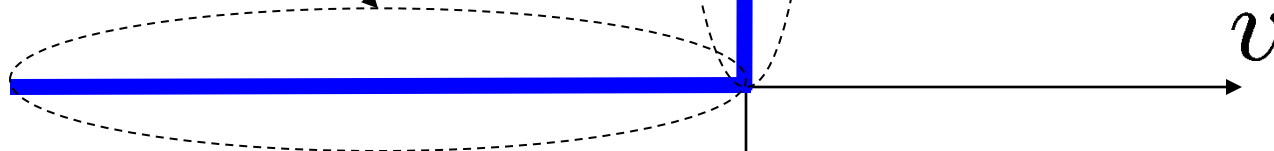




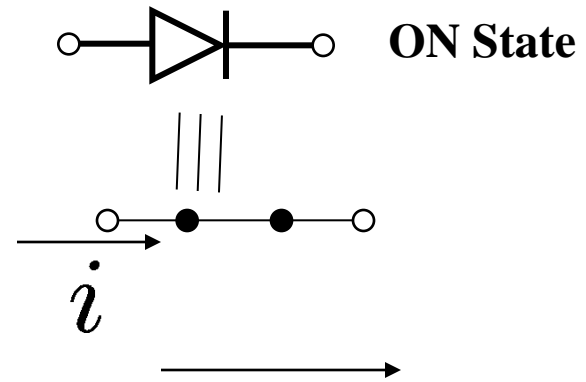
**$i$ - $v$  Characteristics of an ideal diode**

$$\begin{aligned} i &= 0 \\ v &< 0 \end{aligned}$$

$$\begin{aligned} i &> 0 \\ v &= 0 \end{aligned}$$



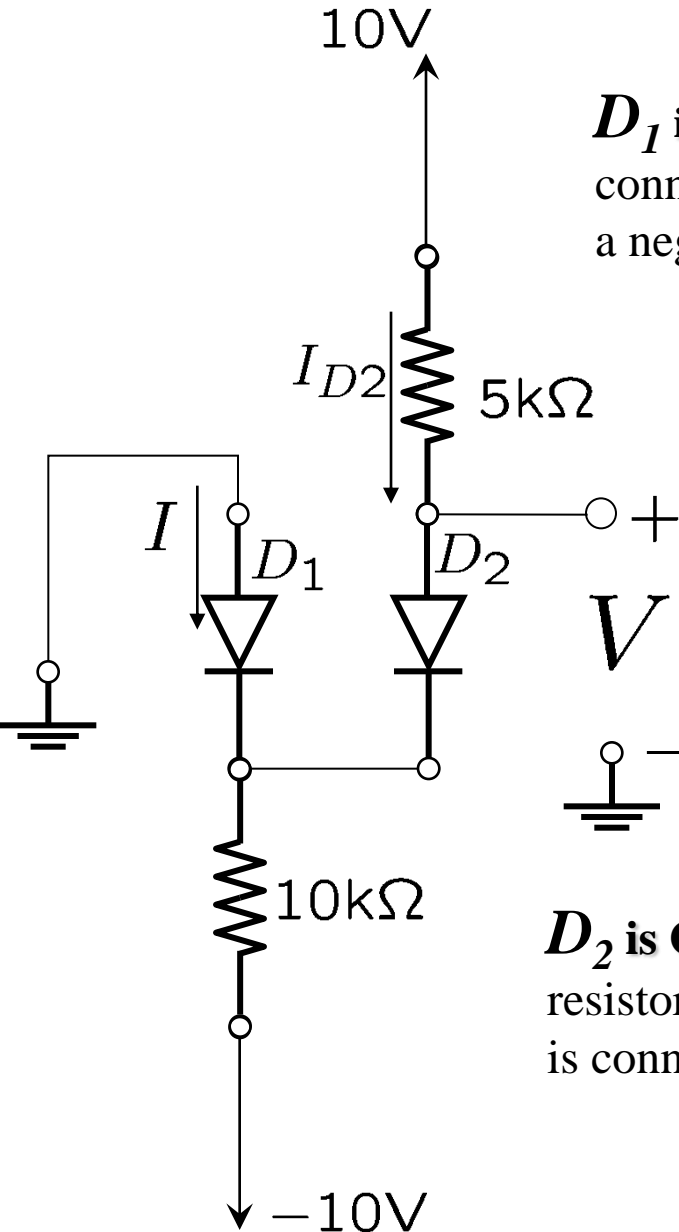
Voltage  $v$  MUST be NEGATIVE, i.e.,  
voltage of ANODE is **LOWER** than  
voltage of the CATHODE



Current  $i$  MUST be in this direction, i.e.,  
FROM the ANODE TO CATHODE



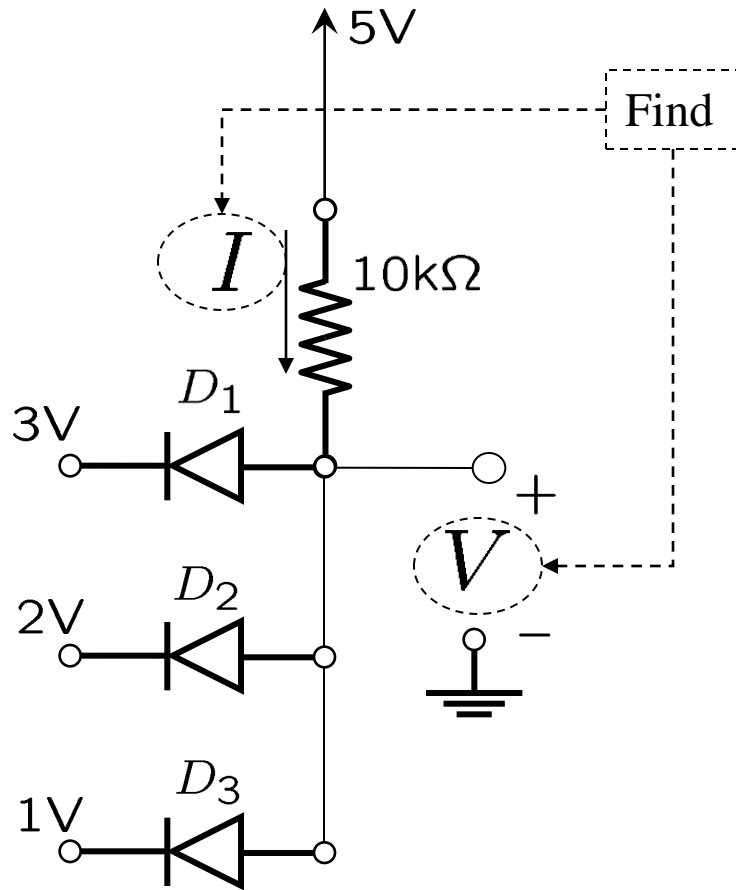
# Diodes in Circuits



$D_1$  is **ON** because its ANODE is connected to  $0\text{ V}$ , while its CATHODE is connected to a negative voltage, though via a  $10\text{ k}\Omega$  resistor.

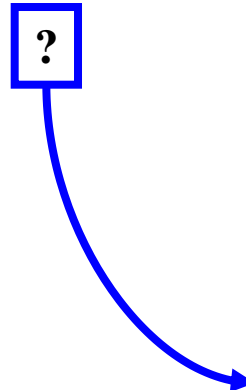
$D_2$  is **ON** because its ANODE is connected to  $10\text{ V}$ , via a  $10\text{ k}\Omega$  resistor while its CATHODE is connected to a negative voltage, though via a  $10\text{ k}\Omega$  resistor.

# Ideas for Digital Gates



Here are the possibilities

$D_3$	$D_2$	$D_1$
OFF	OFF	OFF
OFF	OFF	ON
OFF	ON	OFF
OFF	ON	ON
ON	OFF	OFF
ON	OFF	ON
ON	ON	OFF
ON	ON	ON



# The Forward-Bias Region

$$i = I_S (e^{V/V_T} - 1)$$

$I_S$  is saturation current

$V_T$  is thermal voltage

$$V_T = \frac{kT}{q} = 0.0862T, \text{ mV} = 25,3\text{mV}$$

$$i = I_S e^{V/V_T} \quad v = V_T \ln \frac{i}{I_S}$$

$I$  = Diode current in amps

$I_S$  = Saturation current in amps  
(typically  $1 \times 10^{-12}$  amps)

$e$  = Euler's constant ( $\sim 2.718281828$ )

$q$  = charge of electron ( $1.6 \times 10^{-19}$  coulombs)

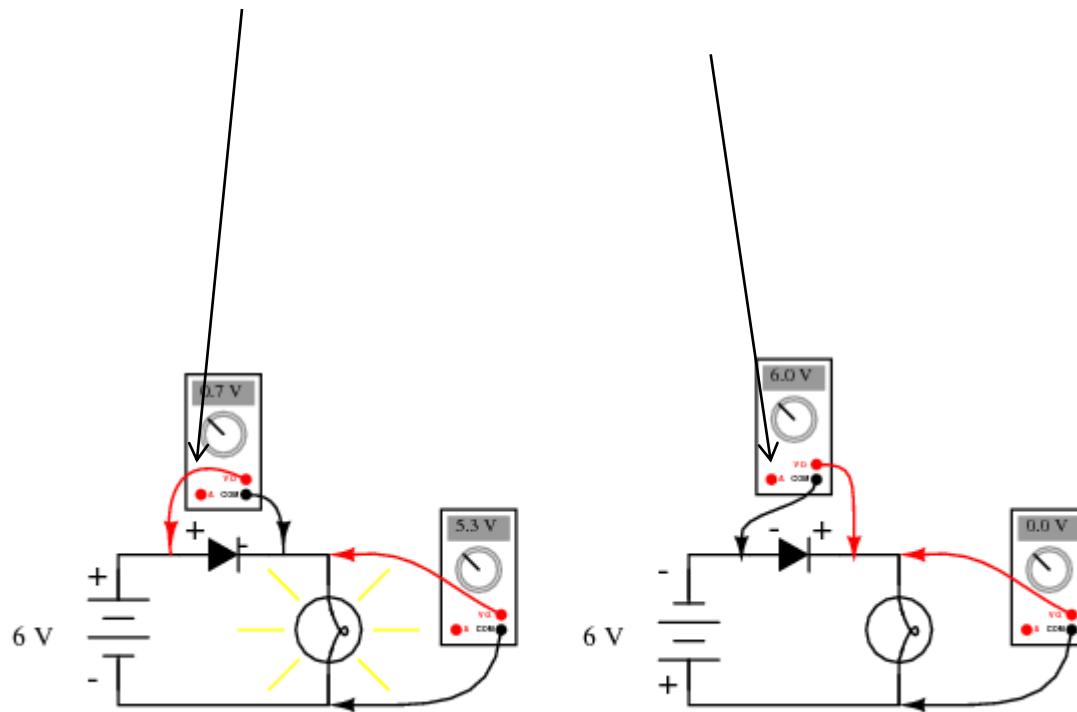
$V_D$  = Voltage applied across diode in volts

$N$  = "Nonideality" or "emission" coefficient  
(typically between 1 and 2)

$k$  = Boltzmann's constant ( $1.38 \times 10^{-23}$ )

$T$  = Junction temperature in Kelvins

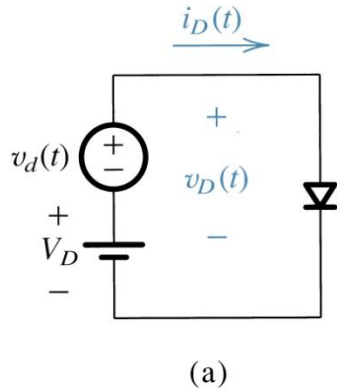
# The Forward and Reverse bias Regions



# The Small-Signal Model

$$I_D = I_S e^{V_D/nV_T}$$

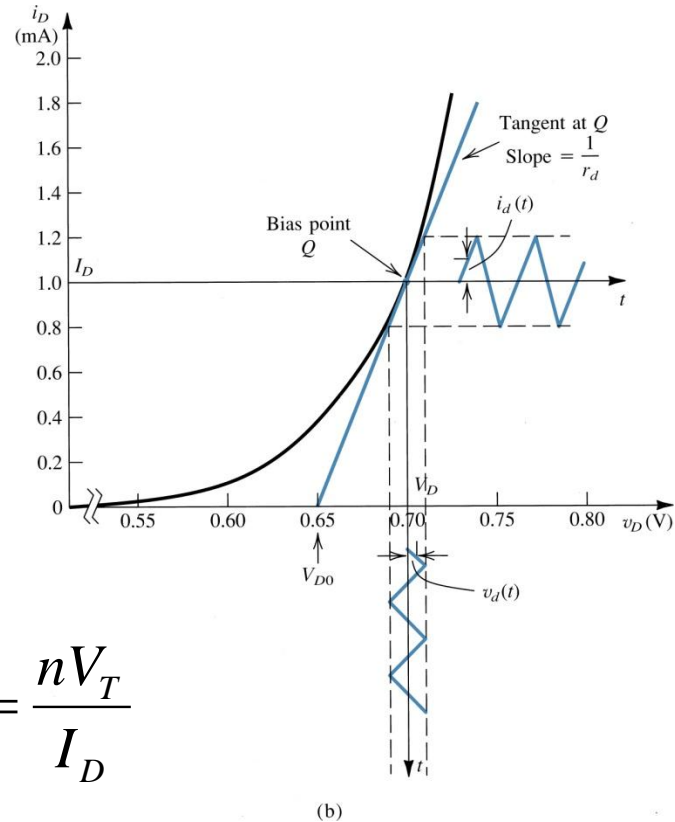
$$v_D(t) = V_D + v_d(t)$$



$$i_D = I_D + i_d$$

$$i_d = \frac{I_D}{nV_T} v_d$$

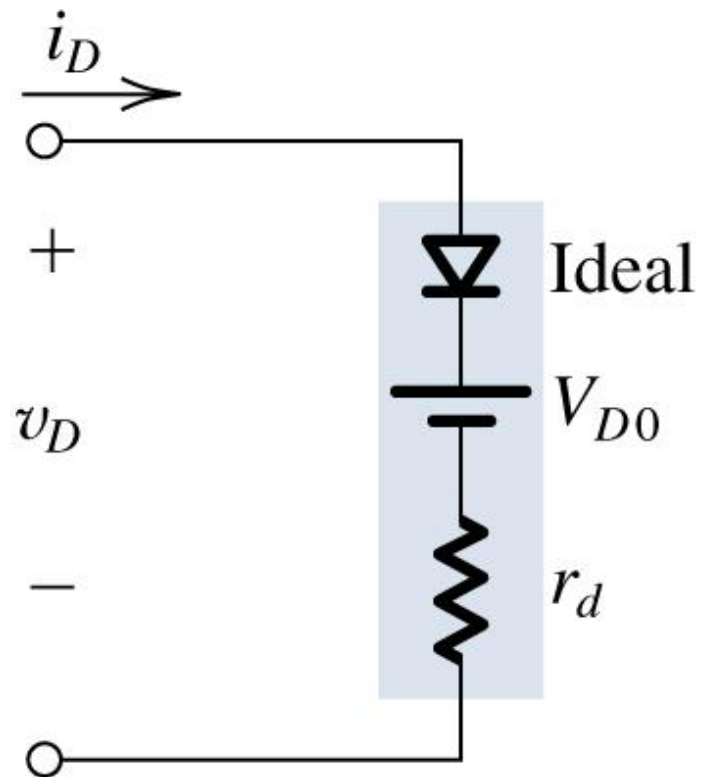
$$r_d = \frac{nV_T}{I_D}$$



$$i_D = \frac{1}{r_d} (v_D - V_{D0})$$

$$v_D = V_{D0} + i_D r_d$$

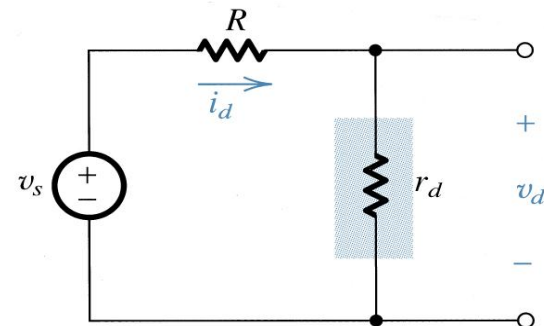
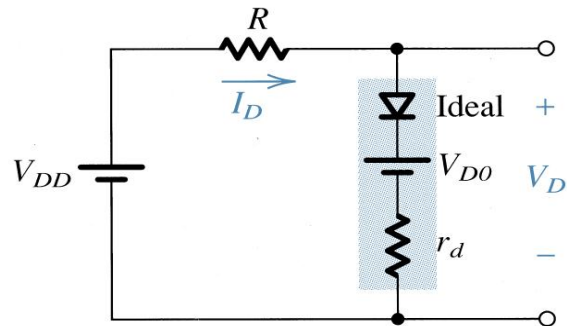
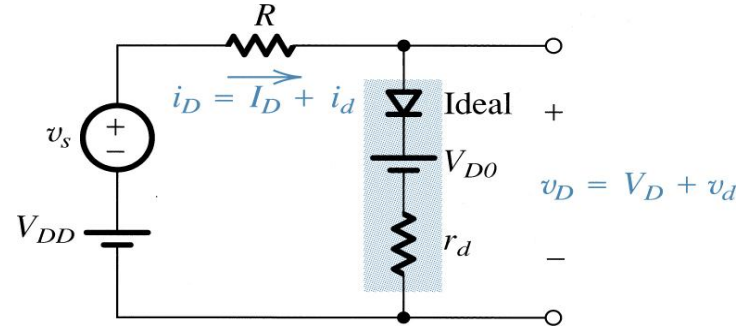
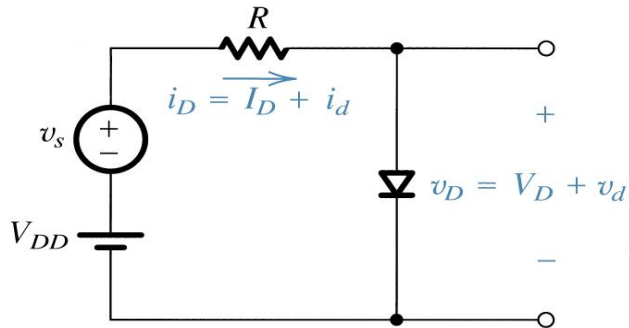
$$v_D = V_D + i_d r_d$$



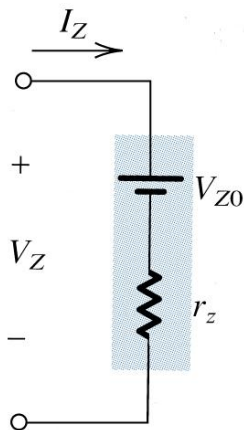
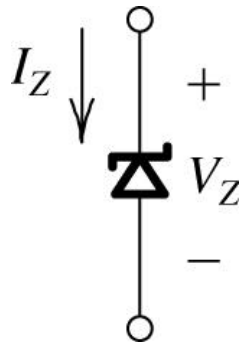
$$V_{DD} = I_D R + V_D$$

$$v_s = i_d (R + r_d)$$

$$v_d = v_s \frac{r_d}{R + r_d}$$



# Operation in the Reverse Region- Zener Diode



$$V_Z = V_{Z0} + r_z I_Z$$

