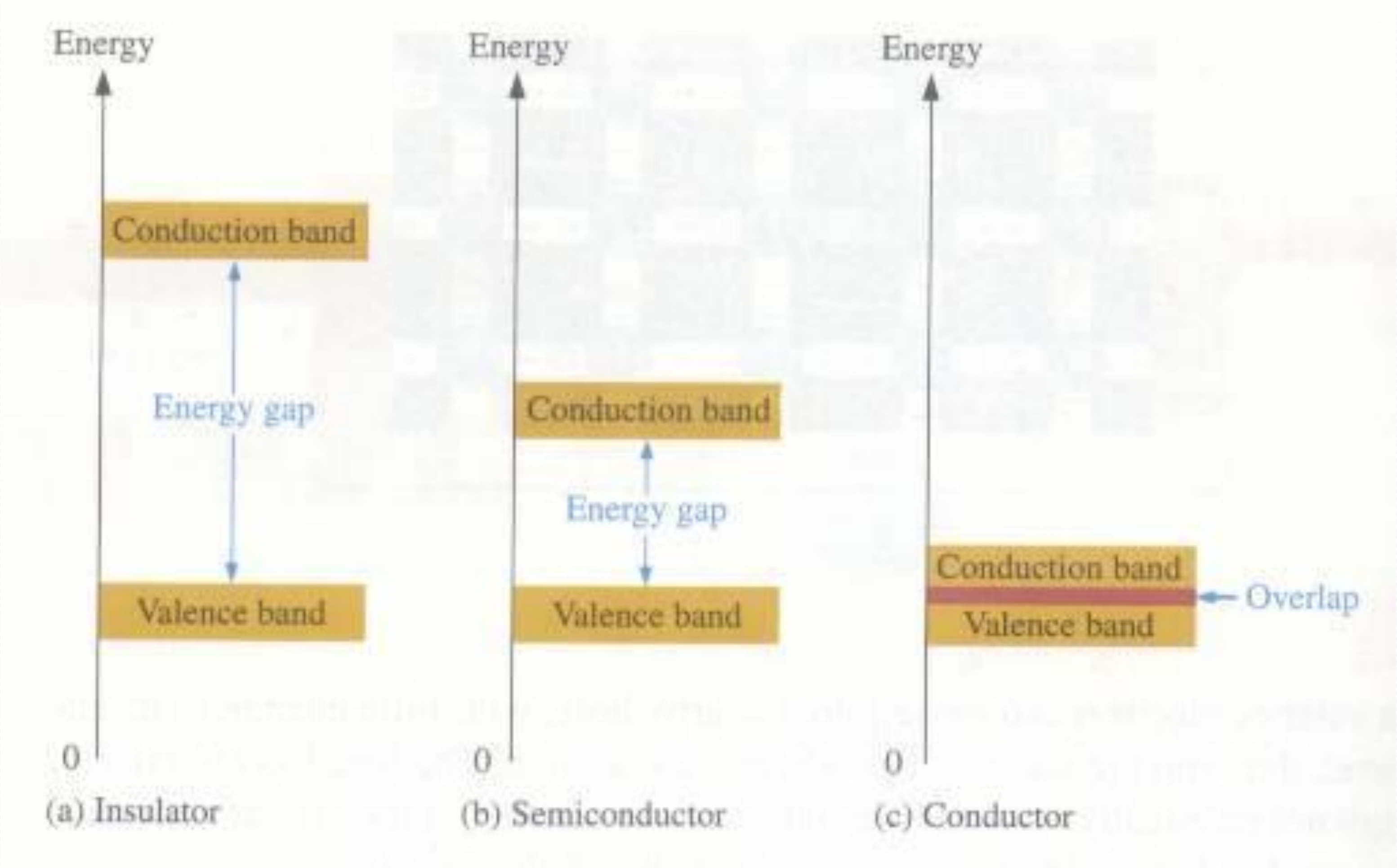
ECE249:
Unit-4

PN junction diode and its applications

Basic Diode Concepts

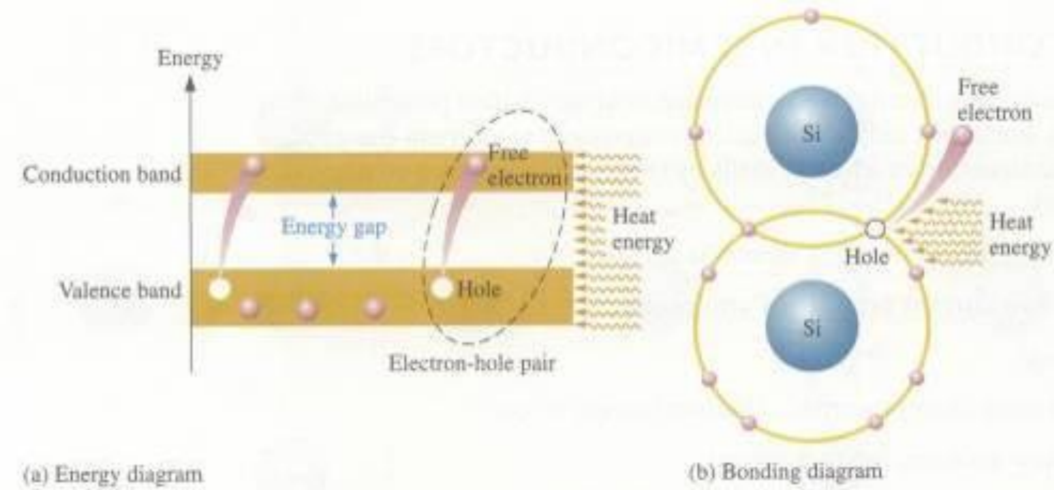
* Energy Diagrams – *Insulator, Semiconductor, and Conductor*

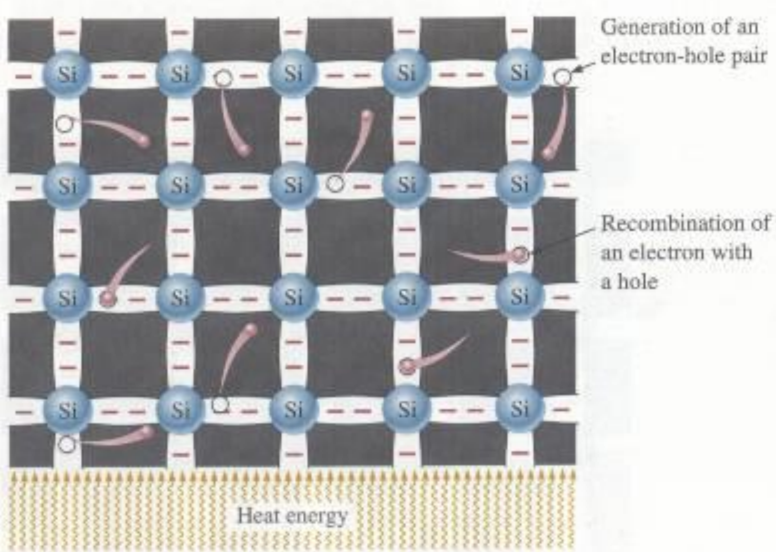
the energy diagram for the three types of solids



Intrinsic Semiconductors

* Intrinsic (pure) *Si* Semiconductor:





When equilibrium between excitation and recombination is reached:

$$\text{electron density} = \text{hole density}$$

$$n_i = p_i = 1.5\times10^{10}\ \text{cm}^{-3}$$

for intrinsic Si crystal at 300 K

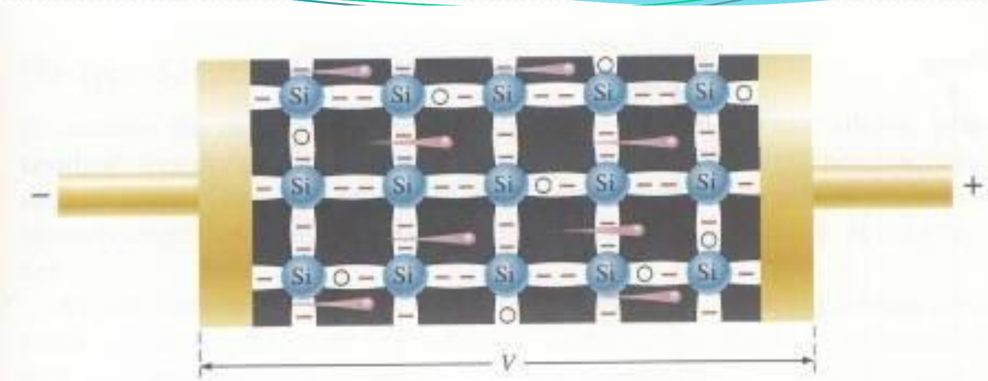
(Note: Si crystal atom density is $\sim 5\times10^{22}\ \text{cm}^{-3}$)

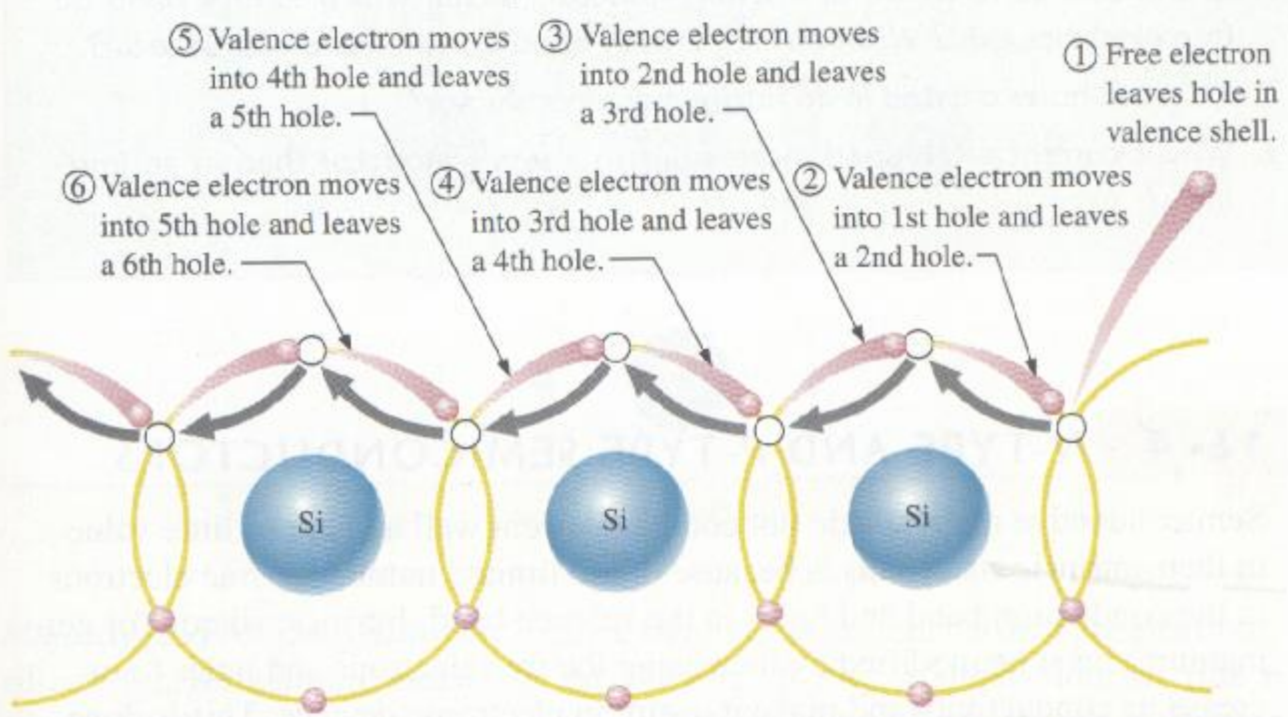
Intrinsic Semiconductors

*Apply a voltage across a piece of *Si:*

electron current

and hole current



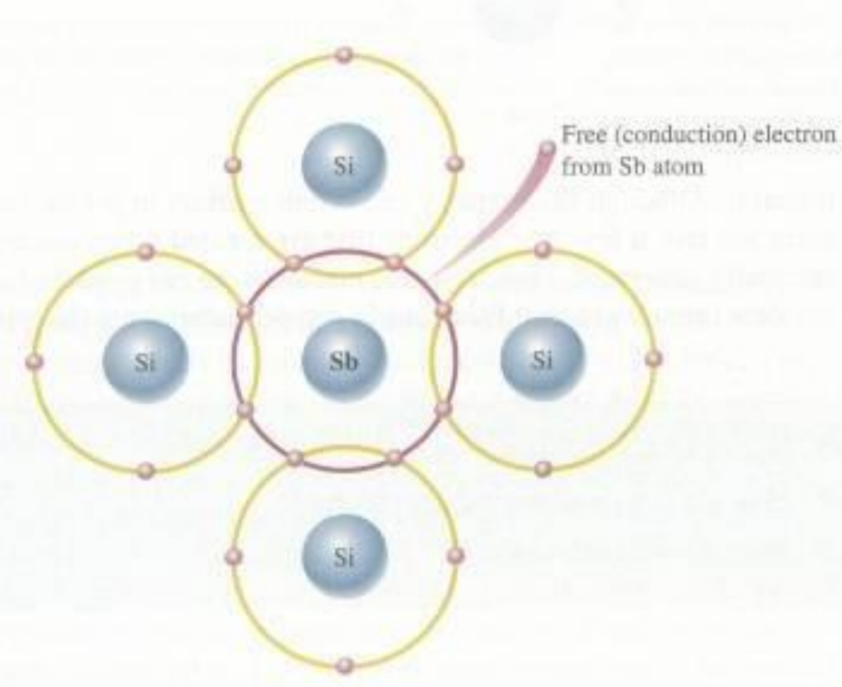


When a valence electron moves left to right to fill a hole while leaving another hole behind, a hole has effectively moved from right to left. Gray arrows indicate effective movement of a hole.

N- and P- Type Semiconductors

* *Doping*: adding of impurities (i.e., dopants) to the intrinsic semi-conductor material.

* *N-type*: adding Group V dopant (or donor) such as As, P, Sb,…



$$n \cdot p = constant\ for\ a\ semiconductor$$

$$For\ \ Si\ \ at\ 300K$$

$$n \cdot p = n_i^2 = p_i^2 = \left(1.5 \times 10^{10}\right)^2$$

$$In\ \ n\text{-}type\ material$$

$$n \cong N_d \quad the\ donor\ conceration$$

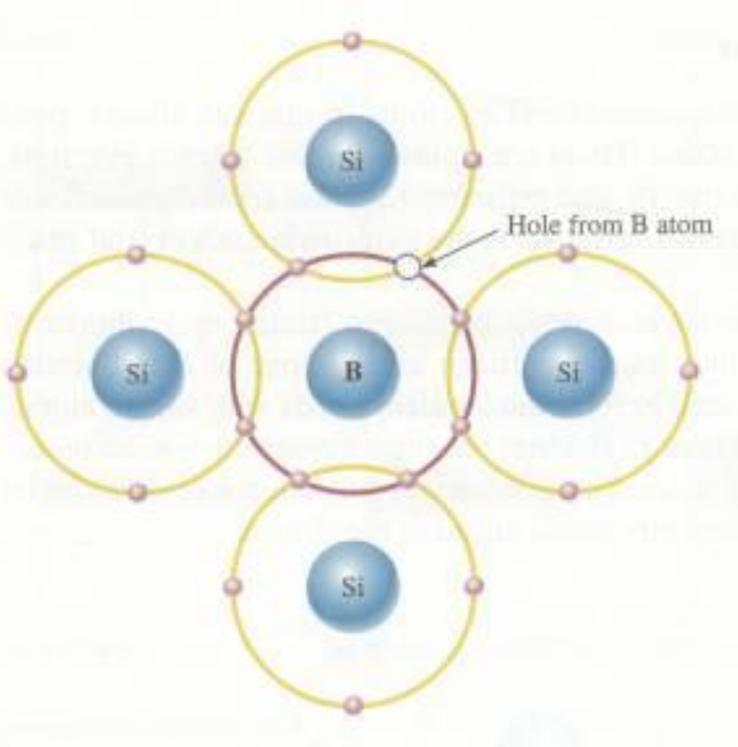
$$n = N_d >> n_i\ ,\ \ p << p_i$$

$$We\ call$$

$$\boxed{\begin{array}{l} electron\ the\ major\ charge\ carrier \\ hole\ the\ minor\ cahage\ carrier \end{array}}$$

N- and P- Type Semiconductors

* *Doping*: adding of impurities (i.e., dopants) to the intrinsic semi-conductor material.
* *P-type*: adding Group III dopant (or acceptor) such as Al, B, Ga,...



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$$In\ \ p\text{-}type\ material$$

$$p \cong N_a\ \ the\ acceptor\ conceration$$

$$p = N_a >> p_i\ ,\ n << n_i$$

$$We\ call$$

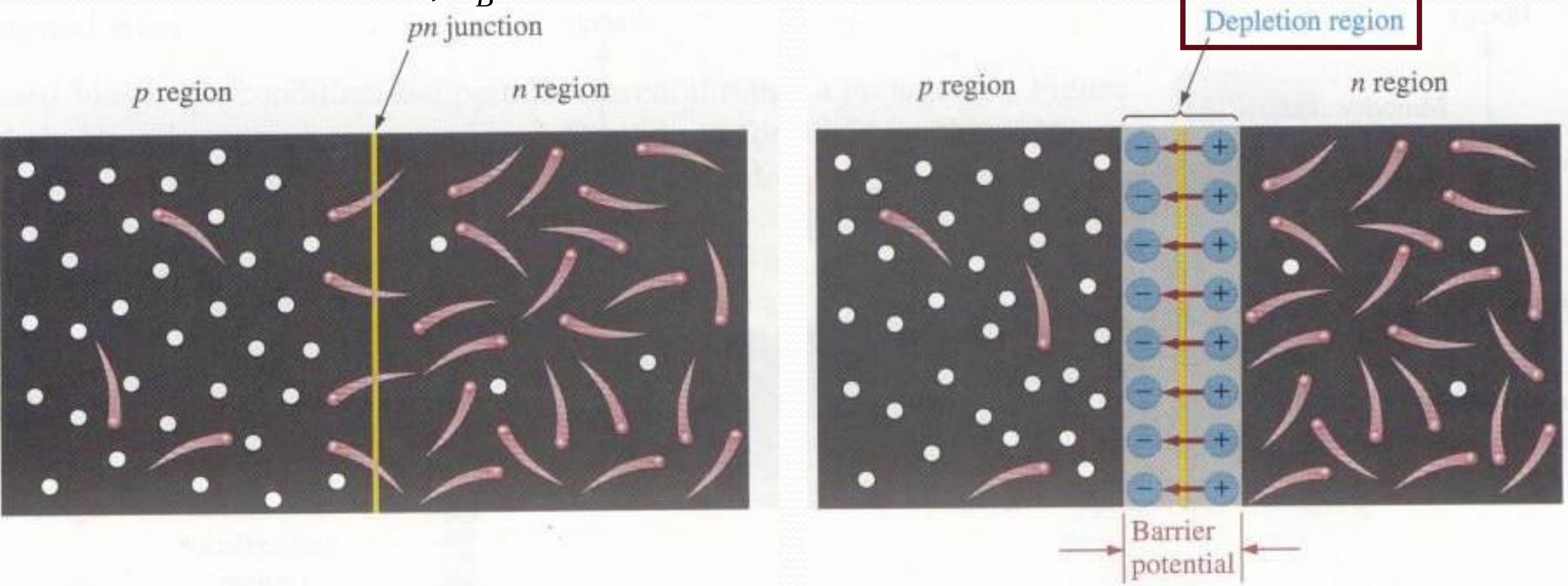
$$\boxed{\begin{array}{l} hole\ the\ major\ charge\ carrier \\ electron\ the\ minor\ cahage\ carrier \end{array}}$$

The PN-Junction

* The interface in-between p-type and n-type material is called a *pn-junction*.

$The\ barrier\ potential\ V_B \cong 0.6 - 0.7V\ \ for\ Si\ and\ 0.3V\ \ for\ Ge$

$at\ 300K:\ \ as\ T \uparrow, V_B \downarrow.$



(a) At the instant of junction formation, free electrons in the *n* region near the *pn* junction begin to diffuse across the junction and fall into holes near the junction in the *p* region.

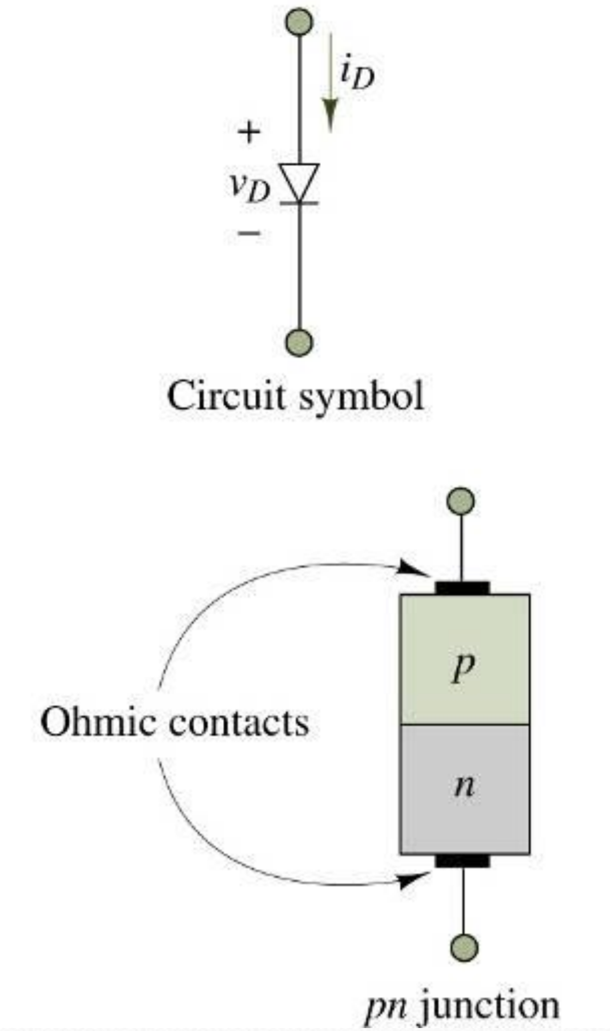
(b) For every electron that diffuses across the junction and combines with a hole, a positive charge is left in the *n* region and a negative charge is created in the *p* region, forming a barrier potential. This action continues until the voltage of the barrier repels further diffusion.

Biasing the PN-Junction

* There is no movement of charge through a PN-junction at equilibrium.

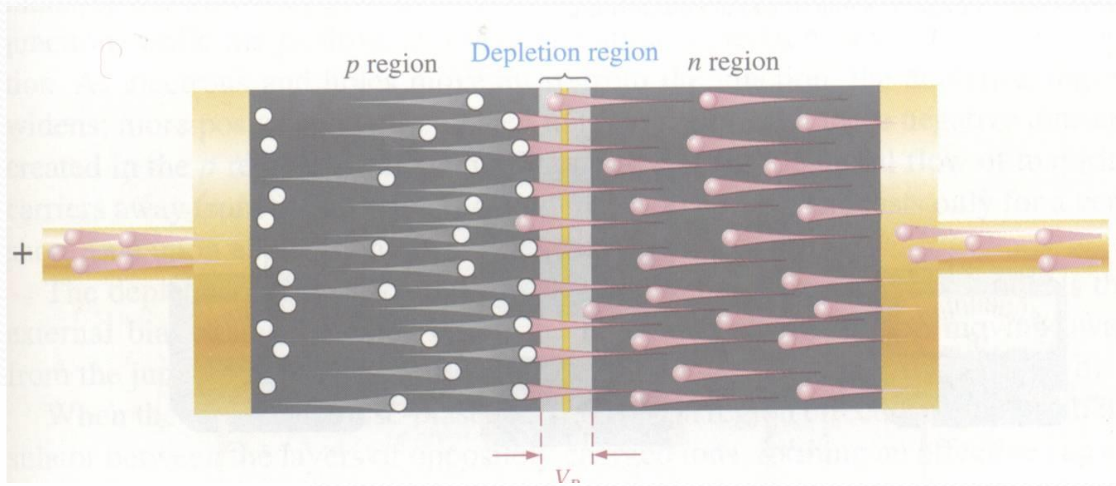
* The PN-junction form a *diode* which allows current in only one direction and prevent the current in the other direction as determined by the *bias*.

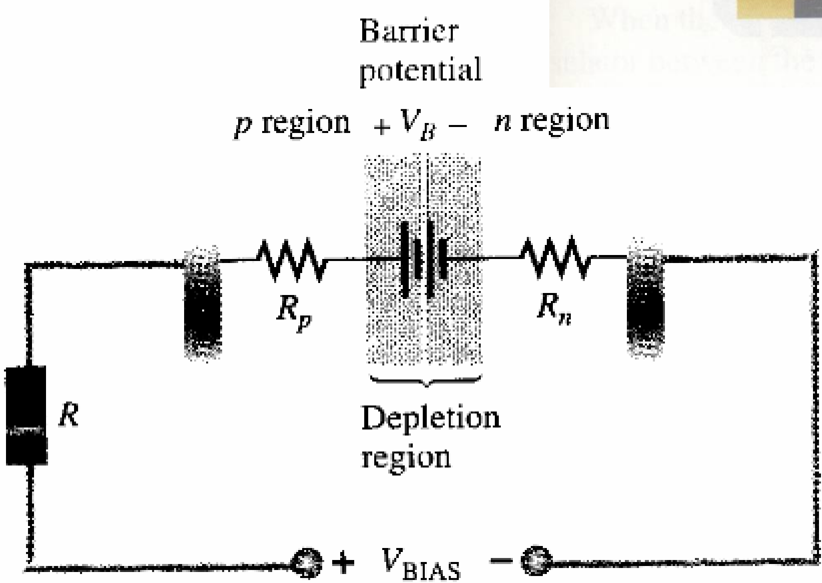
The arrow in the circuit symbol for the diode indicates the direction of current flow when the diode is forward-biased.

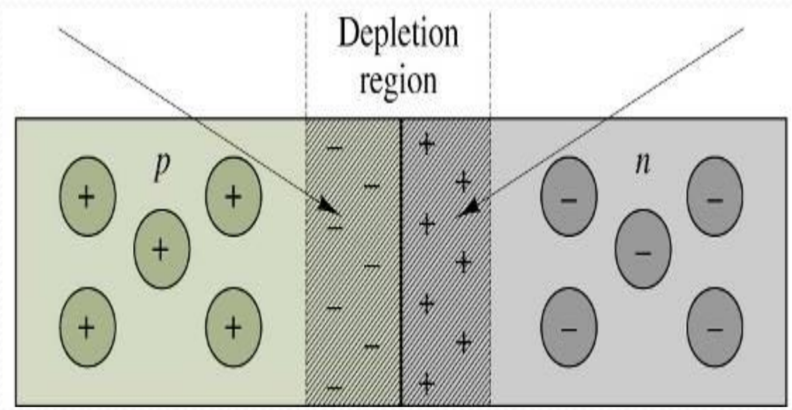


Biasing the PN-Junction

*****Forward Bias**: *dc voltage positive terminal connected to the p region and negative to the n region*. It is the condition that permits current through the pn-junction of a diode.

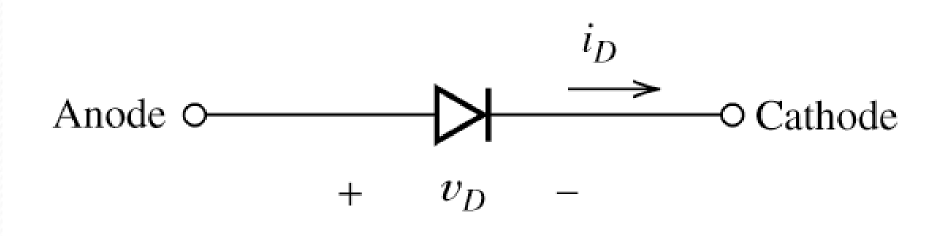


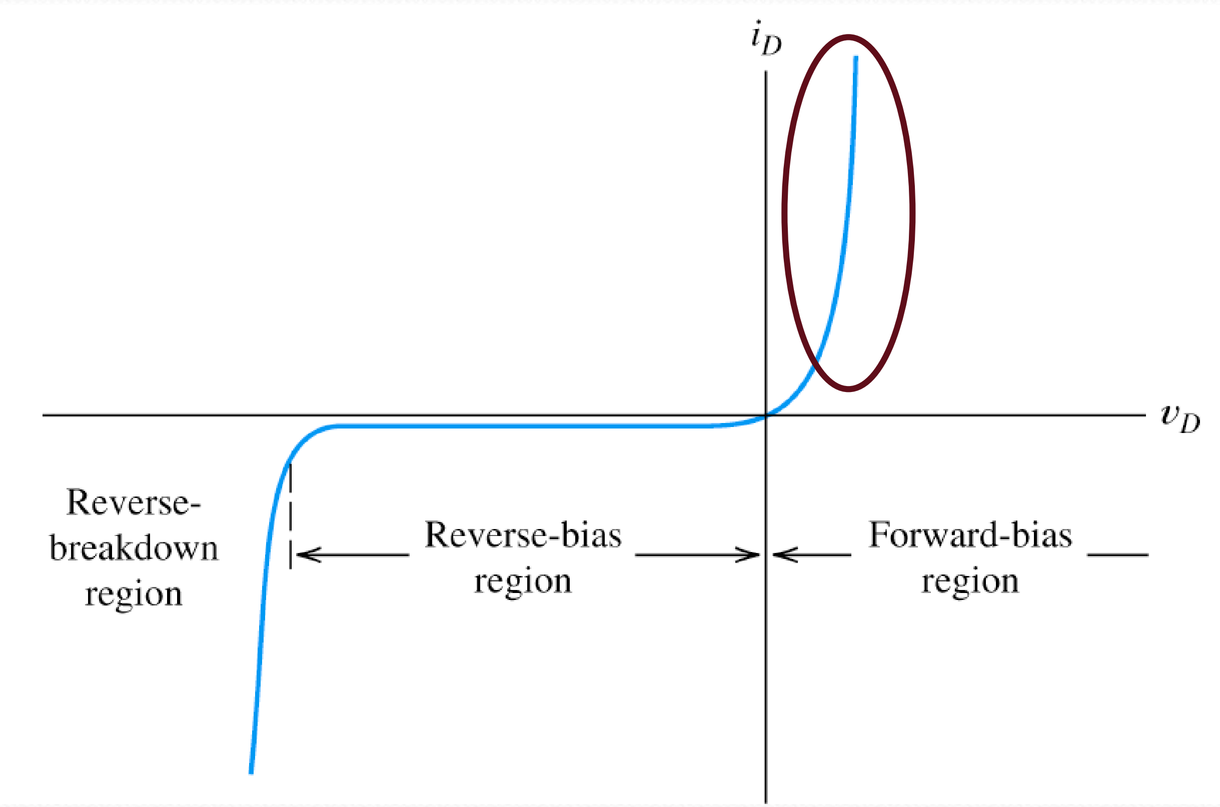




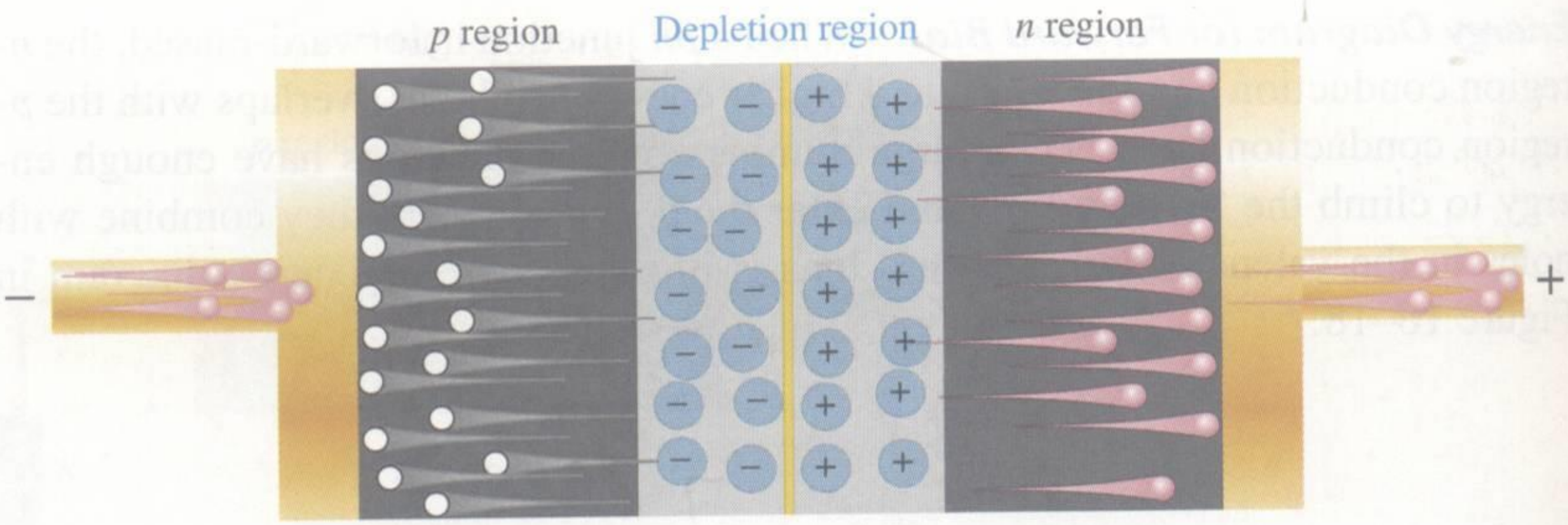
Biasing the PN-Junction

****Forward Bias***:





**Reverse Bias*: *dc voltage negative terminal connected to the p region and positive to the n region*. *Depletion region widens* until its potential difference equals the bias voltage, *majority-carrier current ceases*.

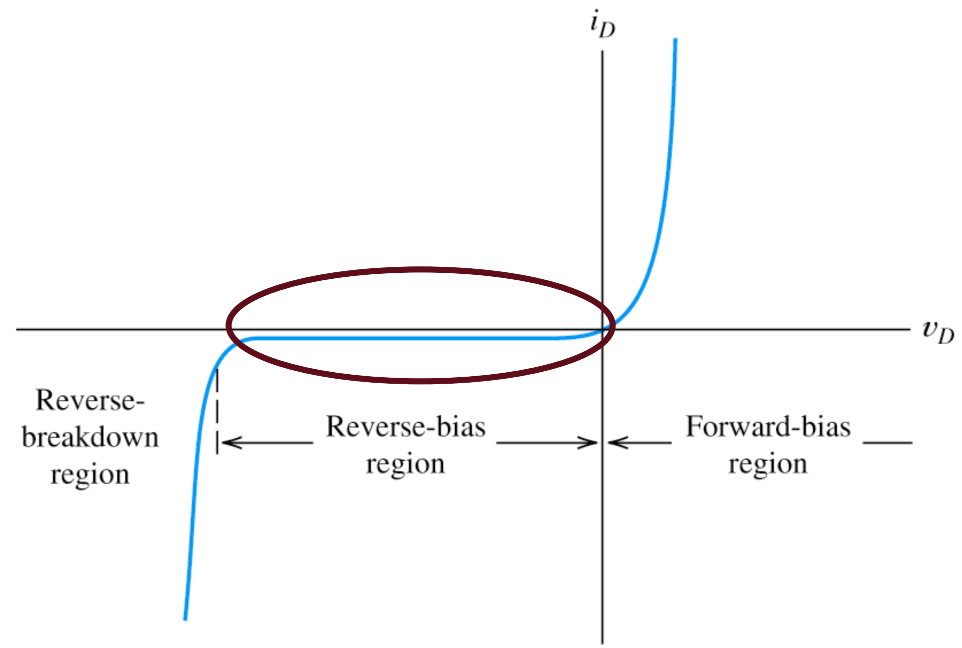


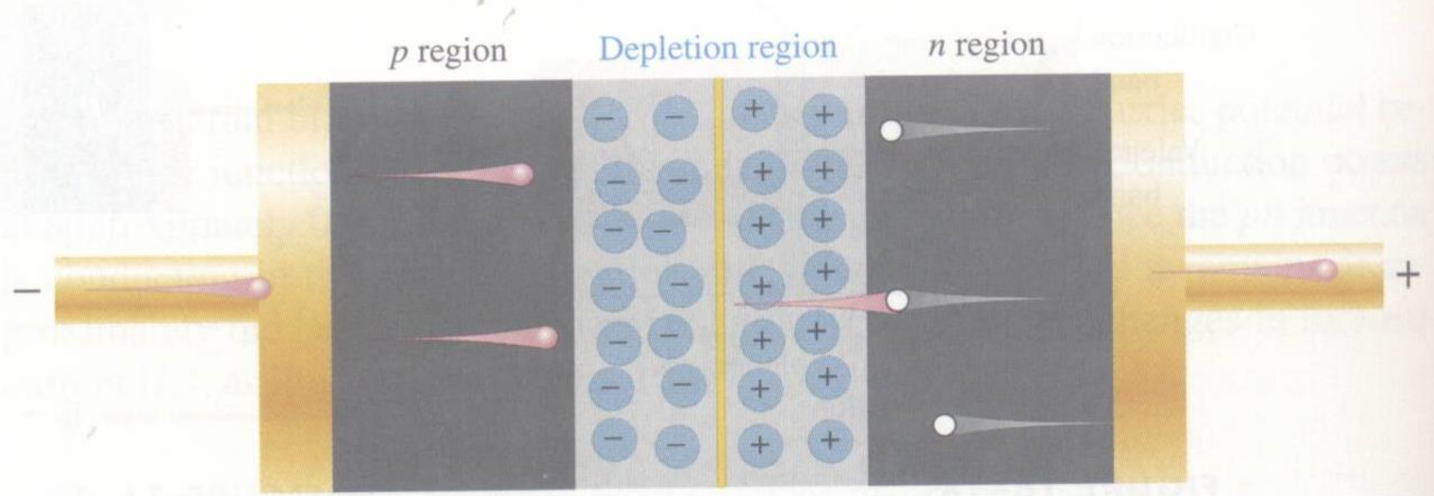
(a) There is transient current as depletion region widens.

***Reverse Bias**:

majority-carrier current ceases.

* However, there is still a very small current produced by minority carriers.



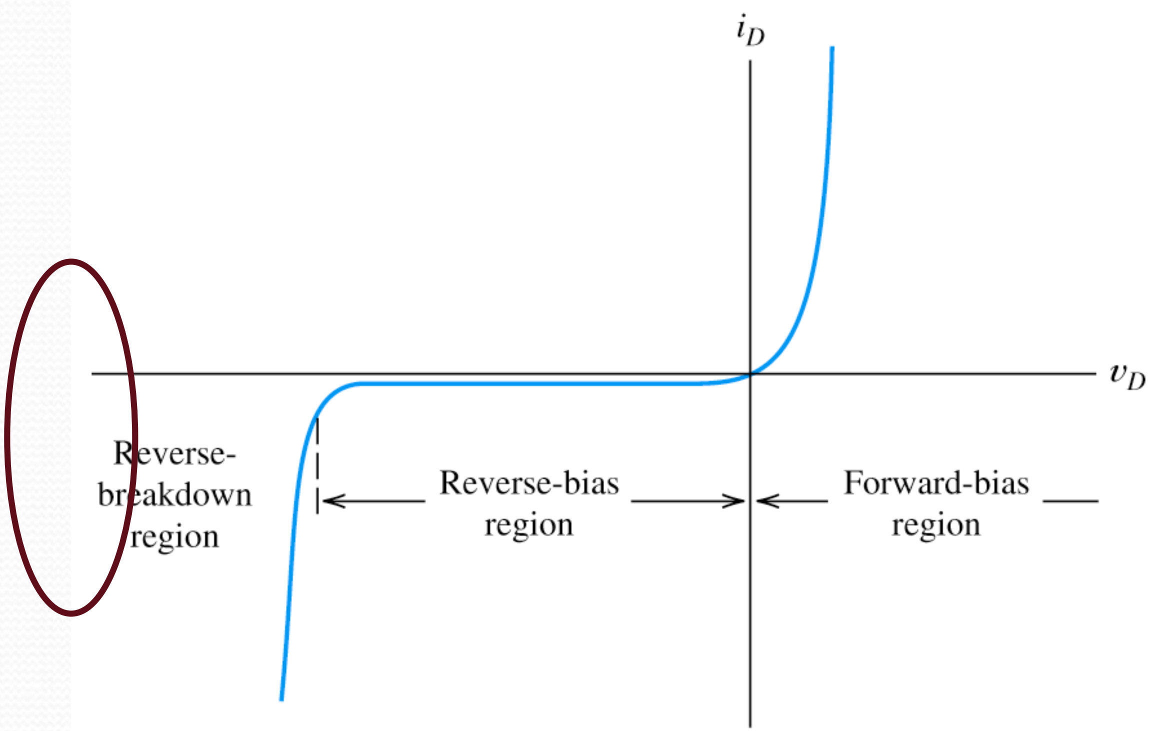


(b) Majority current ceases when barrier potential equals bias voltage. There is an extremely small reverse current due to minority carriers.

Biasing the PN-Junction

* ***Reverse Breakdown:*** As reverse voltage reach certain value, avalanche occurs and generates large current.

Diode Characteristic I-V Curve

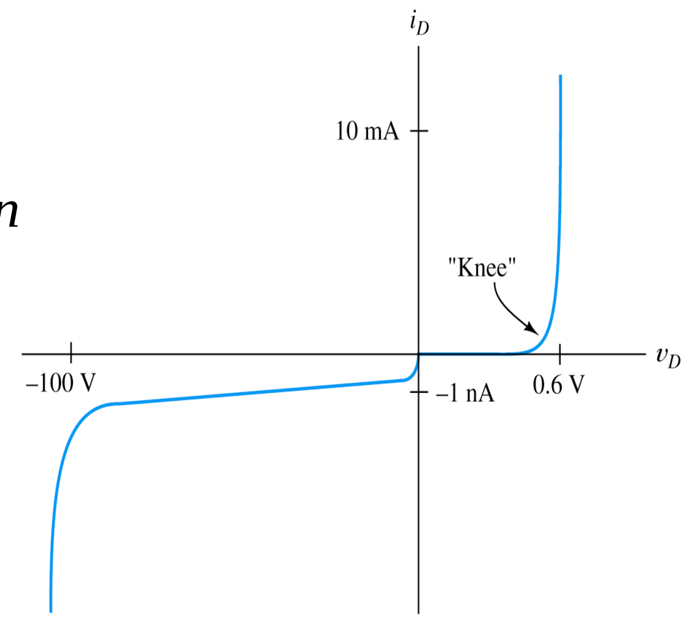


(b) Volt–ampere characteristic

Shockley Equation

* The Shockley equation is a theoretical result under certain simplification:

$$\boxed{i_D = I_s\left[exp\left(\frac{v_D}{nV_T}\right) - 1\right]}$$



where $I_s \cong 10^{-14}$ A at 300K is the (reverse) saturation current, $n \cong 1$ to 2 is the emission coefficient,

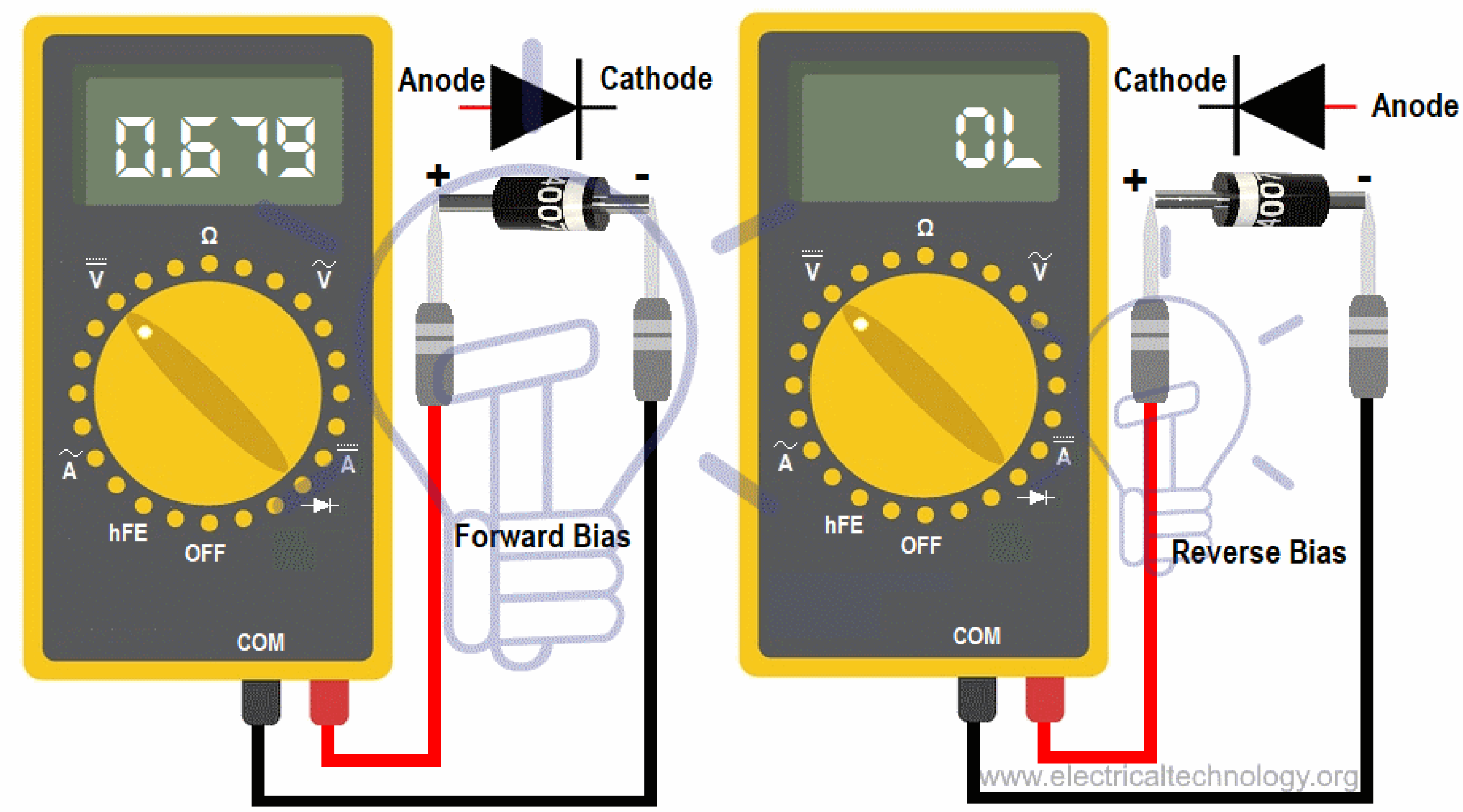
$$V_T = \frac{kT}{q} \cong 0.026V \text{ at } 300K \text{ is the thermal voltage}$$

k is the Boltzman's constant, $q = 1.60 \times 10^{-19}$ C

when $\boxed{v_D \geq\approx 0.1V,\ i_D \cong I_s\, exp\left(\frac{v_D}{nV_T}\right)}$

This equation is not applicable when $v_D < 0$

Diode Testing



Ideal-Diode Model

* We may apply "*Ideal-Diode Model*" to simplify the analysis:

(1) in forward direction: *short-circuit assumption*, zero voltage drop;

(2) in reverse direction: *open-circuit assumption*.

* The ideal-diode model can be used when the forward voltage drop and reverse currents are negligible.

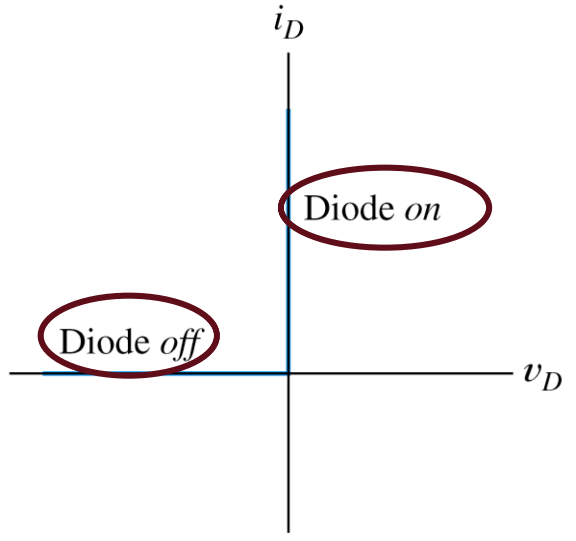
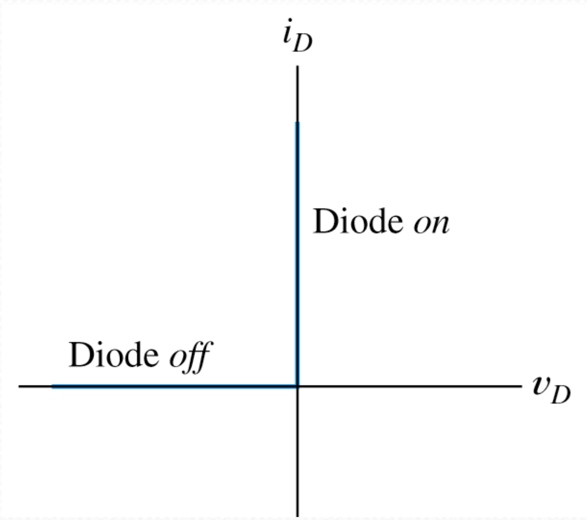


Figure 10.15 Ideal-diode volt–ampere characteristic.

2. Piecewise-Linear Diode Models
Modified Ideal-Diode Model



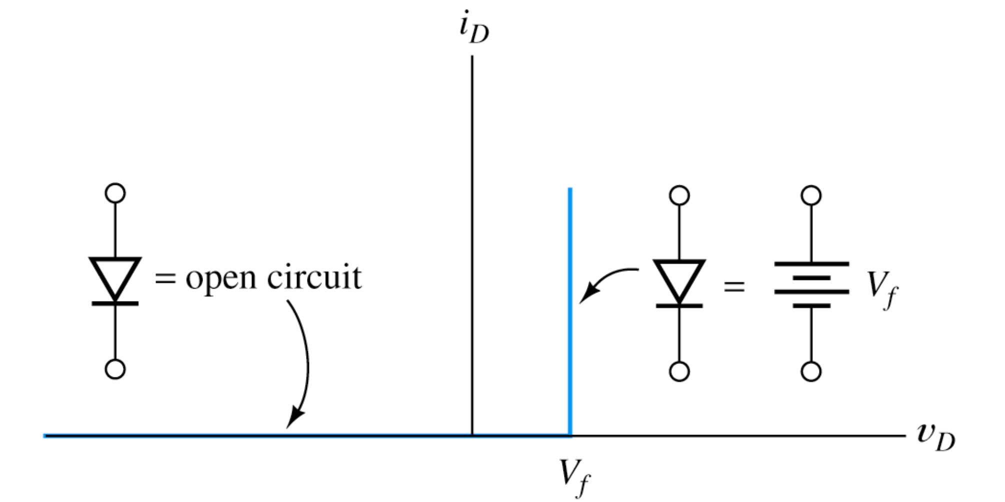


Figure 10.23 Simple piecewise-linear equivalent for the diode.

* This modified ideal-diode model is usually accurate enough in most of the circuit analysis.

Application

Rectifier Circuits

* *Rectifiers* convert ac power to dc power.

* Rectifiers form the basis for electronic power suppliers and battery charging circuits.

Half-Wave Rectifier

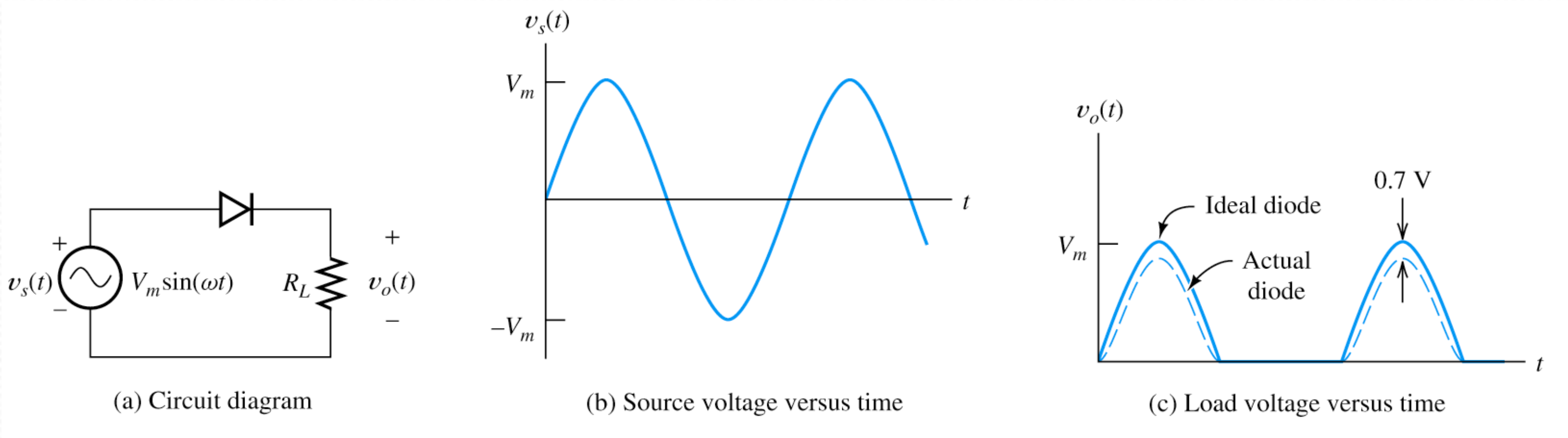
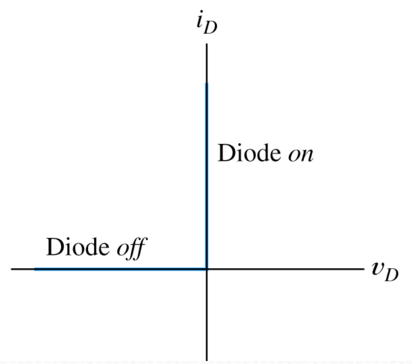
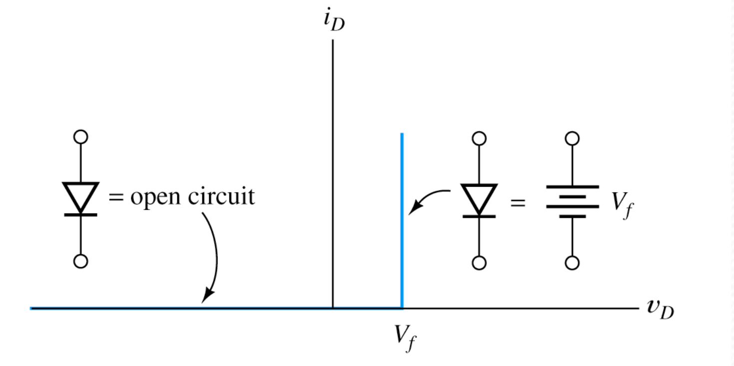


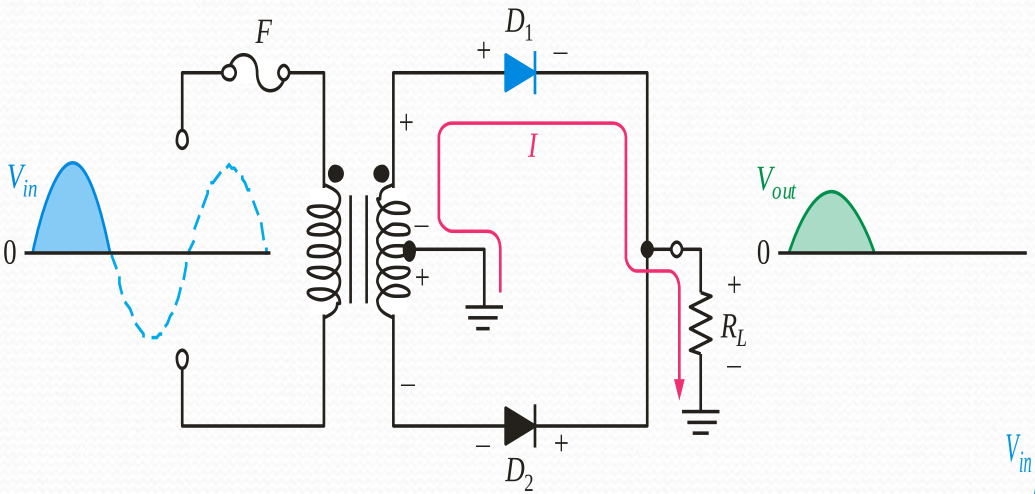
Figure 10.24 Half-wave rectifier with resistive load.



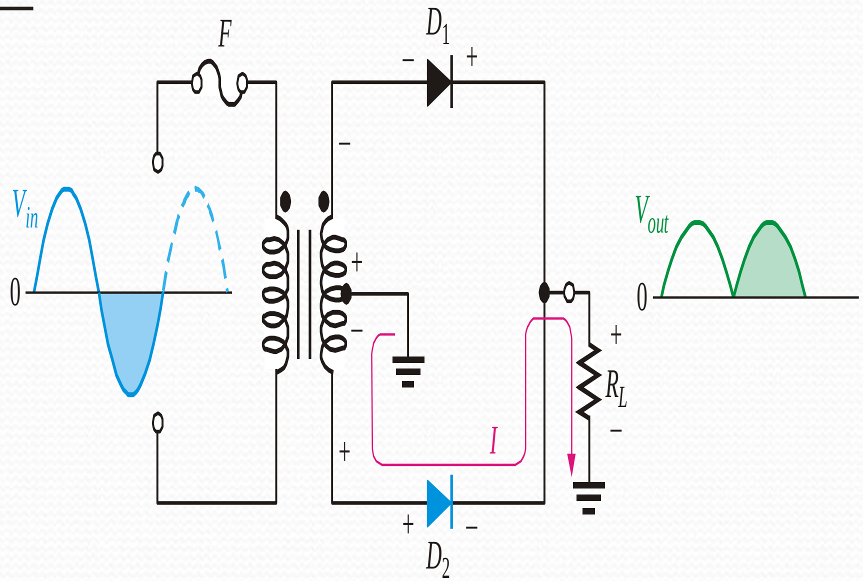


Center-Tapped Full wave rectifiers

- A center-tapped transformer is used with two diodes that conduct on alternating half-cycles.



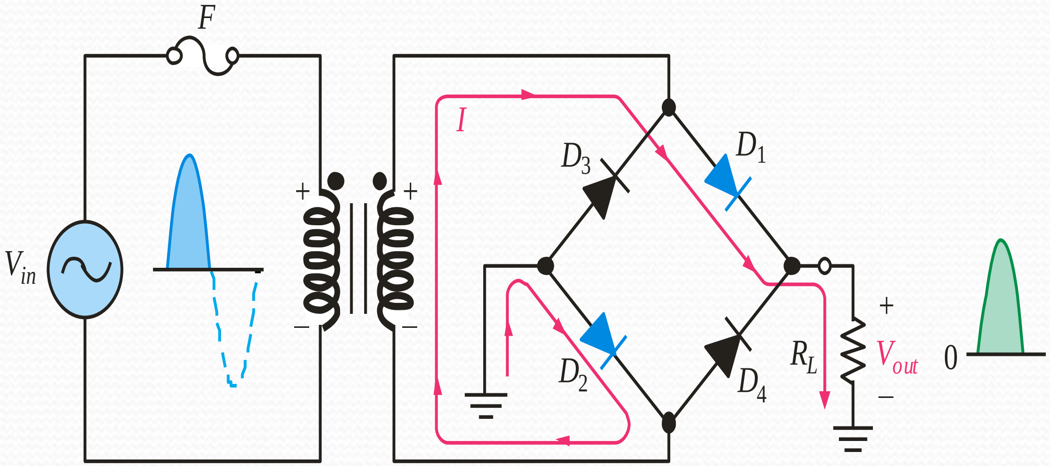
During the negative half-cycle, the lower diode is forward-biased and the upper diode is reverse-biased.



During the positive half-cycle, the upper diode is forward-biased and the lower diode is reverse-biased.

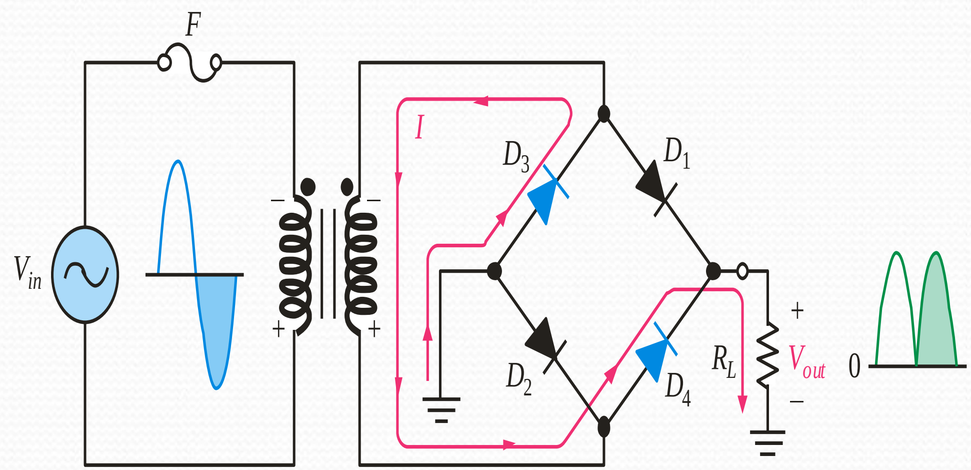
Bridge Full-wave rectifiers

- The Bridge Full-Wave rectifier uses four diodes connected across the entire secondary as shown.



Conduction path for the positive half-cycle.

Conduction path for the negative half-cycle.



MCQ

The forward voltage drop across a silicon diode is about ....

(a) 0.3 V

(b) 3 V

(C) 7 V

(d) 0.7 V

MCQ

The leakage current in a crystal diode is due to ……………..

(a) minority carriers

(b) majority carriers

(C)junction capacitance

(d) none of the above