

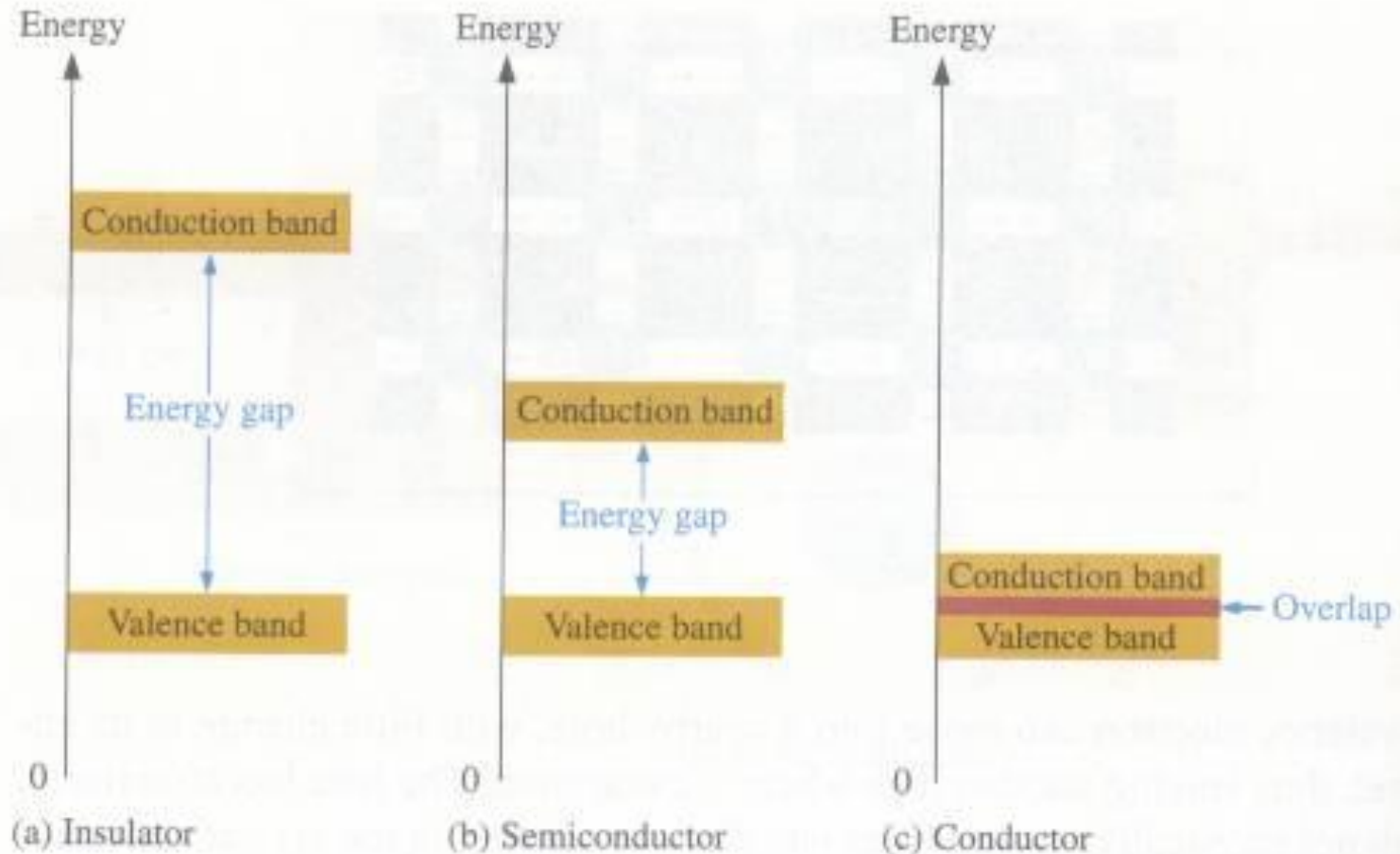


ECE249: Unit-4

PN junction diode and its applications

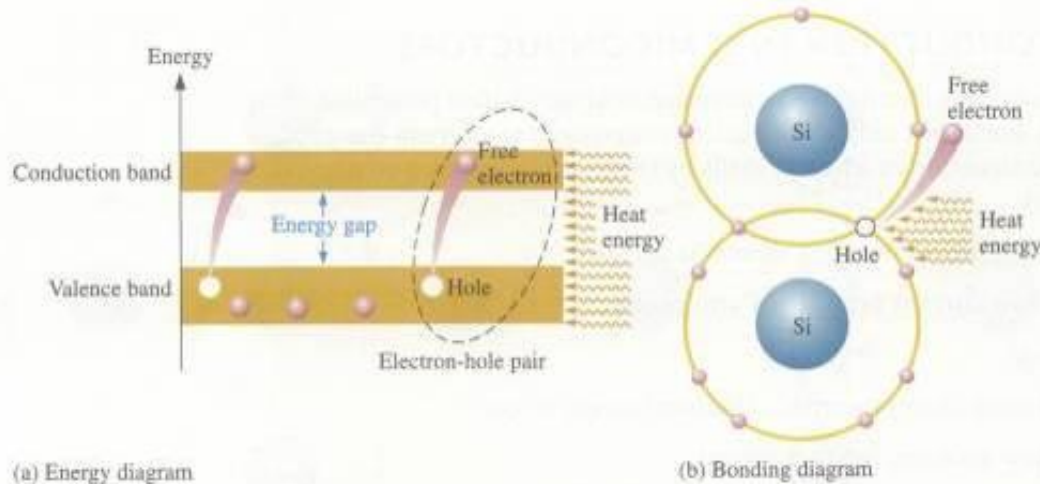
Basic Diode Concepts

- * 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:

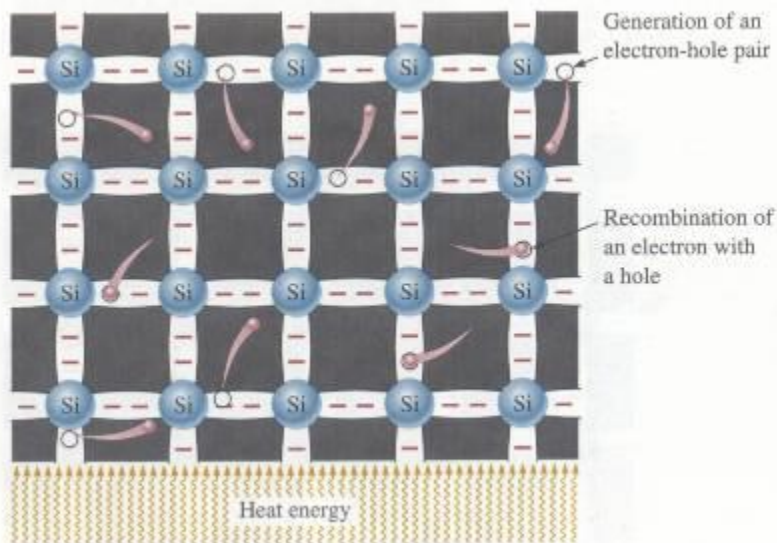
electron density = hole density

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

for intrinsic Si crystal at 300 K

(Note: Si crystal atom density

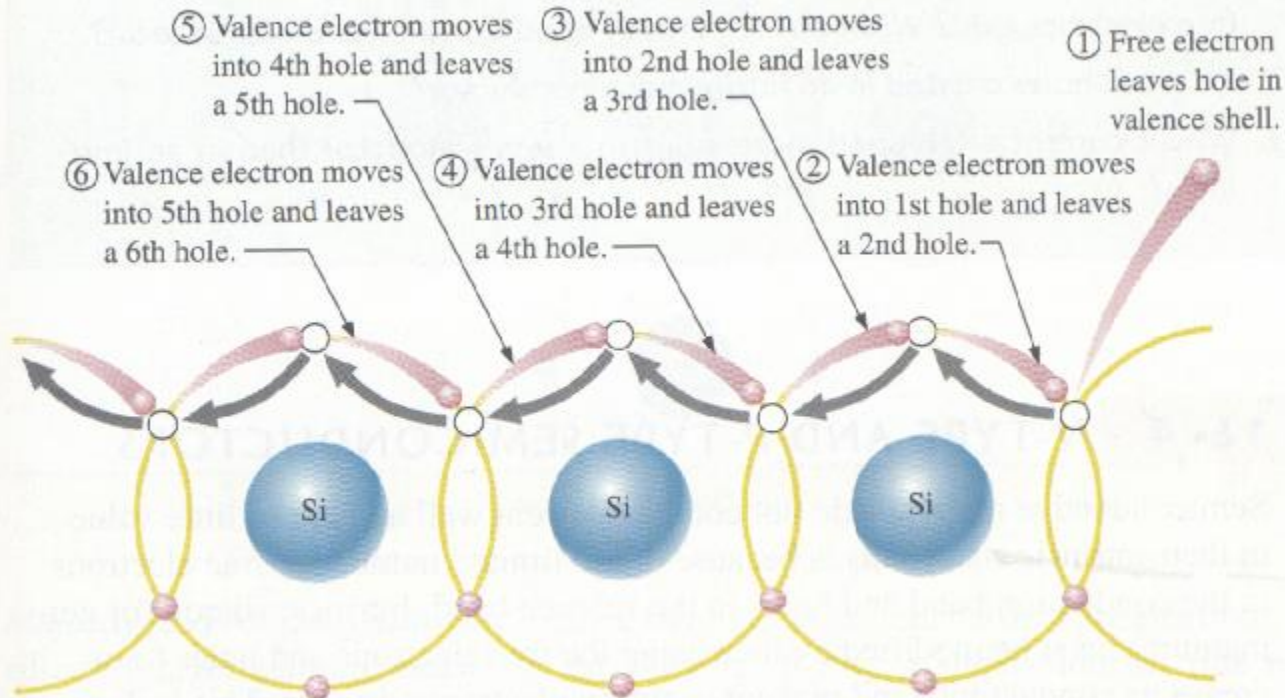
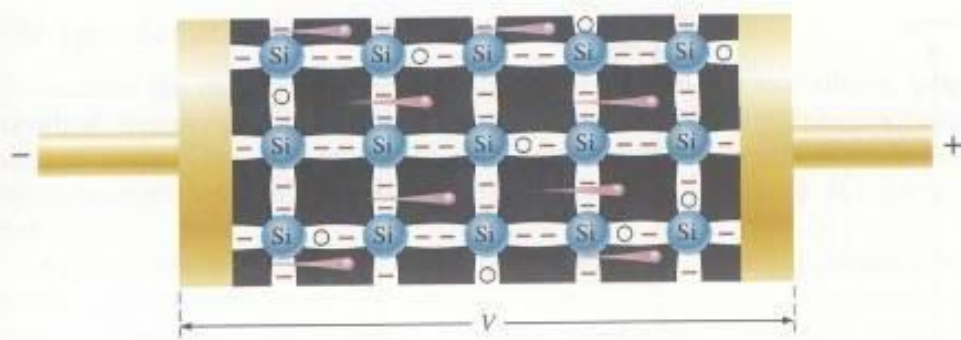
is $\sim 5 \times 10^{22} \text{ cm}^{-3}$)



Intrinsic Semiconductors

*Apply a voltage across
a piece of Si:

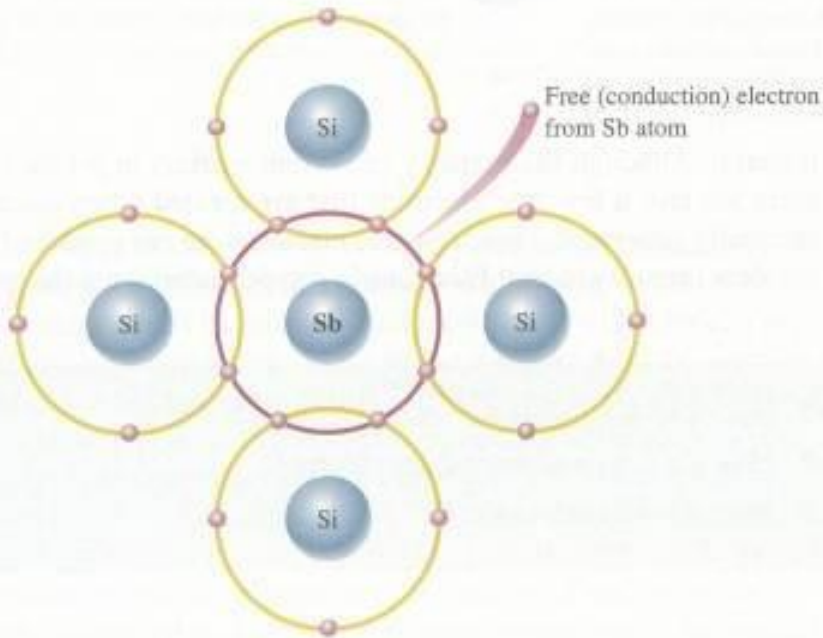
electron current
and hole current



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



$n \cdot p = \text{constant for a semiconductor}$

For Si at 300K

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

In n - type material

$n \cong N_d$ the donor concentration

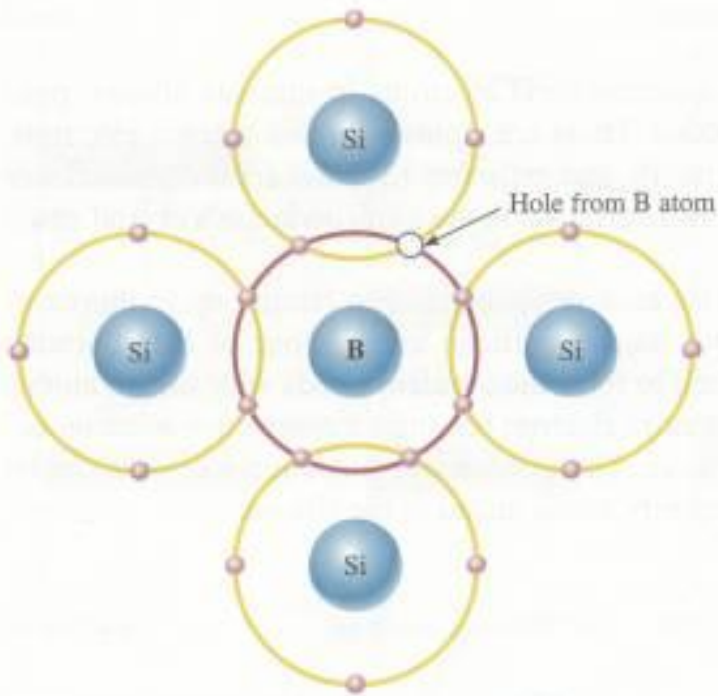
$$n = N_d \gg n_i, \quad p \ll p_i$$

We call

*electron the major charge carrier
hole the minor charge carrier*

N- and P- Type Semiconductors

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



$n \cdot p = \text{constant for a semiconductor}$

For Si at 300K

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

In p - type material

$p \cong N_a$ the acceptor concentration

$$p = N_a \gg p_i, n \ll n_i$$

We call

hole the major charge carrier

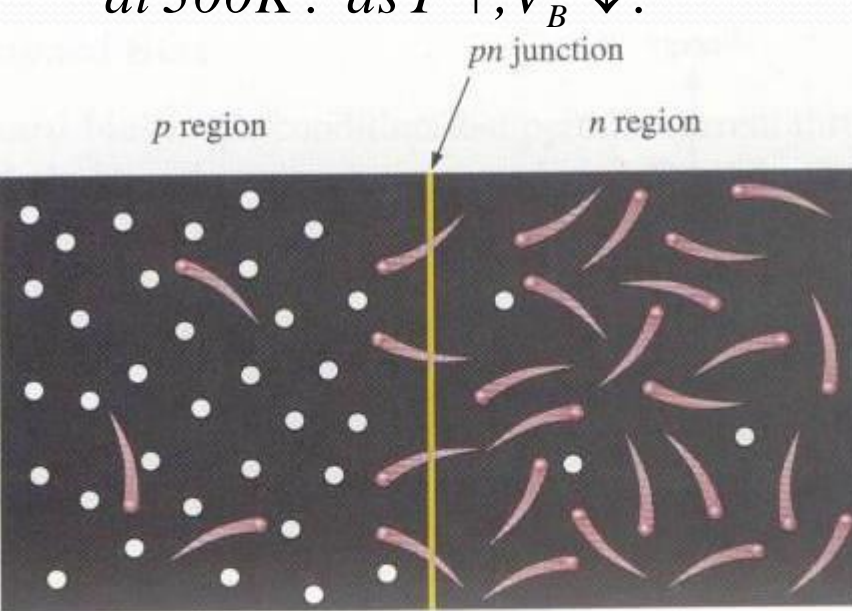
electron the minor charge carrier

The PN-junction

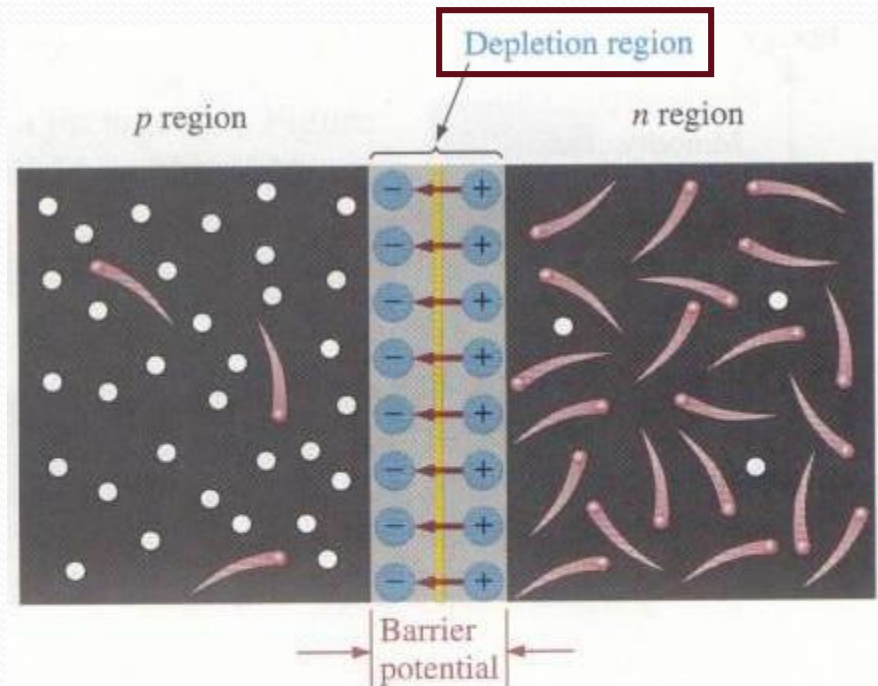
- * The interface in-between p-type and n-type material is called a *pn-junction*.

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.

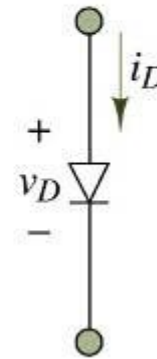


(b) For every electron that diffuses across the junction and combines with a hole, a positive charge is left in the *n* region and a negative charge is created in the *p* region, forming a **barrier potential**. This action continues until the voltage of the barrier repels further diffusion.

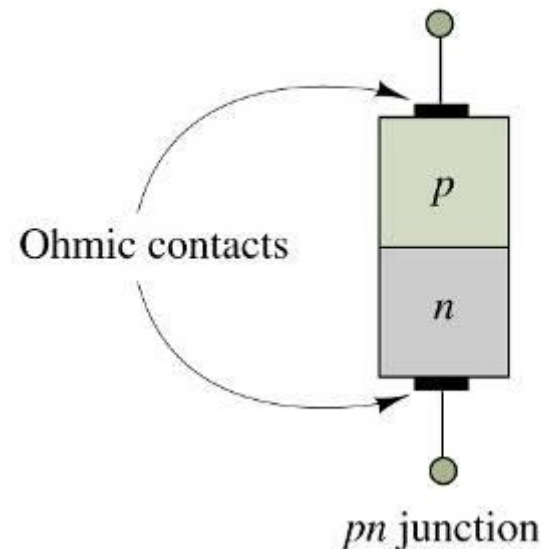
Biasing the PN-Junction

- * 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.

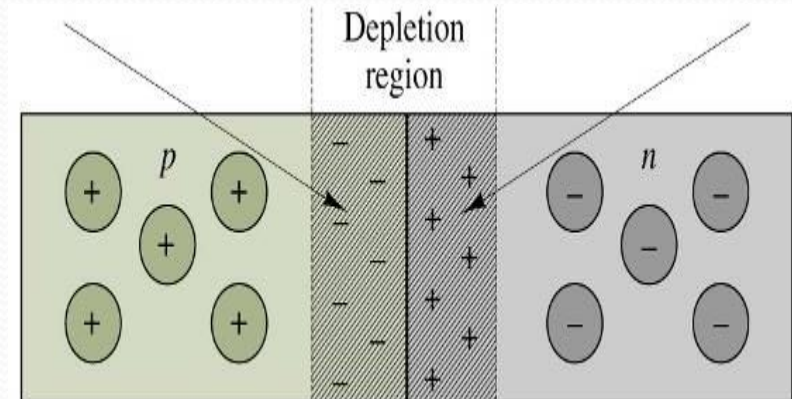
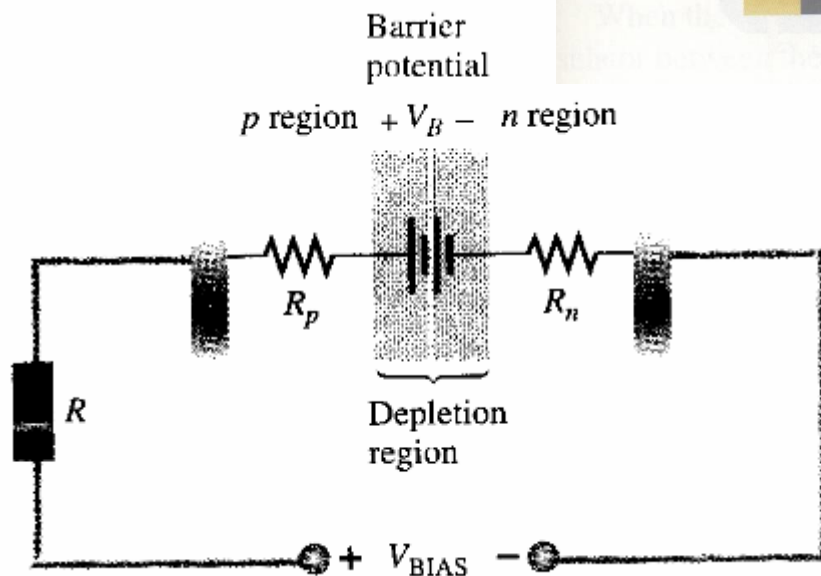
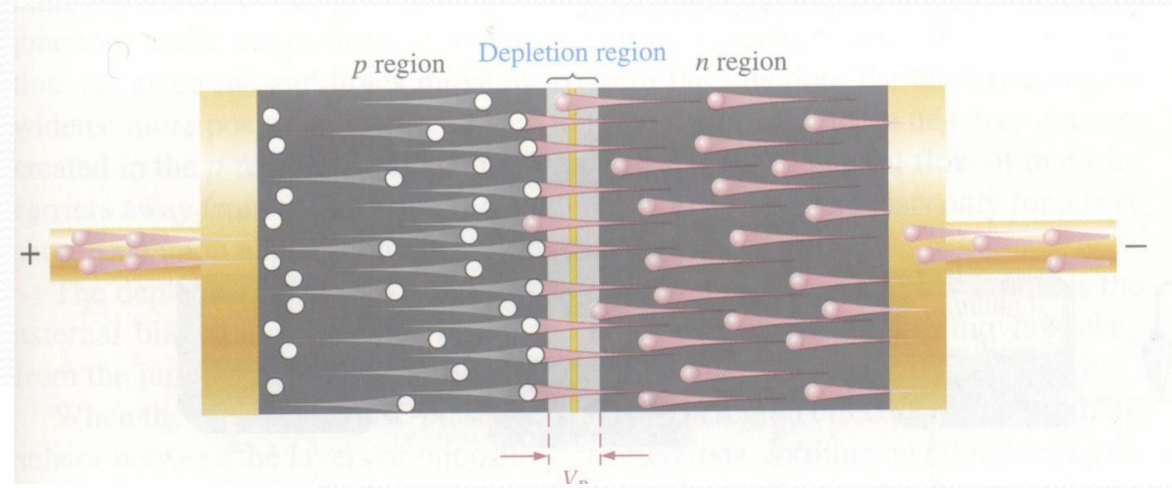


Circuit symbol



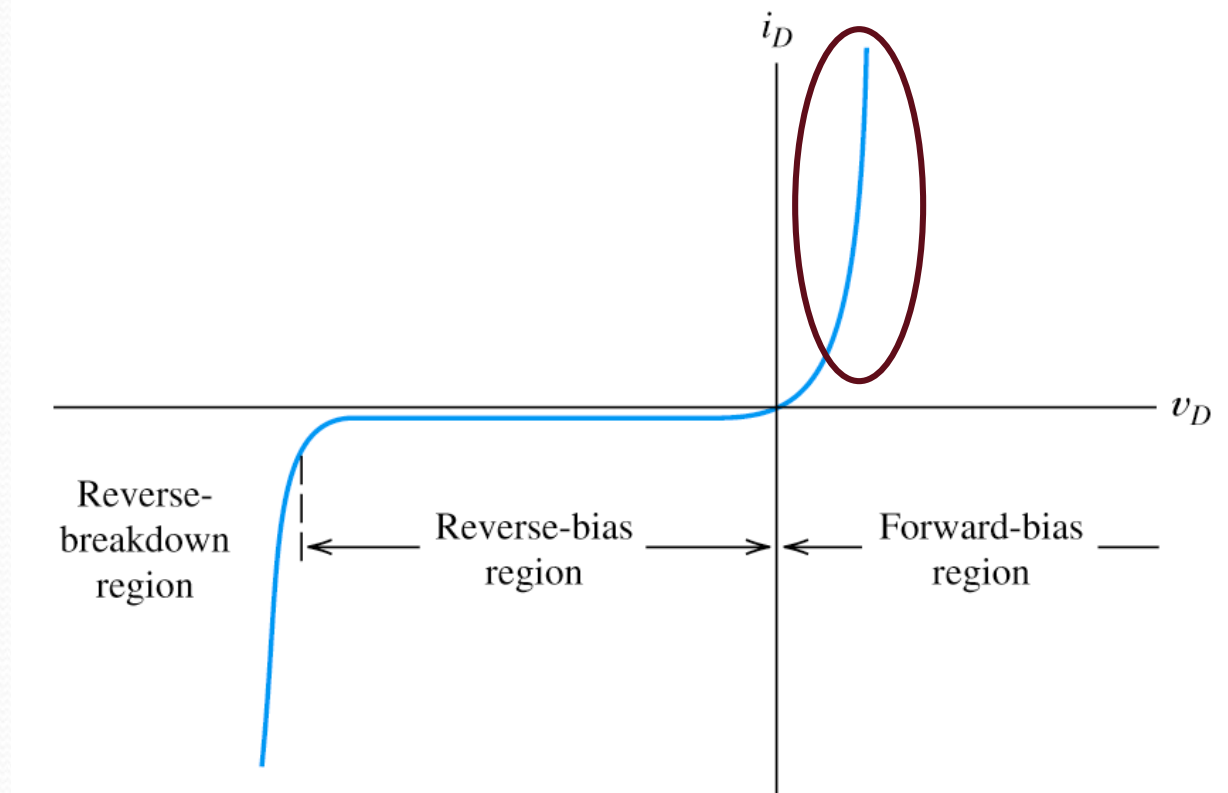
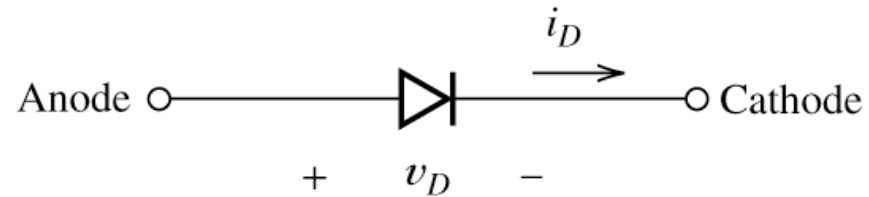
Biasing the PN-Junction

***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.

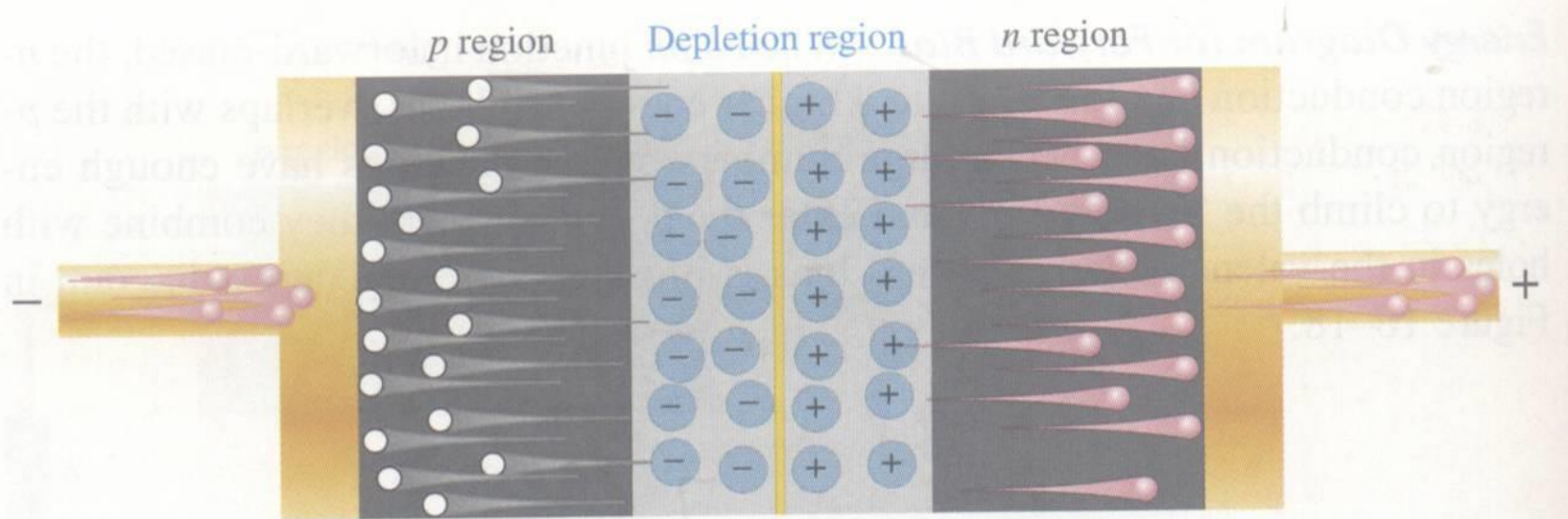


Biasing the PN-Junction

*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.*



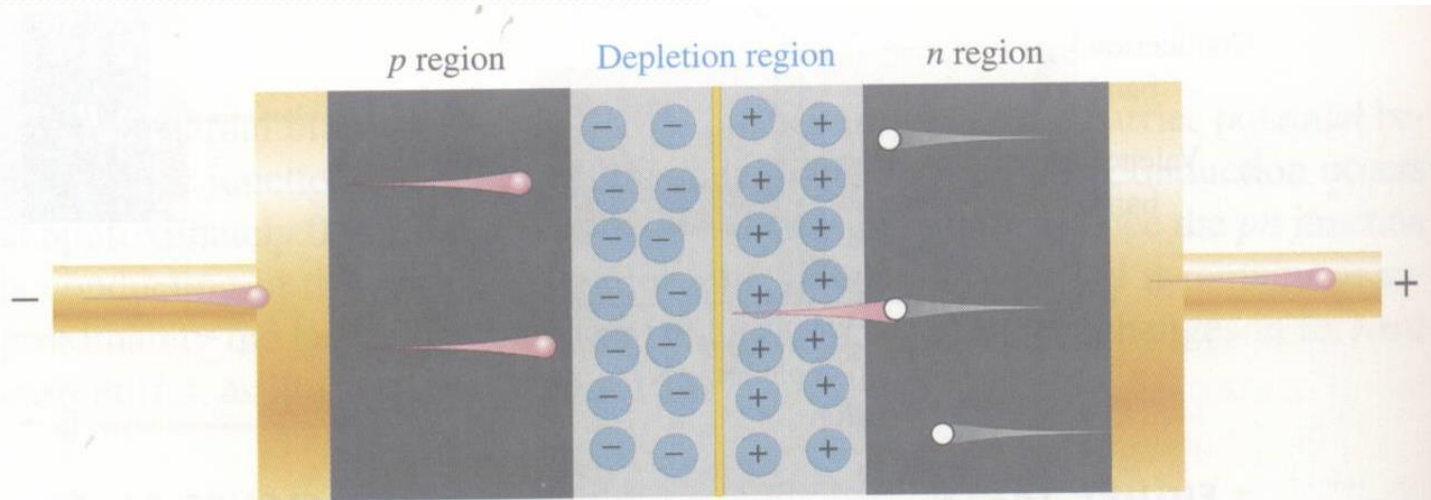
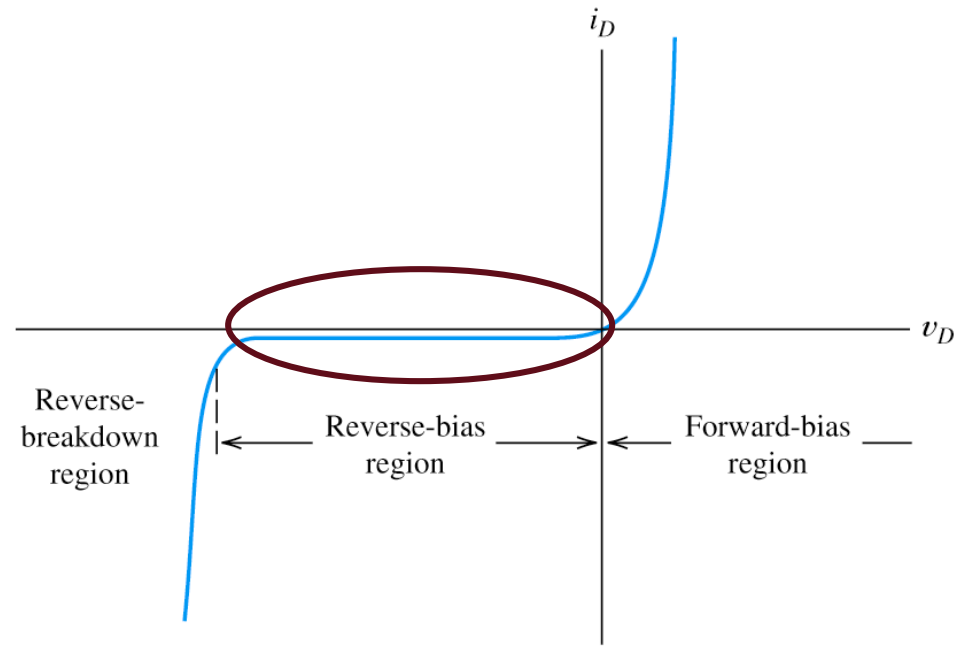
(a) There is transient current as depletion region widens.

2. Diodes – Basic Diode Concepts

* **Reverse Bias:**

majority-carrier current ceases.

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



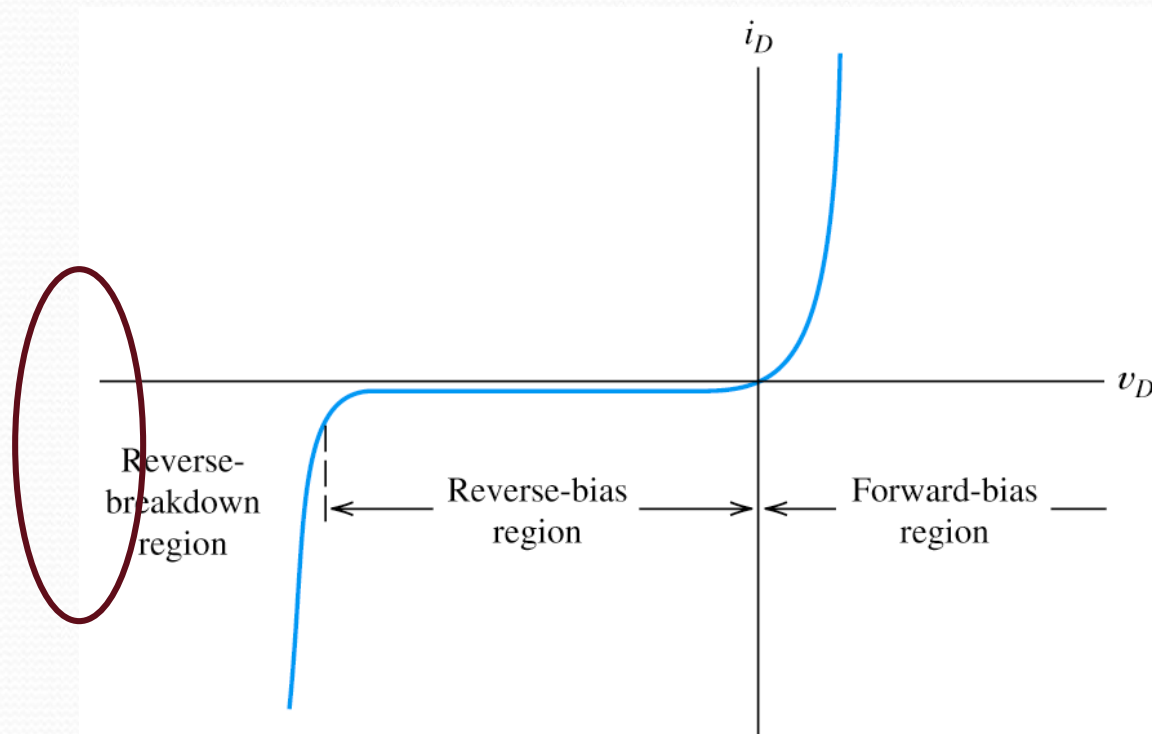
(b) Majority current ceases when barrier potential equals bias voltage. There is an extremely small reverse current due to minority carriers.

2. Diodes – Basic Diode Concepts

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:

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

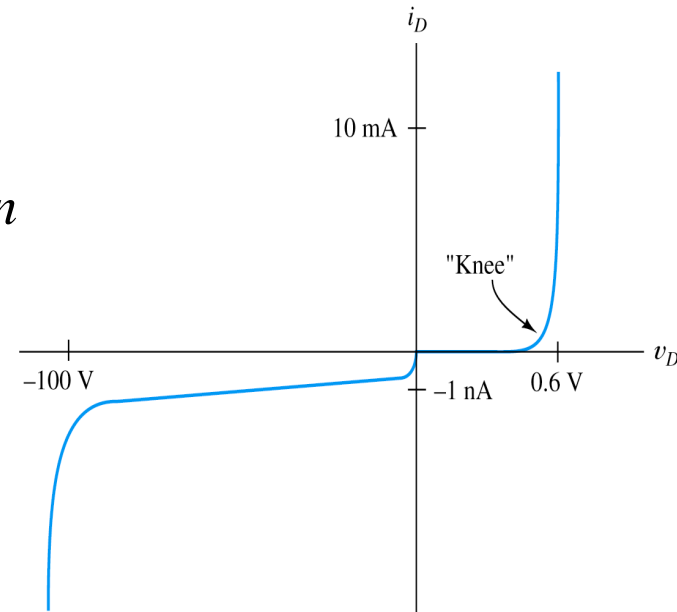
where $I_s \cong 10^{-14}$ A at 300K is the (reverse) saturation current, $n \cong 1$ to 2 is the emission coefficient,

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

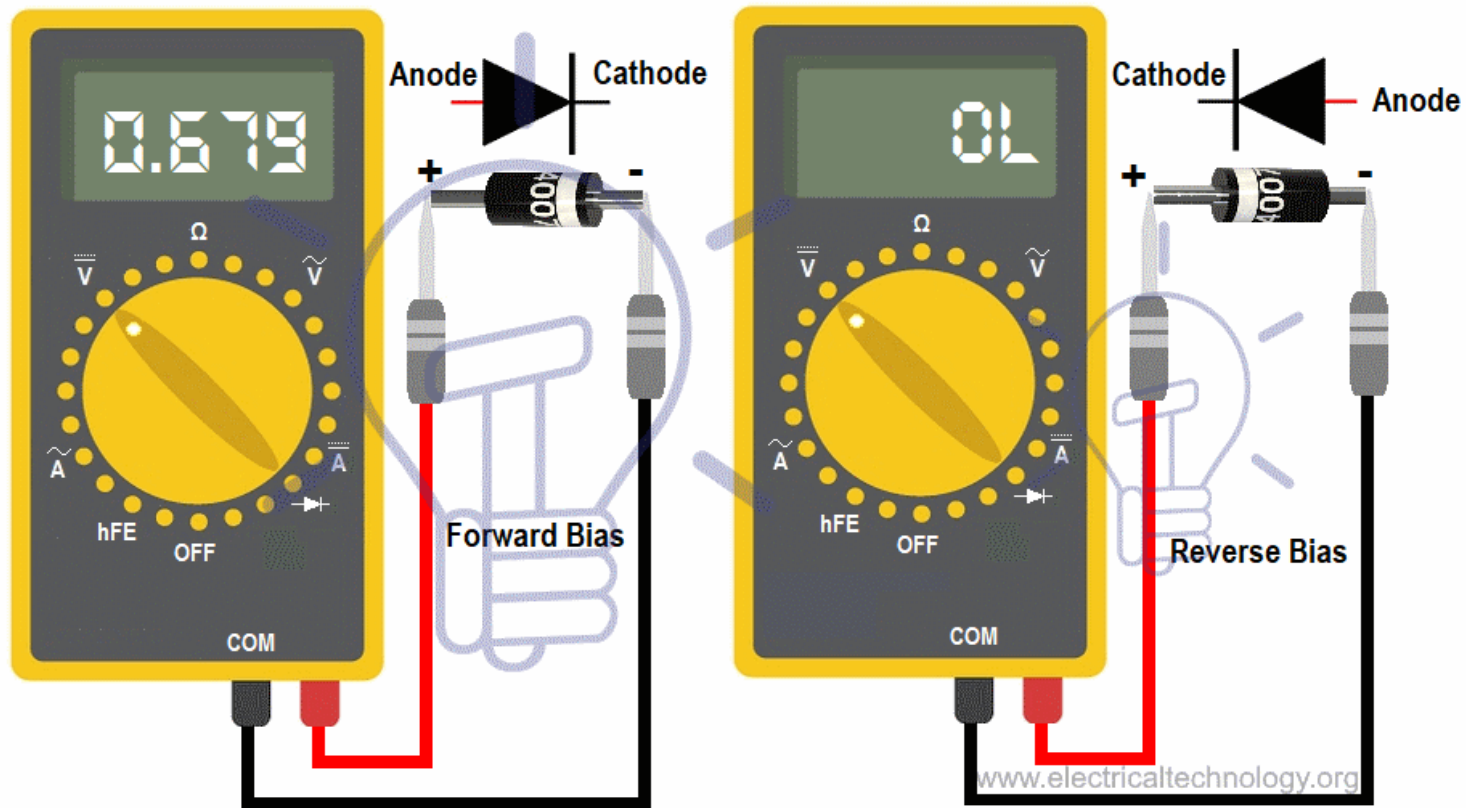
k is the Boltzman's constant, $q = 1.60 \times 10^{-19}$ C

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

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.

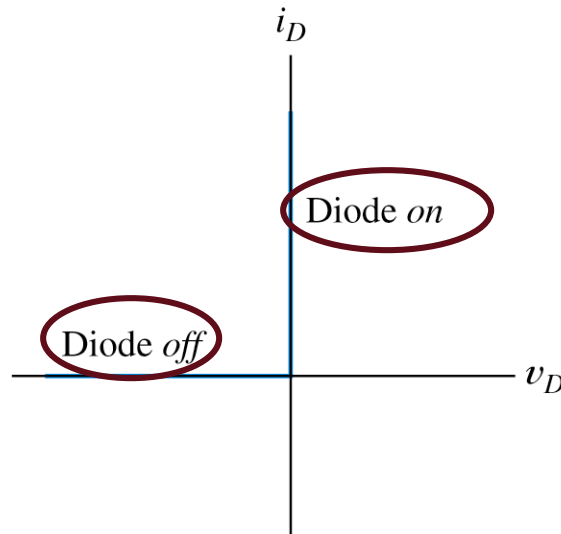


Figure 10.15 Ideal-diode volt-ampere characteristic.

2. Piecewise-Linear Diode Models

Modified Ideal-Diode Model

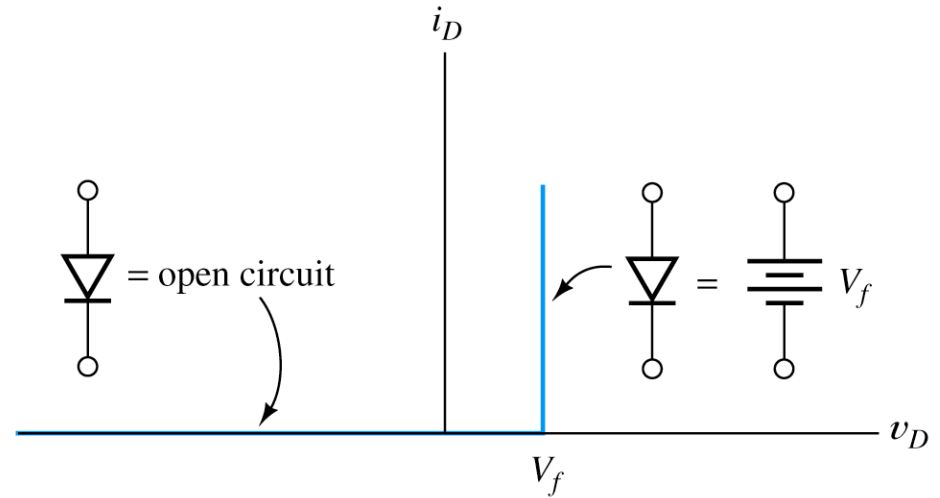
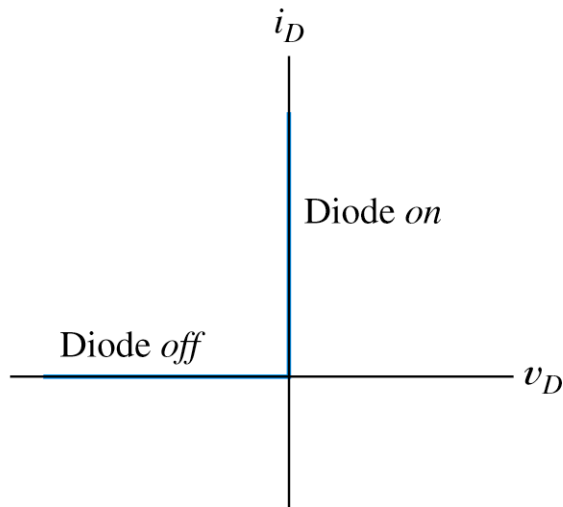


Figure 10.23 Simple piecewise-linear equivalent for the diode.

* 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

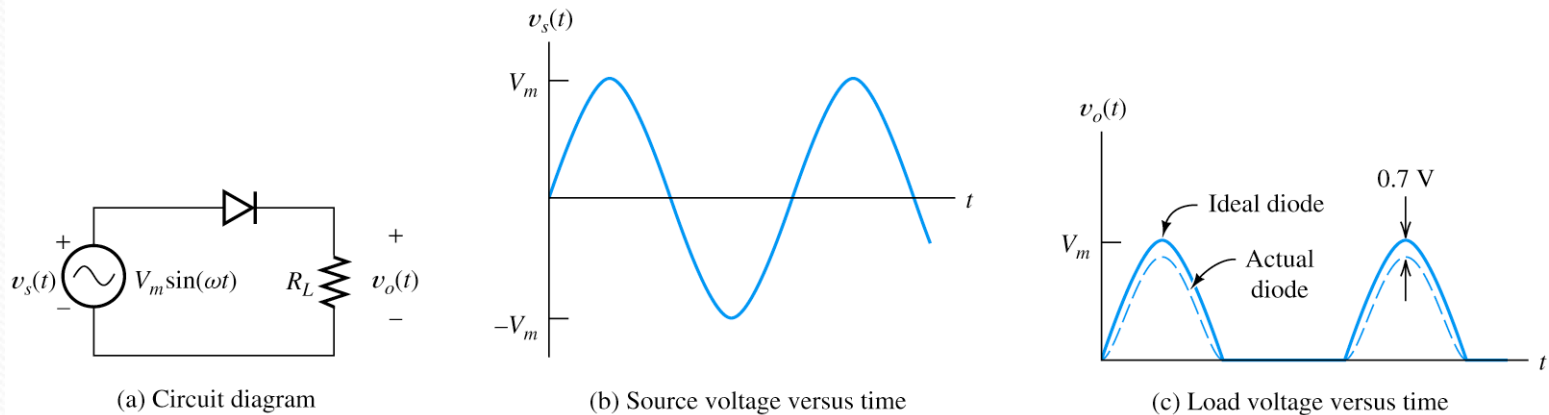
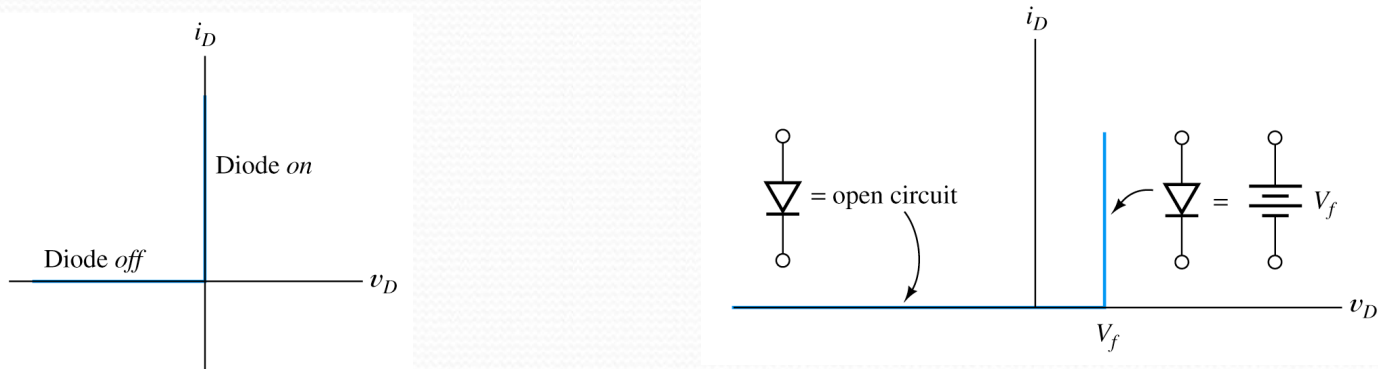
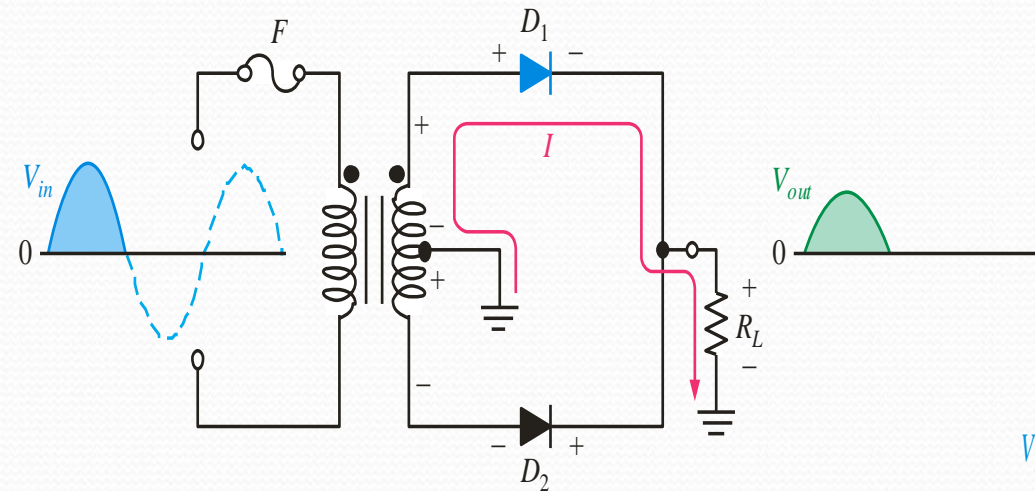


Figure 10.24 Half-wave rectifier with resistive load.



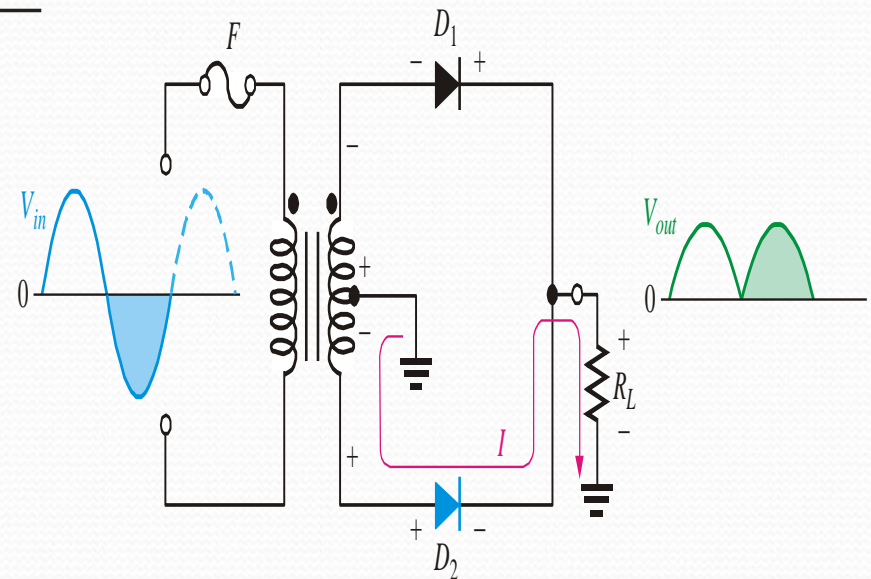
Center-Tapped Full wave rectifiers

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



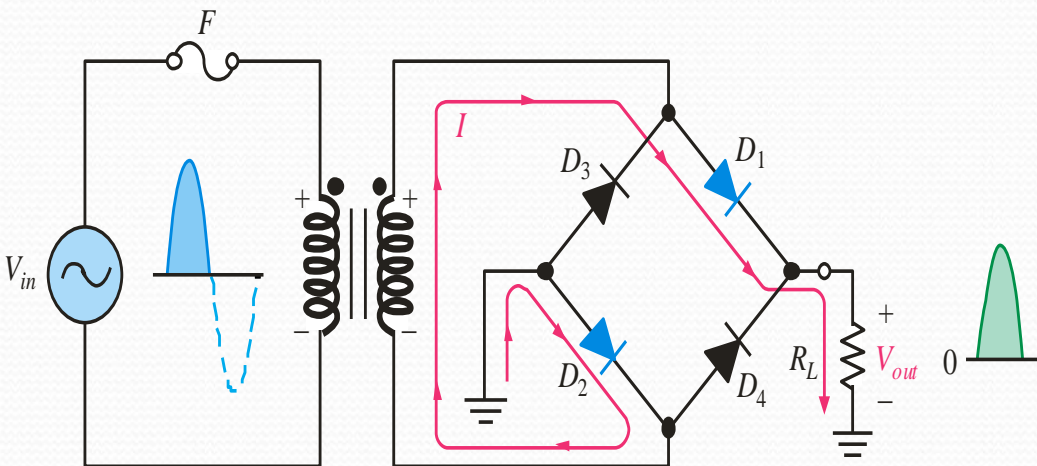
During the positive half-cycle, the upper diode is forward-biased and the lower diode is reverse-biased.

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



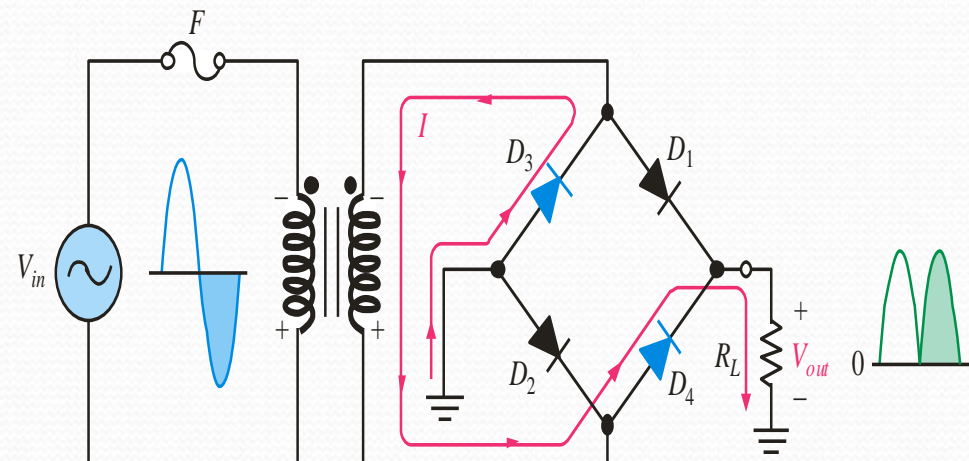
Bridge Full-wave rectifiers

- ❖ 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