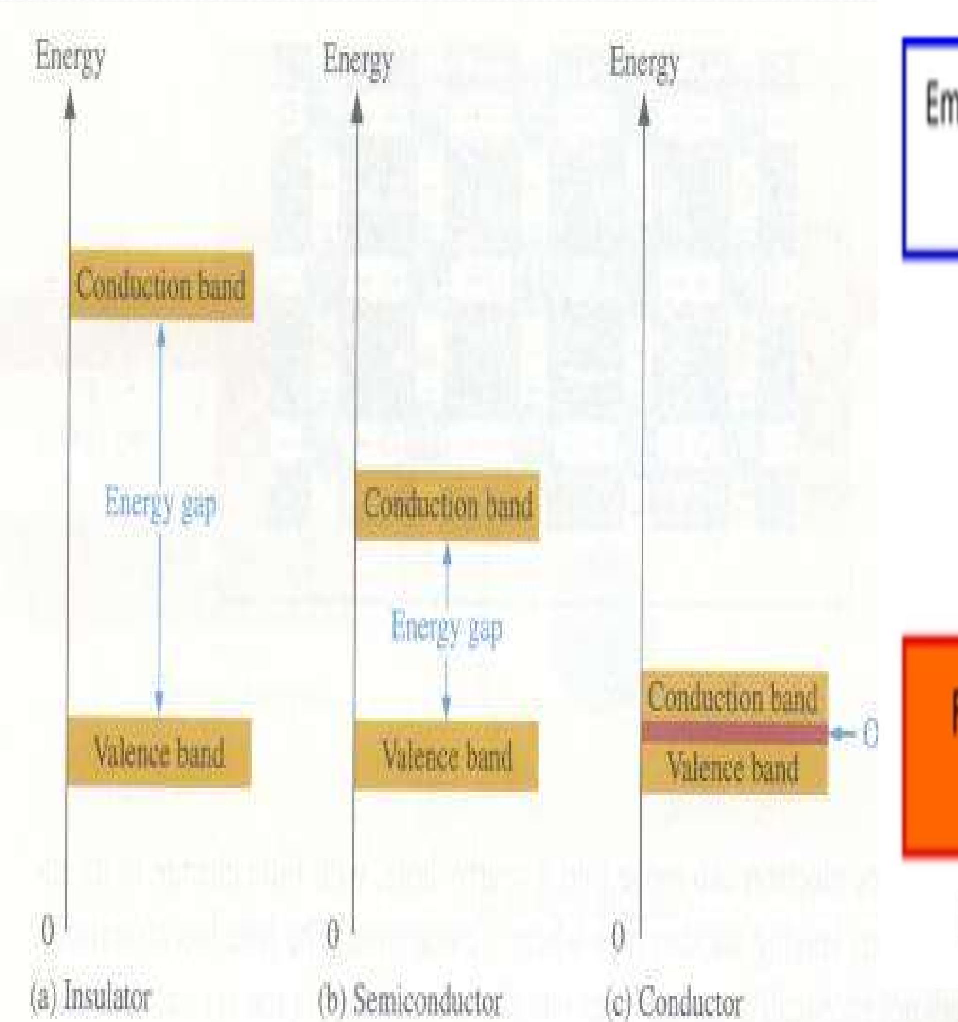
ECE249:
Unit-2

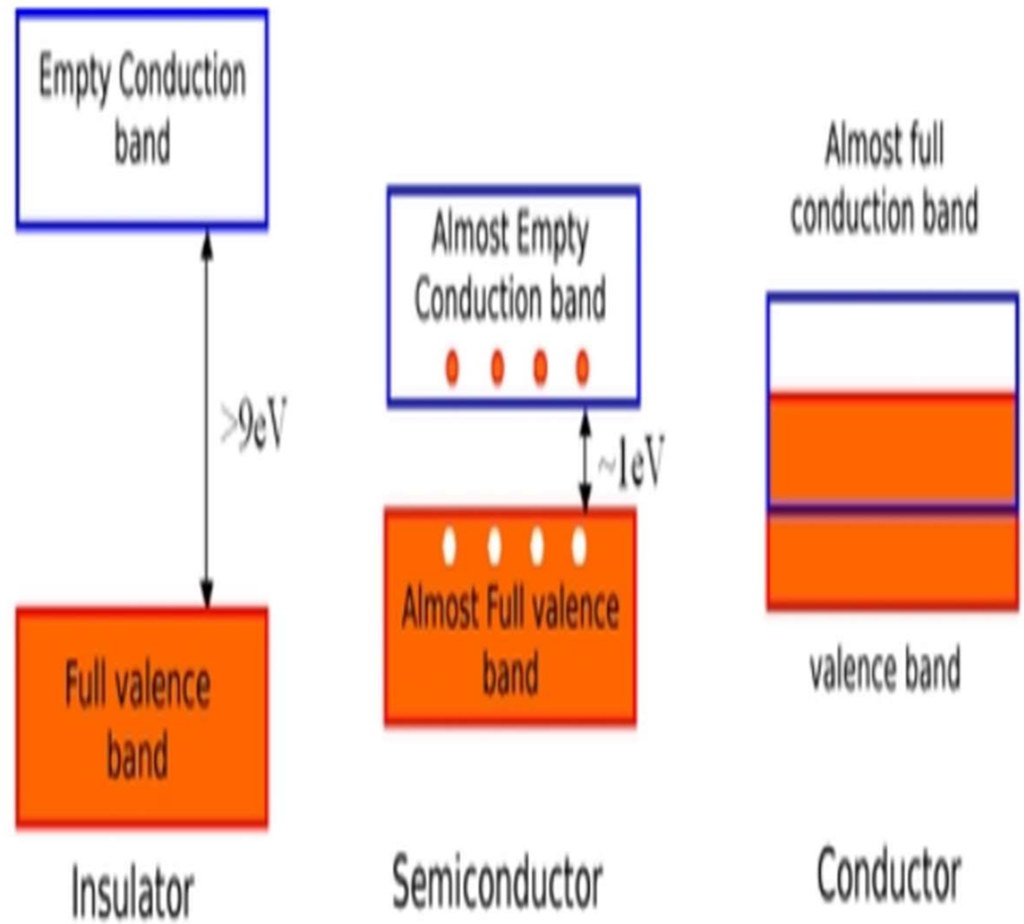
PN junction diode and its applications

Basic Diode Concepts

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

the energy diagram for the three types of solids





Intrinsic Semiconductors

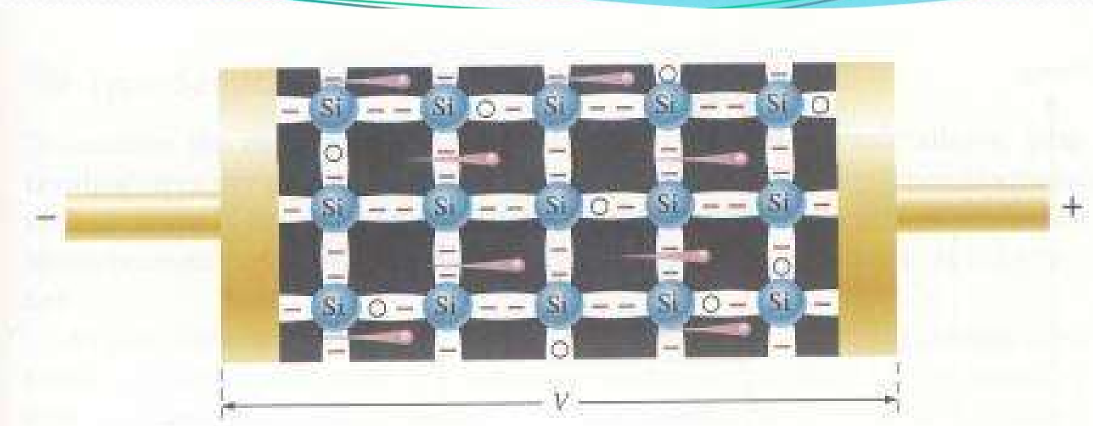
- Intrinsic (pure) *Si* Semiconductor:
- An intrinsic semiconductor is a pure semiconductor material like silicon (Si) or germanium (Ge) with no intentional impurities added.
- At absolute zero temperature (0 Kelvin), intrinsic semiconductors behave as insulators because there is not enough thermal energy to free charge carriers. As the temperature increases, results in increased conductivity.
- The number of free electrons (electrons available for conduction) is equal to the number of holes (absences of electrons that act like positive charge carriers). **This equilibrium condition holds at a specific temperature, known as the intrinsic carrier concentration**.
- Intrinsic semiconductors have a characteristic energy band structure, with a valence band (completely filled with electrons) and a conduction band (partially filled with electrons). The energy gap between the valence and conduction bands is called the bandgap.

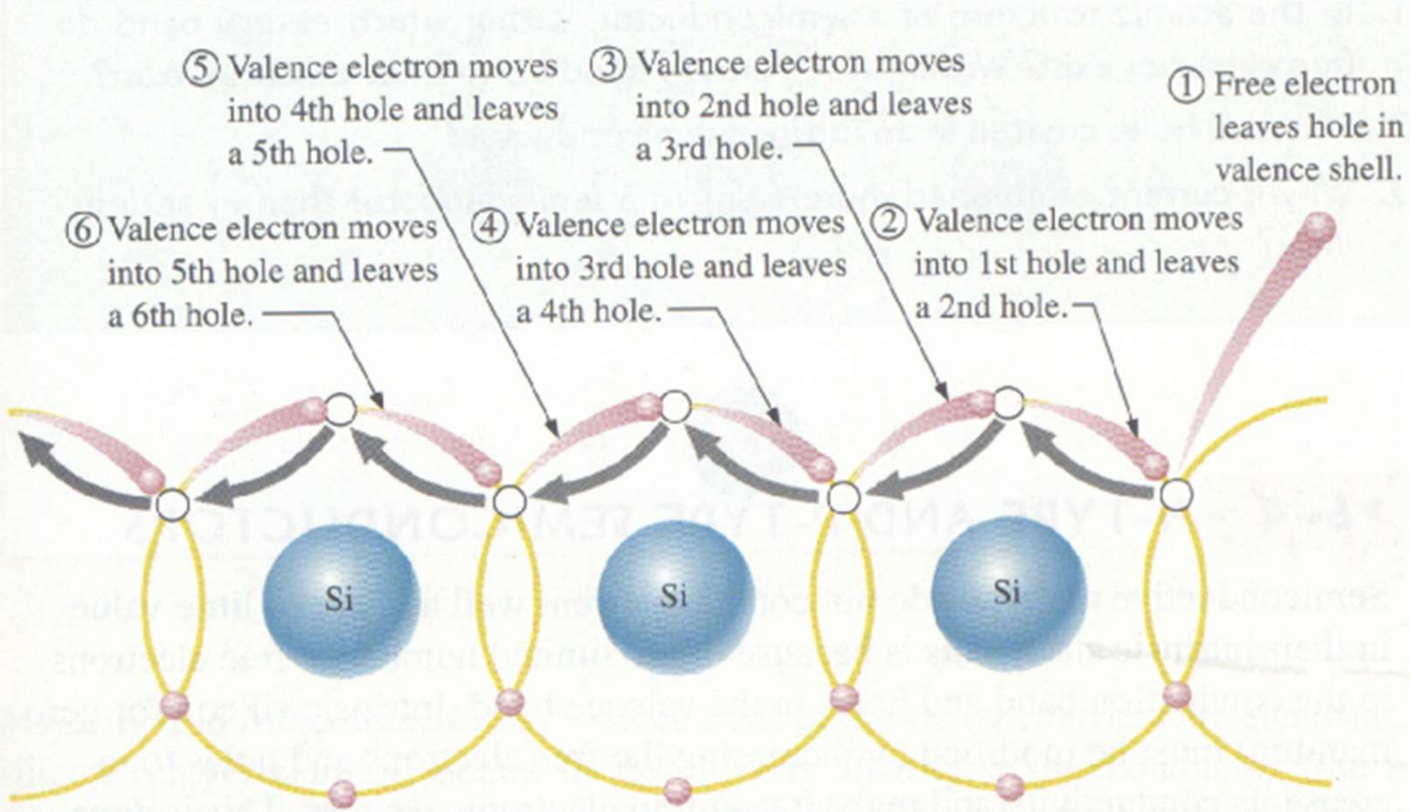
Intrinsic Semiconductors

*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.

- **Extrinsic Semiconductor:**
- An extrinsic semiconductor is a semiconductor material that has been intentionally doped with specific impurities to modify its electrical properties.
- Doping introduces additional charge carriers into the semiconductor, significantly affecting its conductivity. Extrinsic semiconductors are classified into two types based on the type of doping

N- and P- Type Semiconductors

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

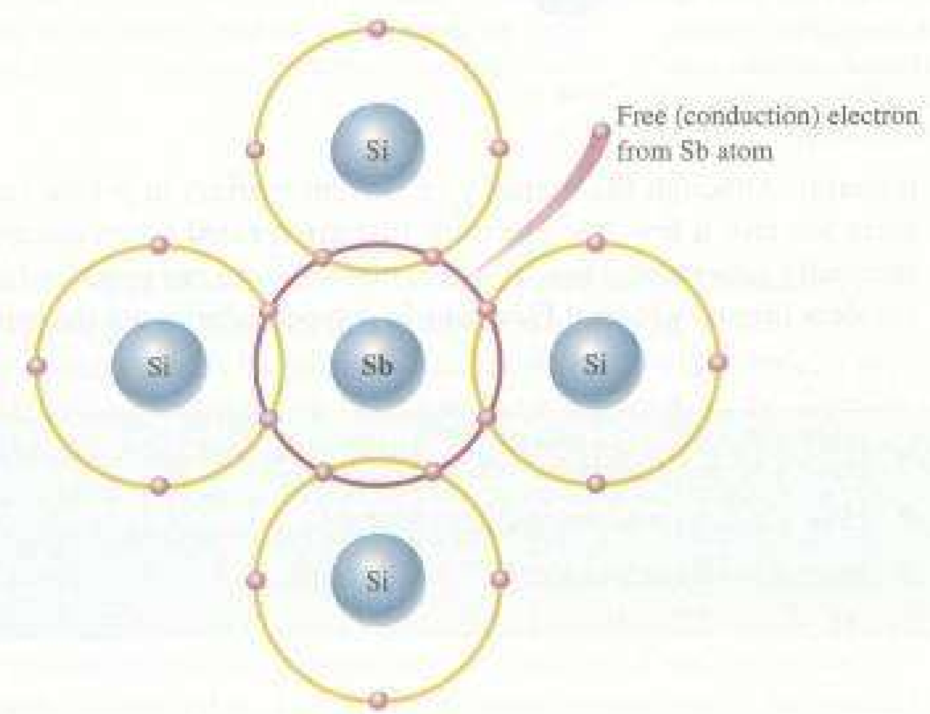
* *P-type*: adding Group III dopant (or acceptor) such as Al, B, Ga,…

- :

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 Phosphorus (P) and arsenic (As),...

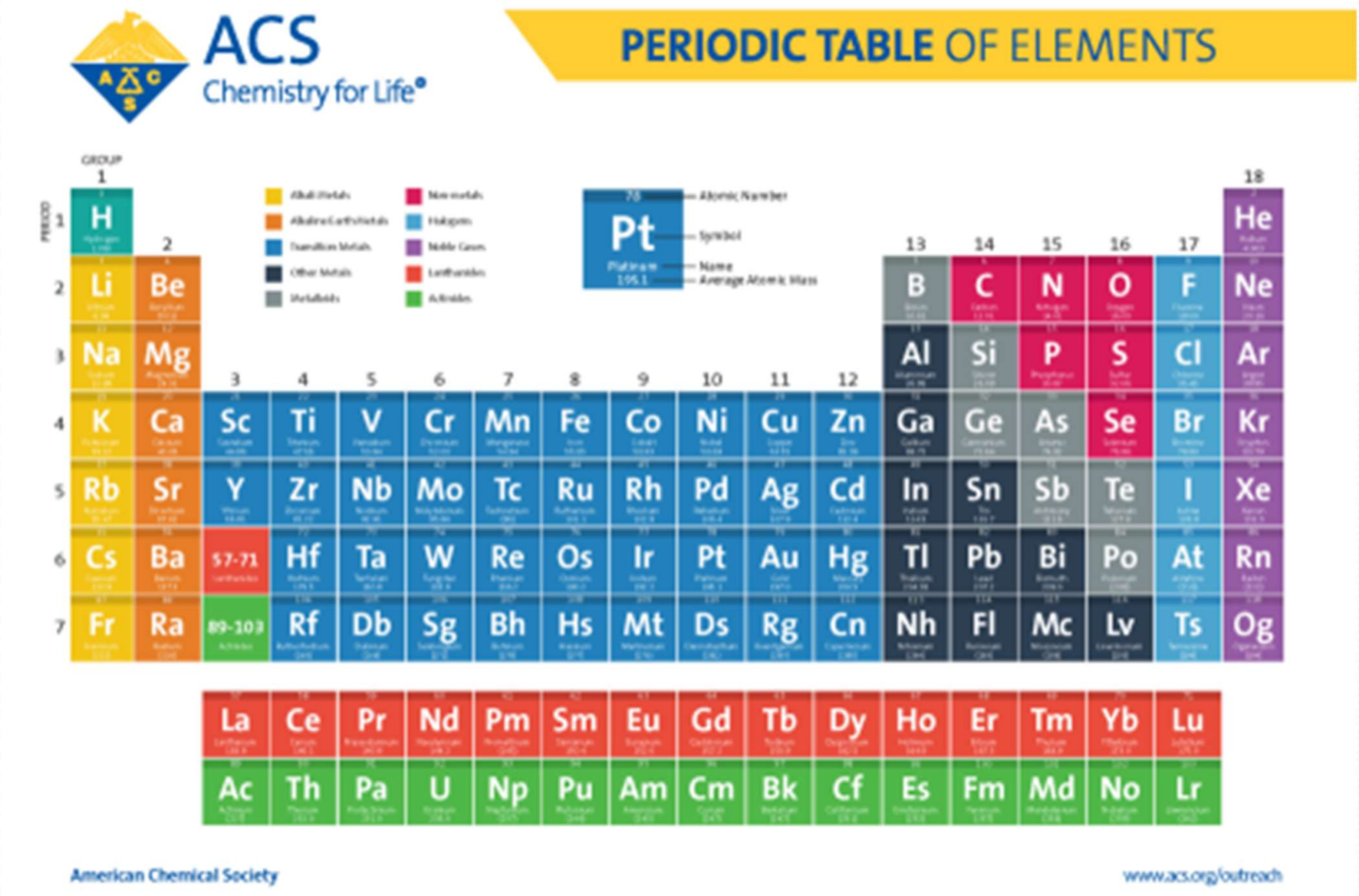


electron the major charge carrier

hole the minor cahage carrier

Impurities are **pentavalent and trivalent are in nature**

For silicon the threshold voltage is about 0.7V
For germanium it is about 0.3V


ACS
Chemistry for Life®
PERIODIC TABLE OF ELEMENTS
GROUP
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
1 H He
2 Li Be B C N O F Ne
3 Na Mg Al Si P S Cl Ar
4 K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
5 Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
6 Cs Ba 57-71 Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
7 Fr Ra 89-103 Rf Db Sg Bh Hs Mt Ds Rg Cn Nh Fl Mc Lv Ts Og
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr
Pt
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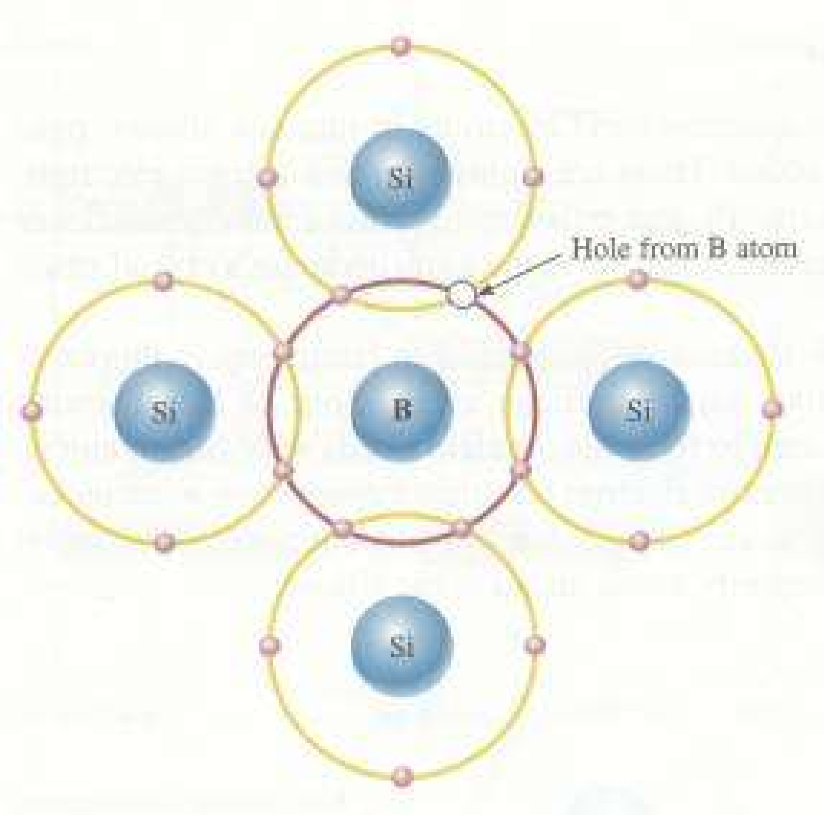
N- and P- Type Semiconductors

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



hole the major charge carrier

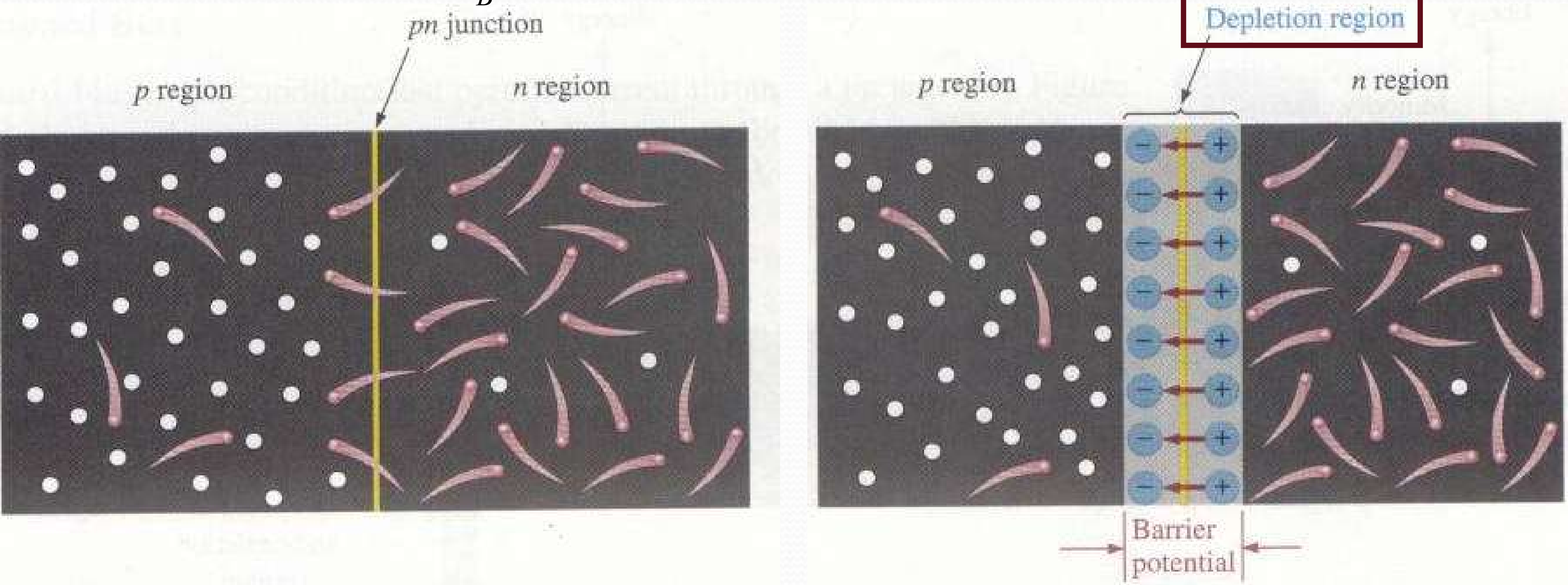
electron the minor cahage carrier

The PN-Junction

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

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

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



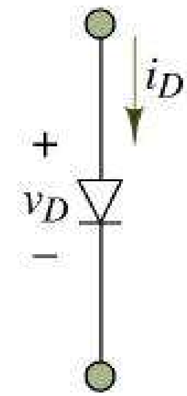
(a) At the instant of junction formation, free electrons in the *n* region near the *pn* junction begin to diffuse across the junction and fall into holes near the junction in the *p* region.

(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.

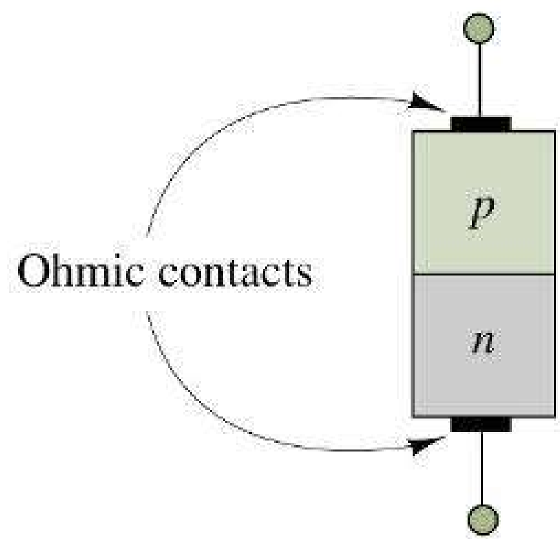
Biasing the PN-Junction

* 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.



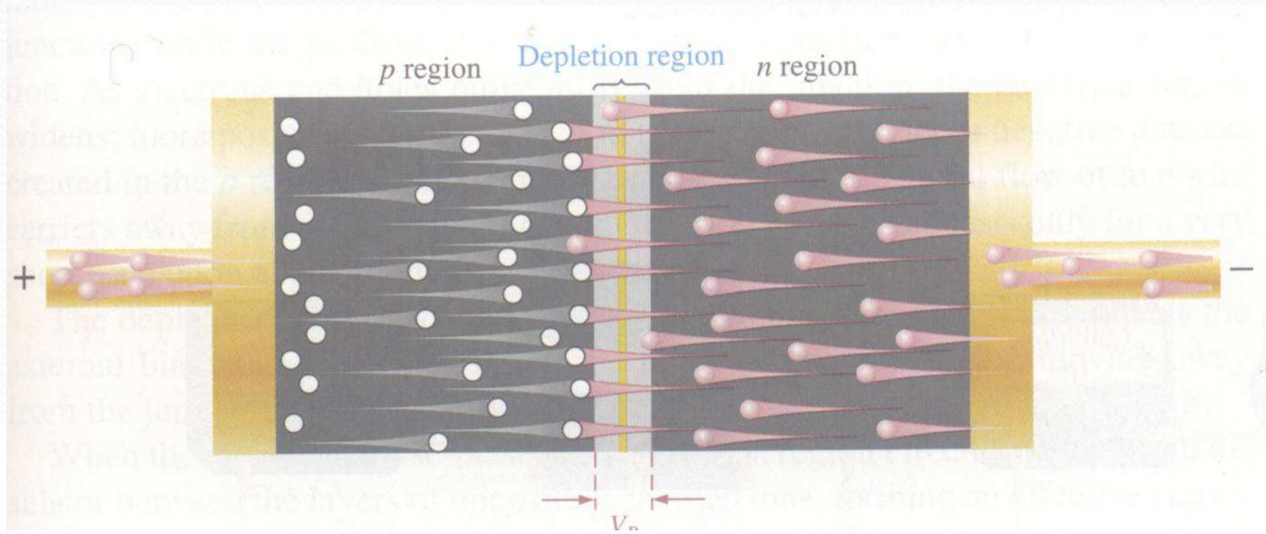
Circuit symbol

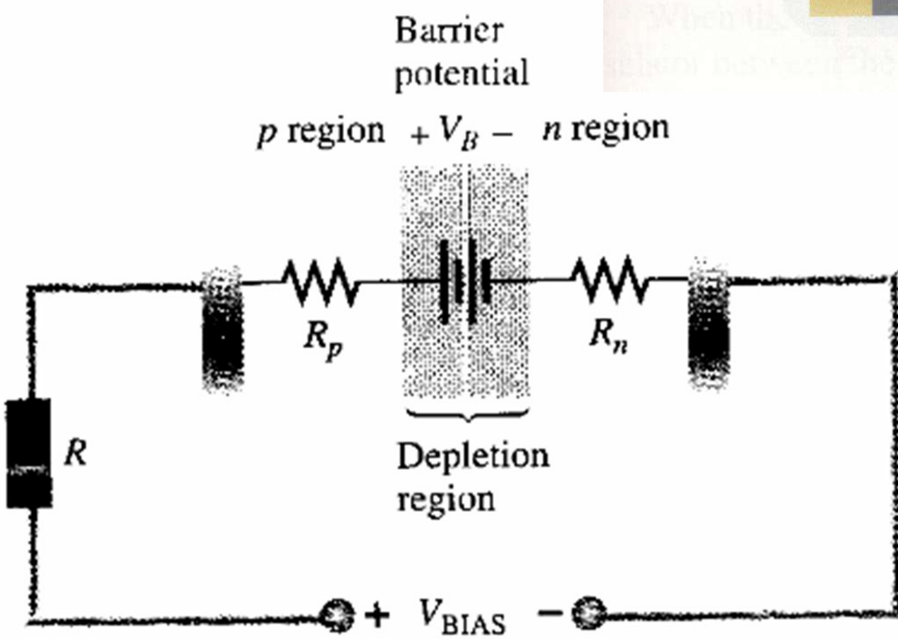


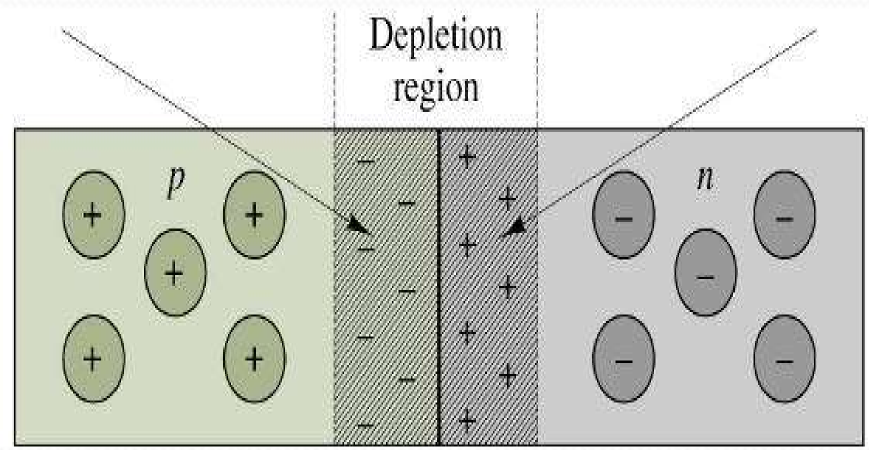
pn junction

Biasing the PN-Junction

***Forward Bias**: *DC voltage's 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.

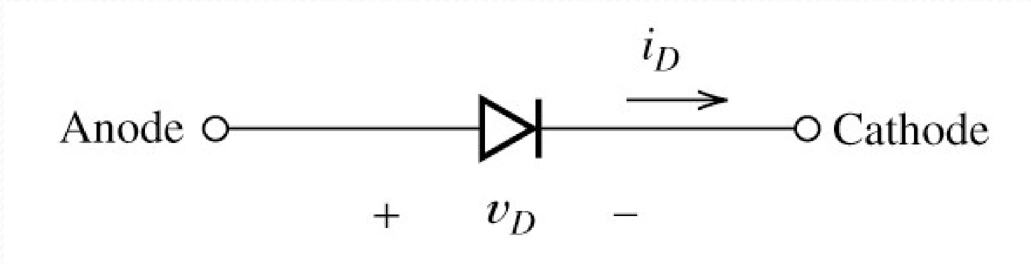


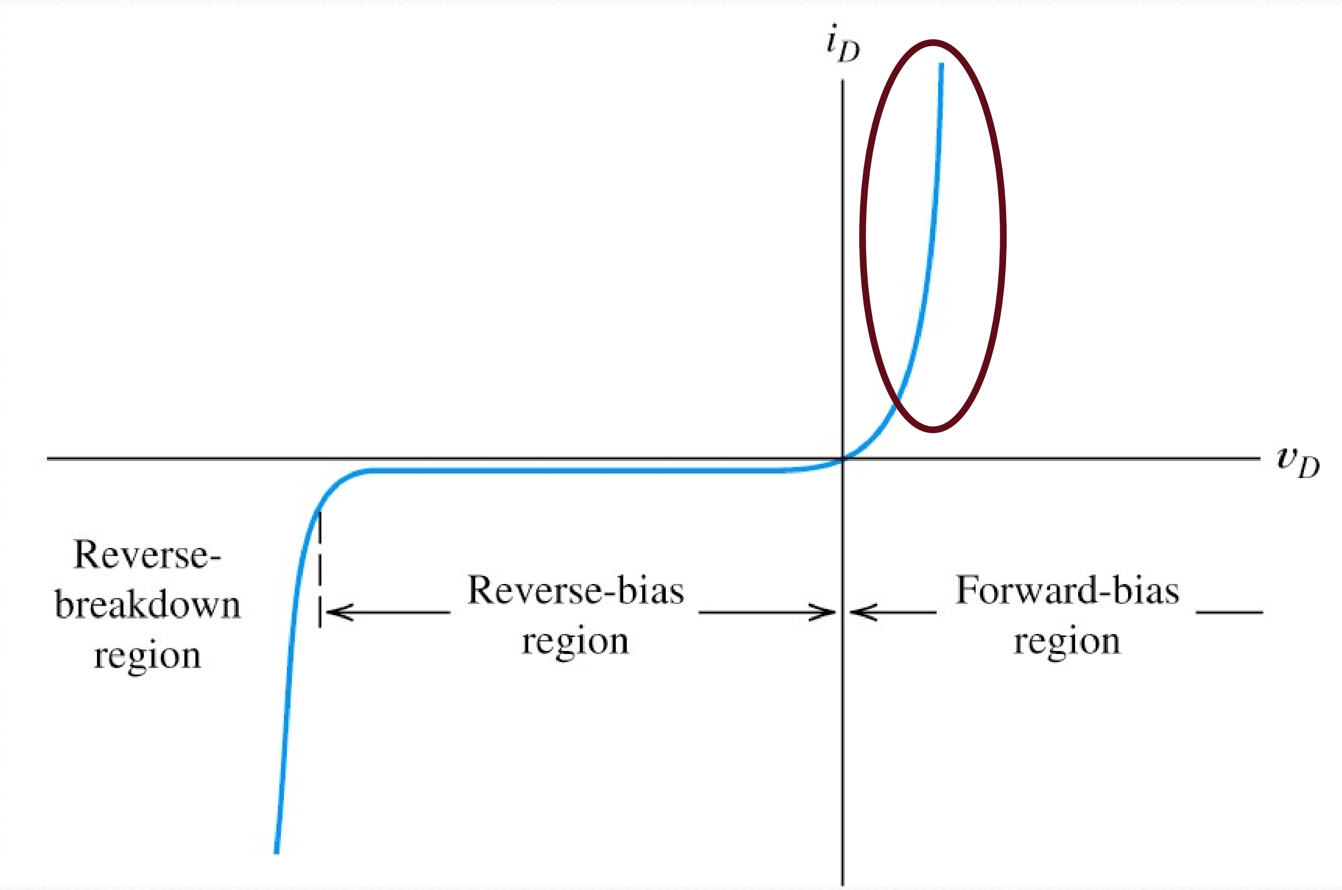




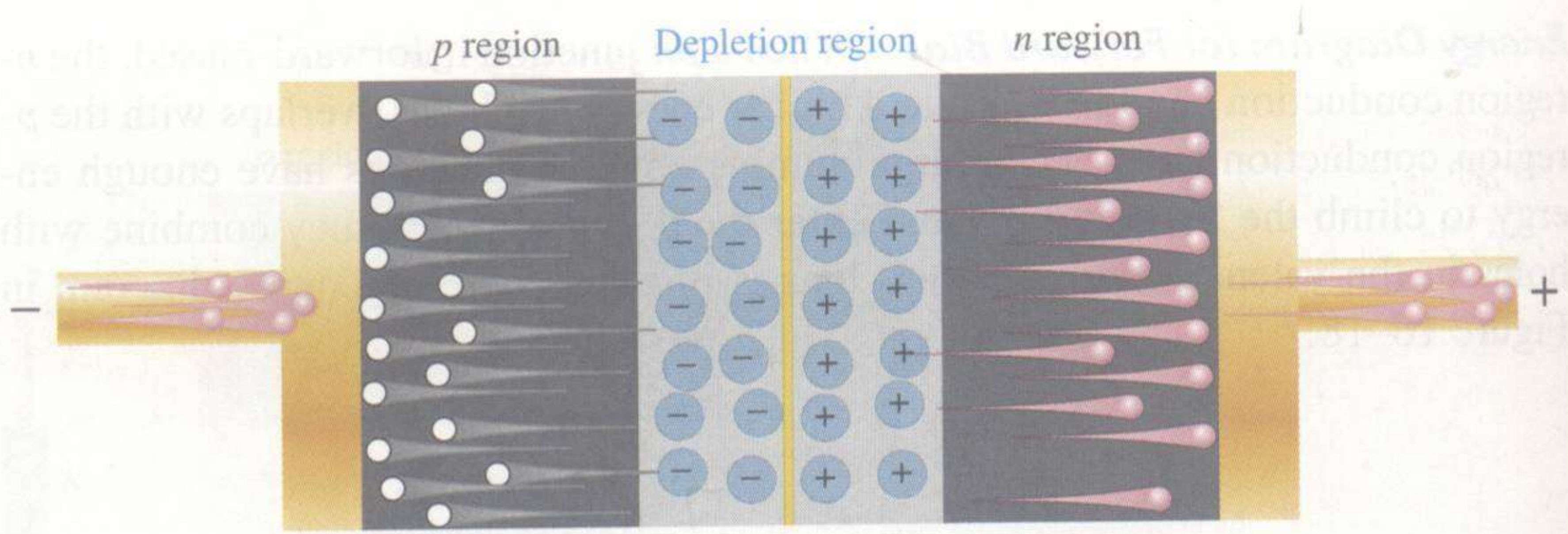
Biasing the PN-Junction

*****Forward Bias***:





****Reverse Bias***: *DC voltage's 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*.

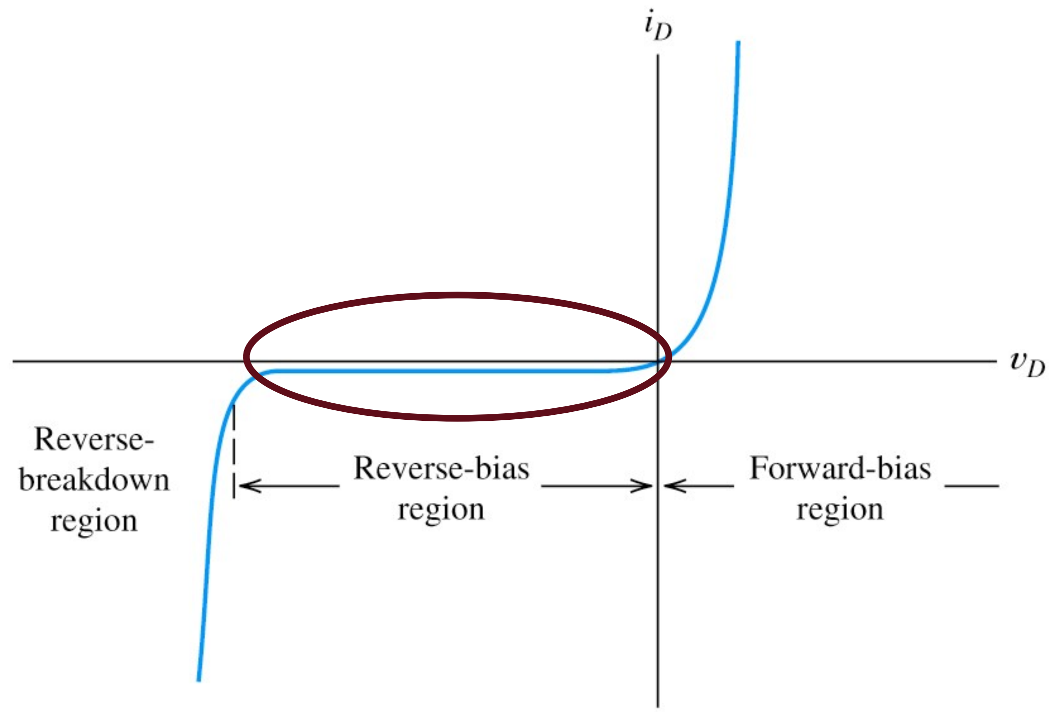


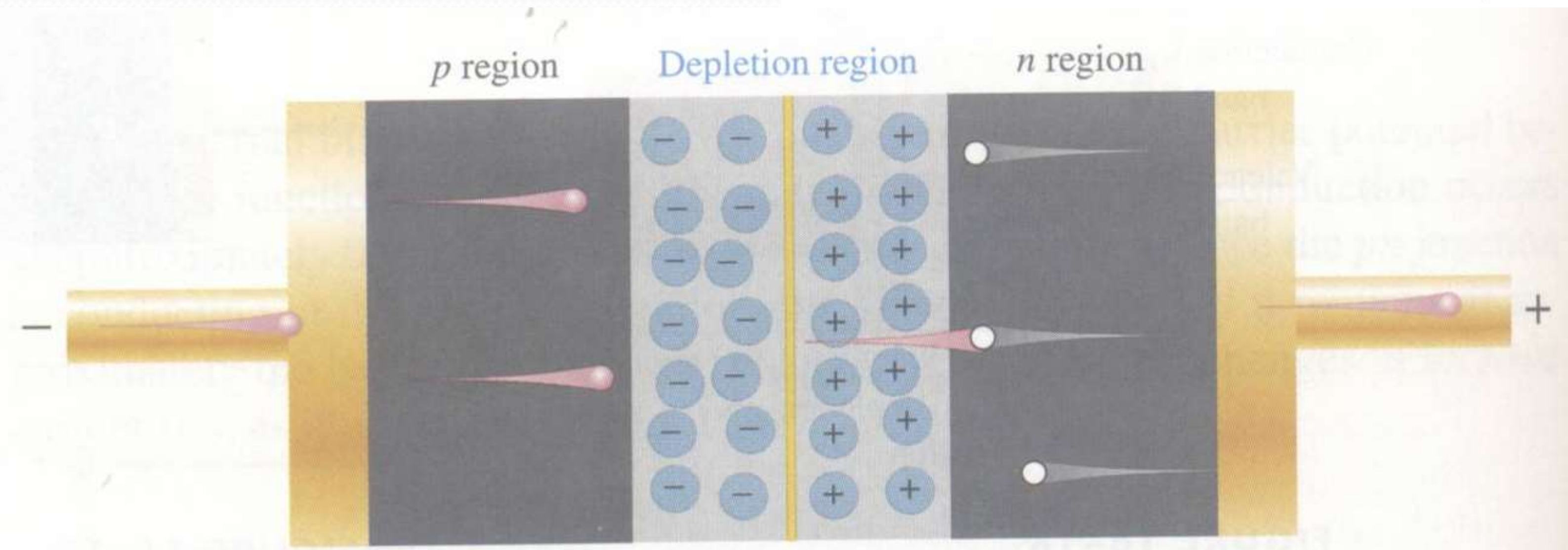
(a) There is transient current as depletion region widens.

*__*Reverse Bias*__:

majority-carrier current ceases.

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



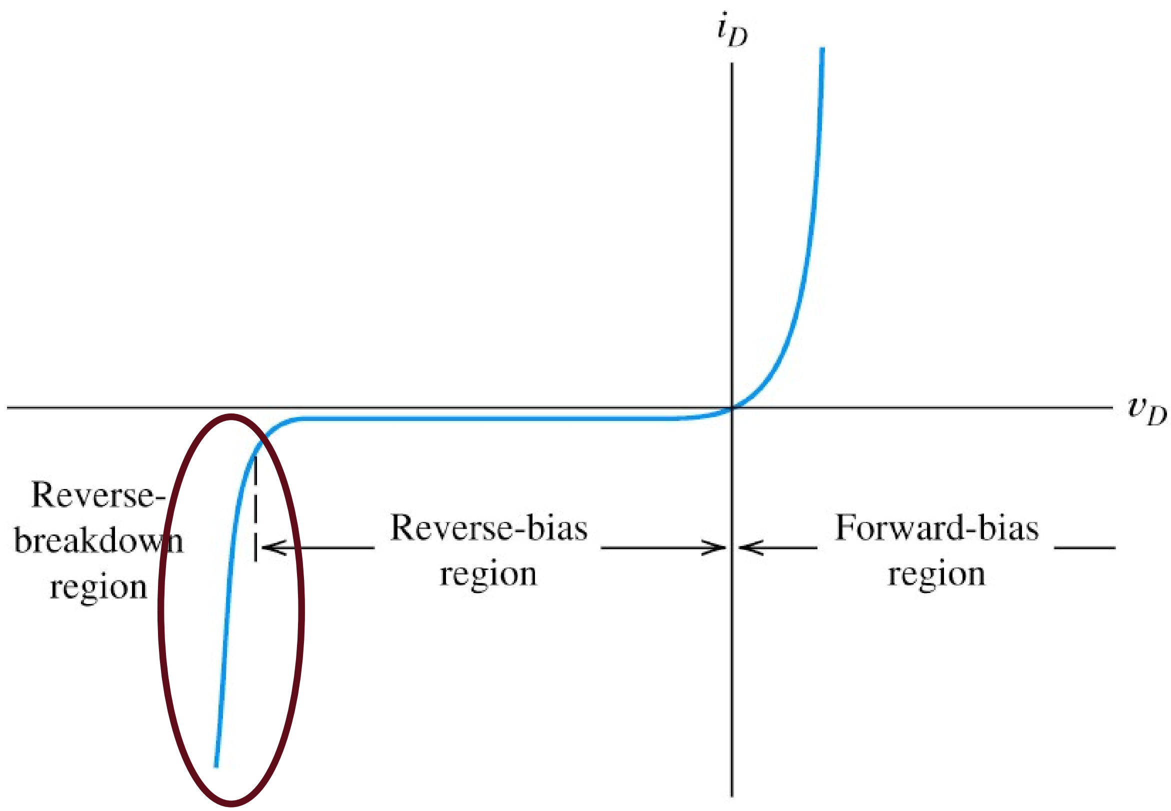


(b) Majority current ceases when barrier potential equals bias voltage. There is an extremely small reverse current due to minority carriers.

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:

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

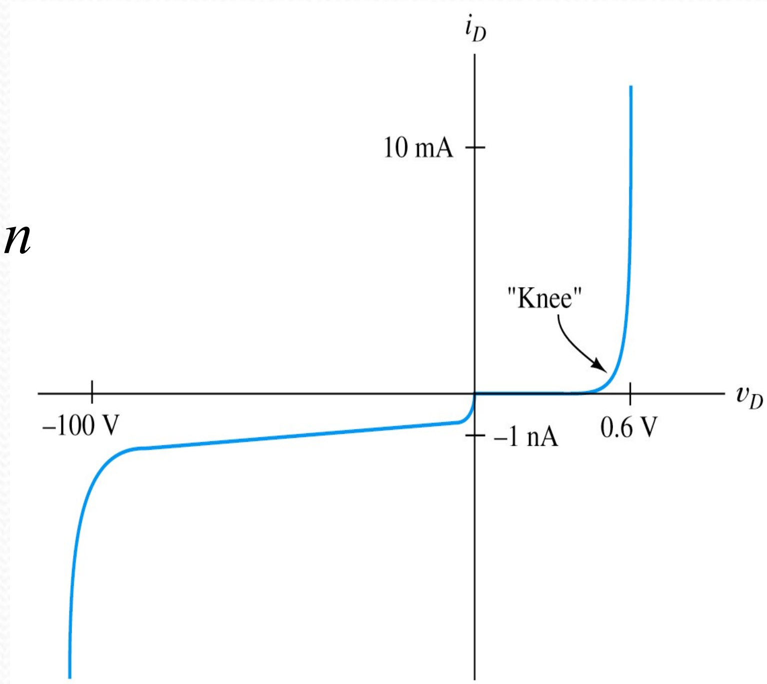
where $I_s \cong 10^{-14}$ A at 300K is the (reverse) saturation current, $n \cong 1$ to 2 is the emission coefficient,

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

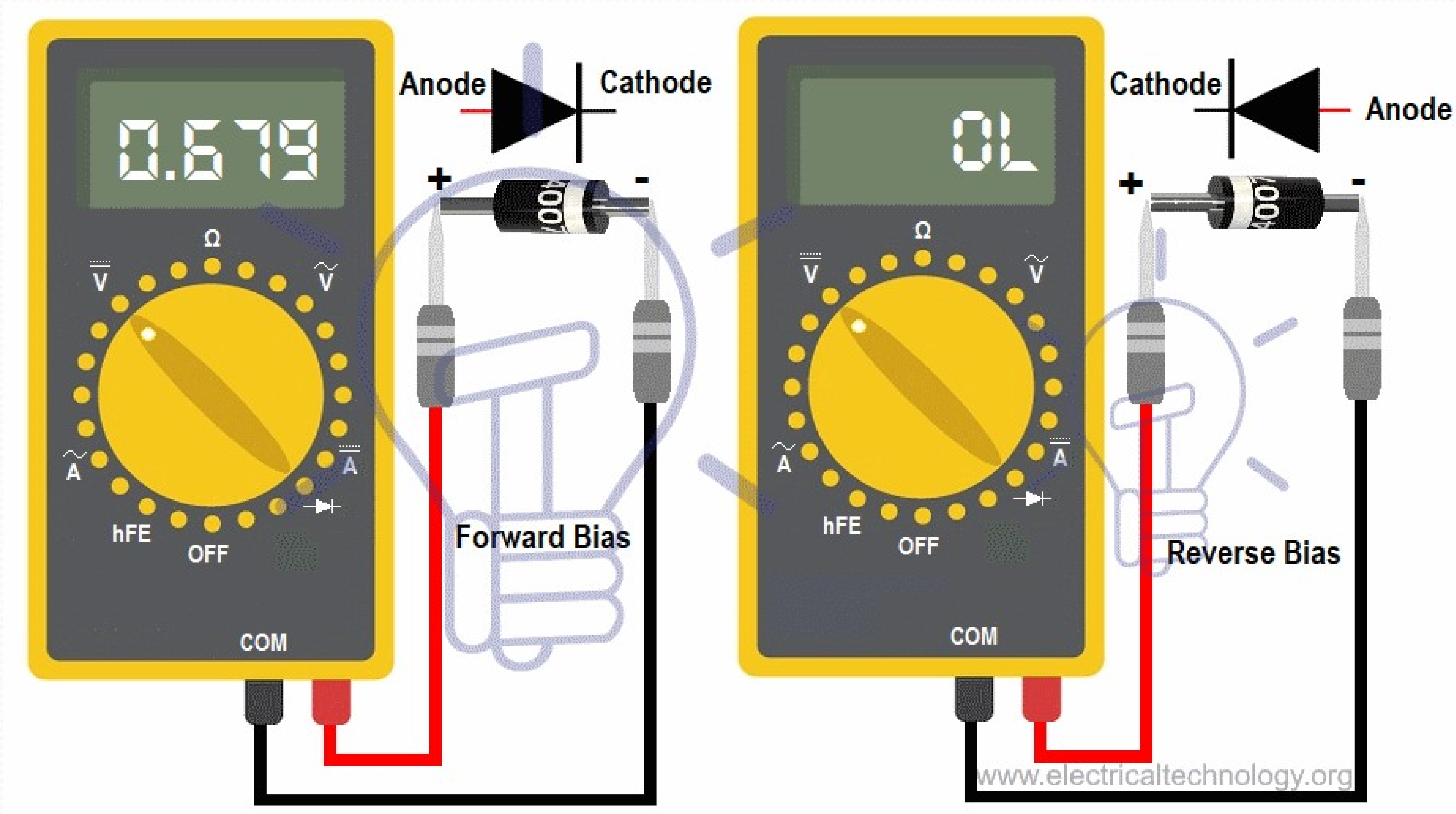
k is the Boltzman's constant, $q = 1.60 \times 10^{-19}$ C

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

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.

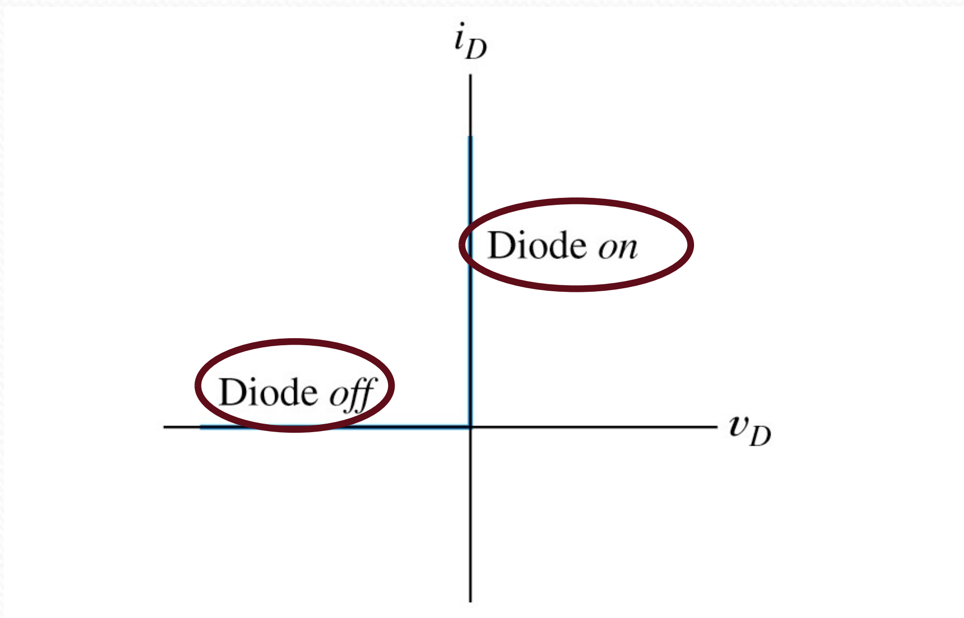
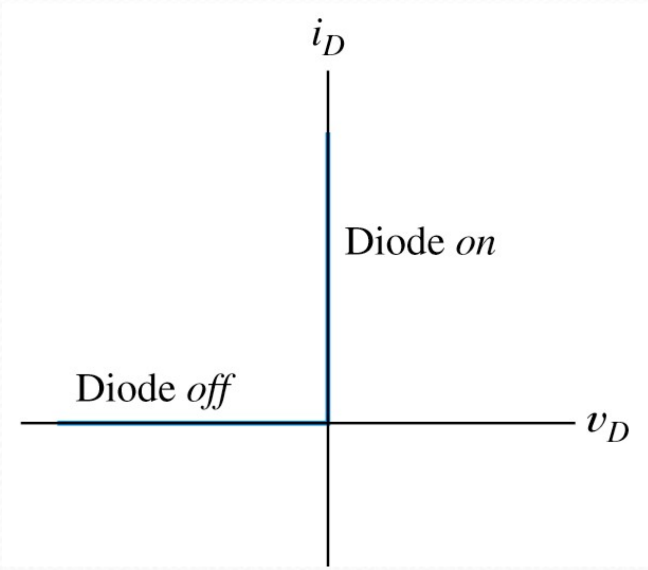


Figure 10.15 Ideal-diode volt–ampere characteristic.

2. *Piecewise-Linear Diode Models*

Modified Ideal-Diode Model



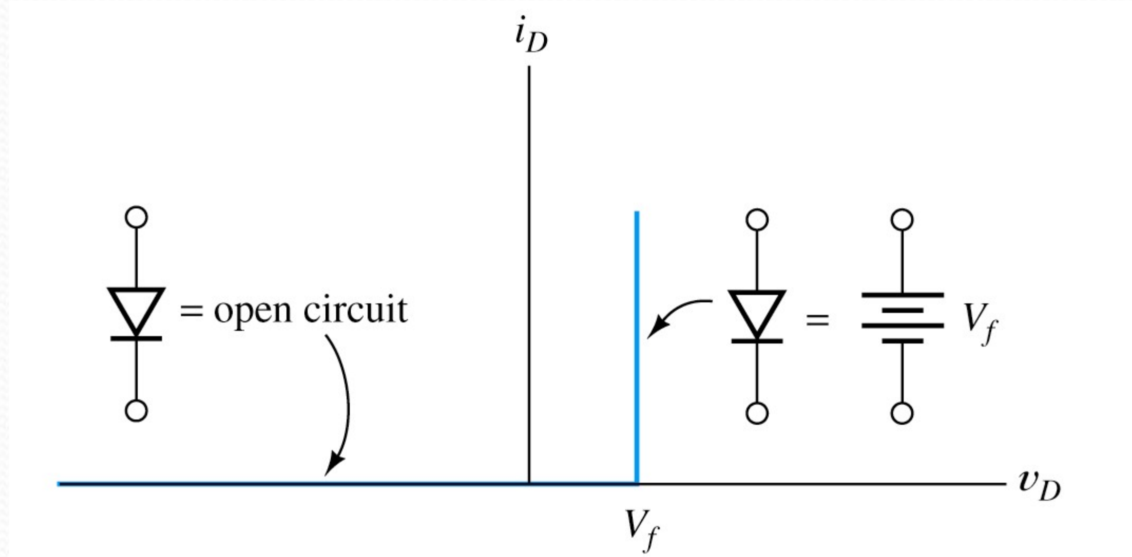


Figure 10.23 Simple piecewise-linear equivalent for the diode.

* 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

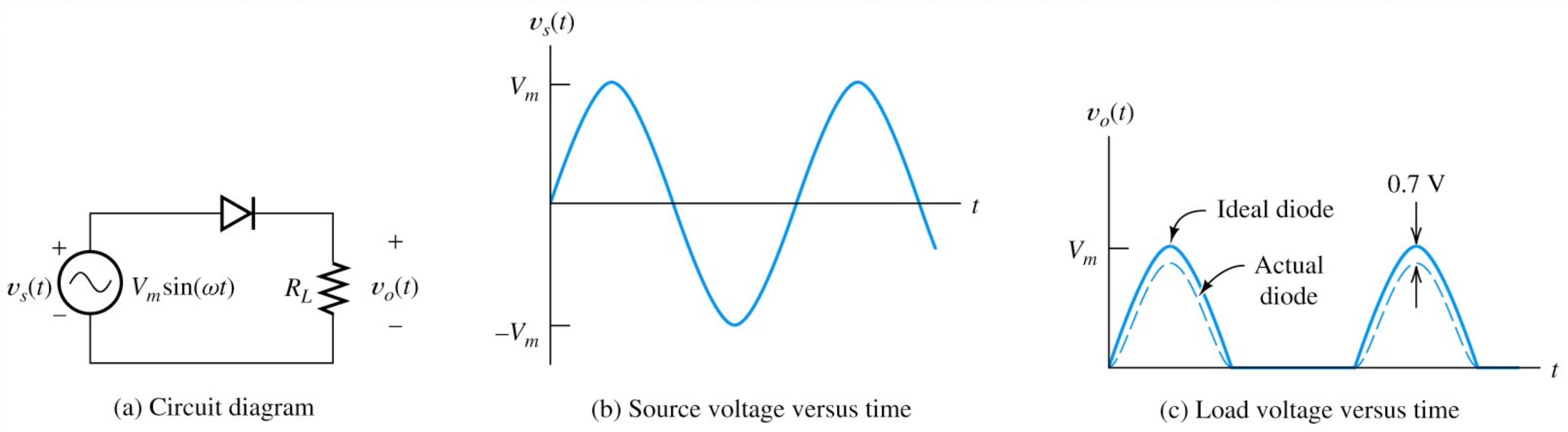
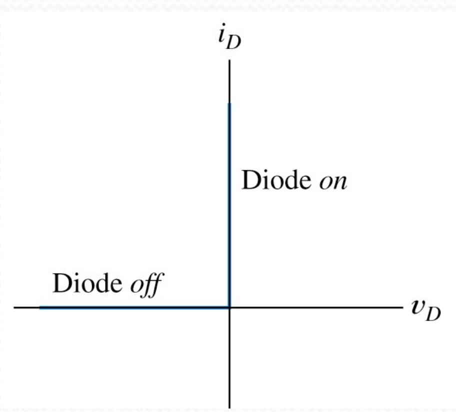
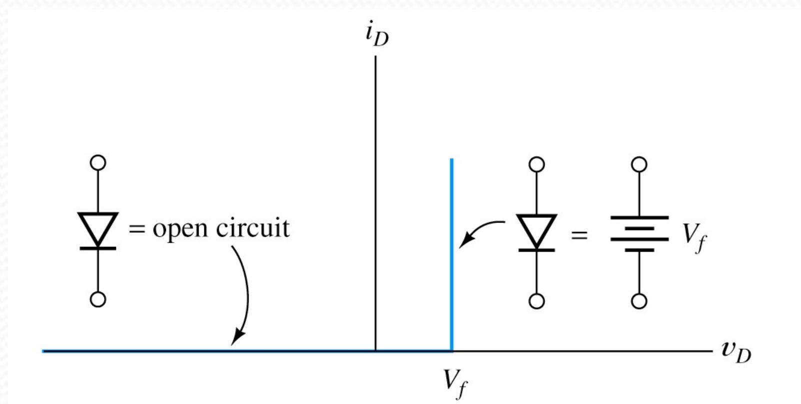


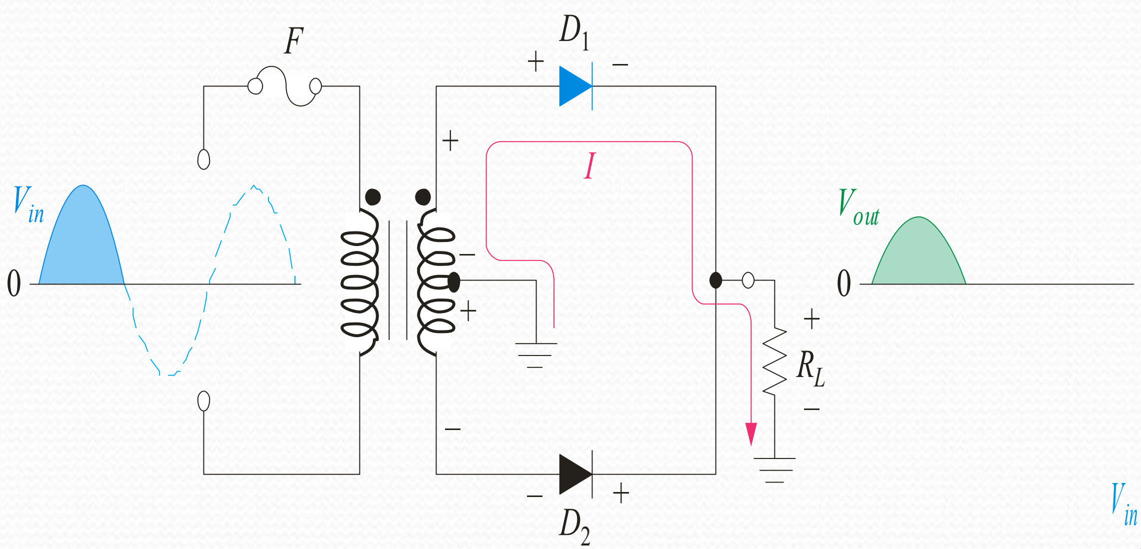
Figure 10.24 Half-wave rectifier with resistive load.





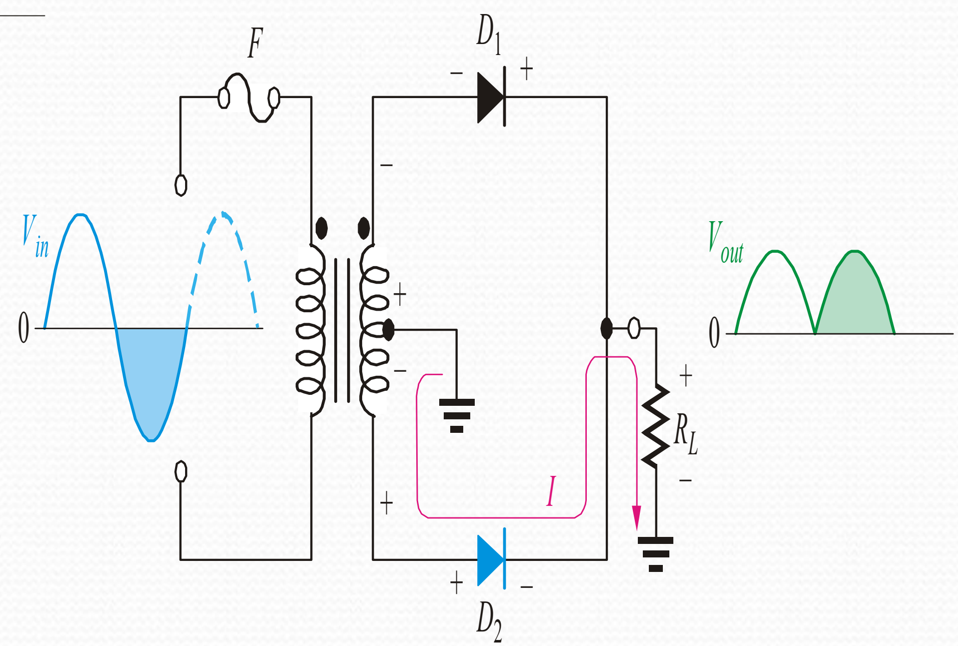
Center-Tapped Full wave rectifiers

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



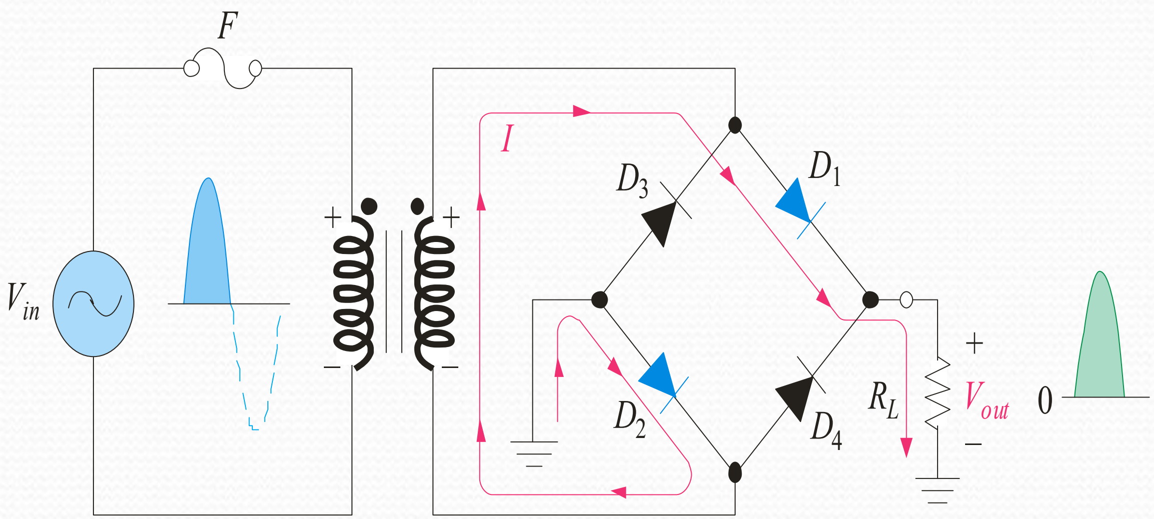
During the positive half-cycle, the upper diode is forward-biased and the lower diode is reverse-biased.

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



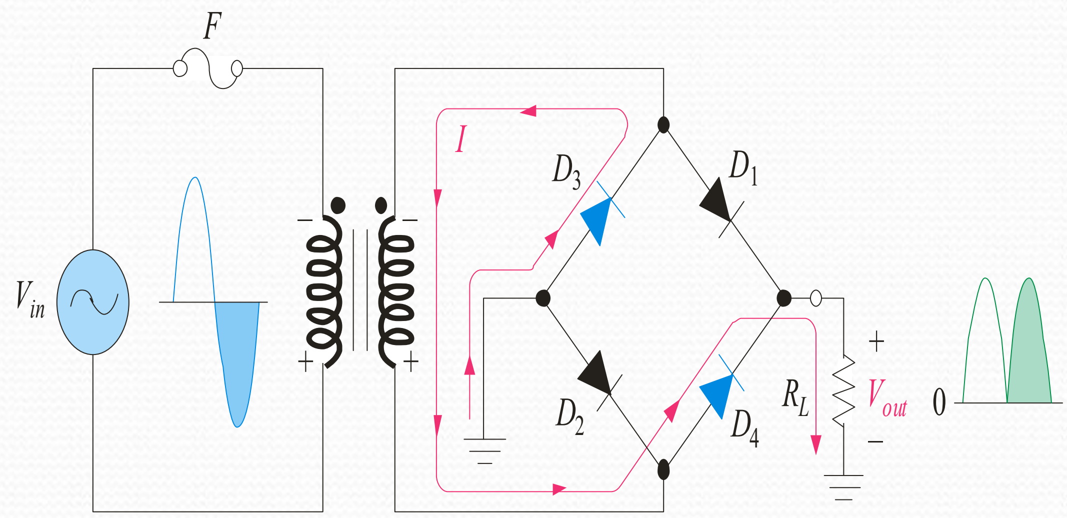
Bridge Full-wave rectifiers

- 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