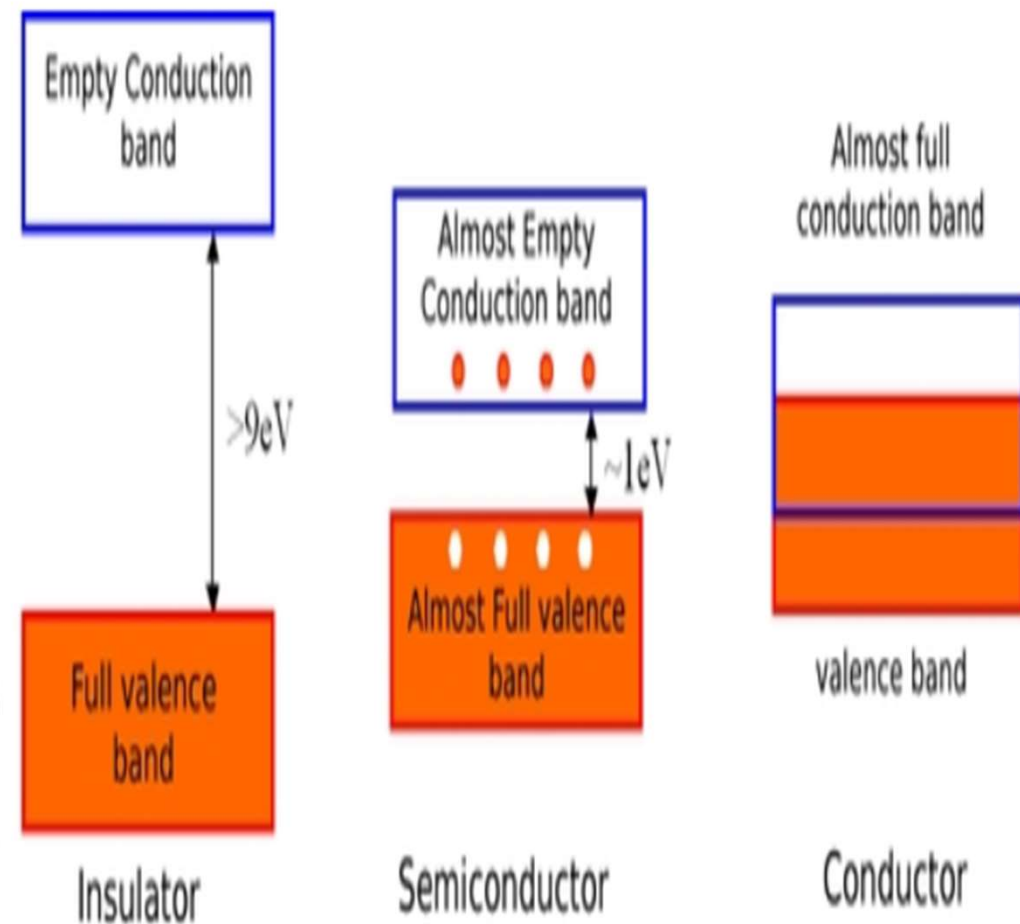
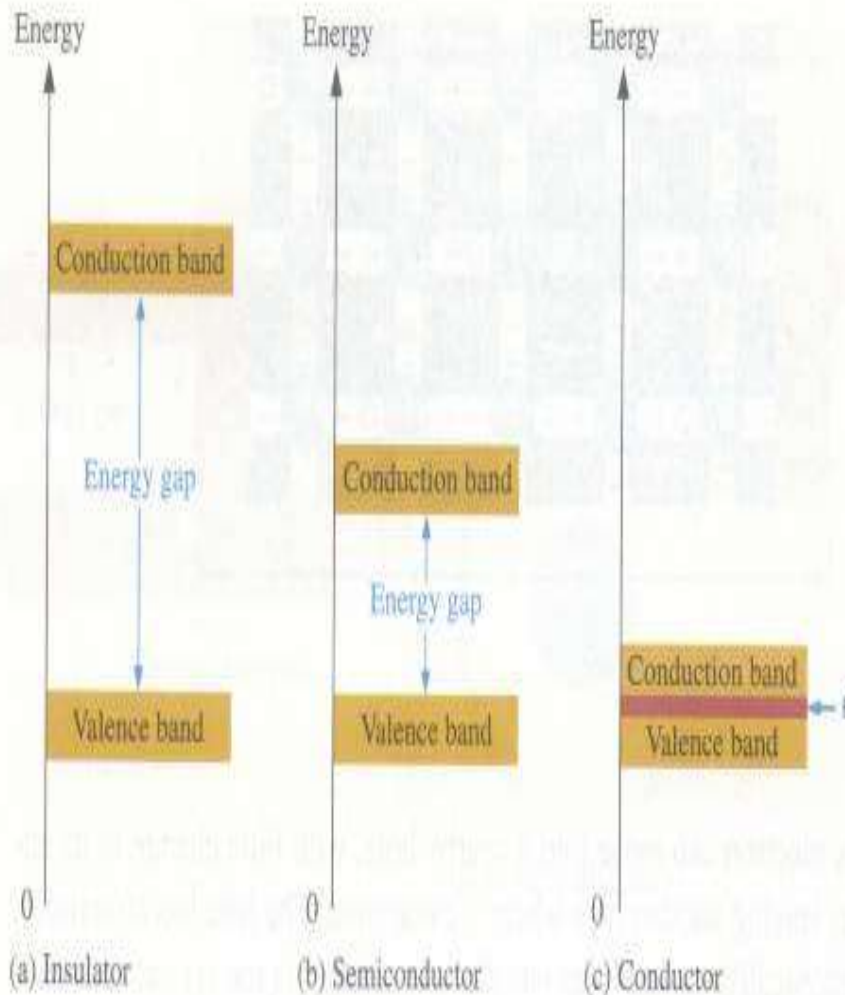


ECE249: Unit-2

PN junction diode and its applications

Basic Diode Concepts

- * Energy Diagrams – *Insulator, Semiconductor, and Conductor*
the energy diagram for the three types of solids



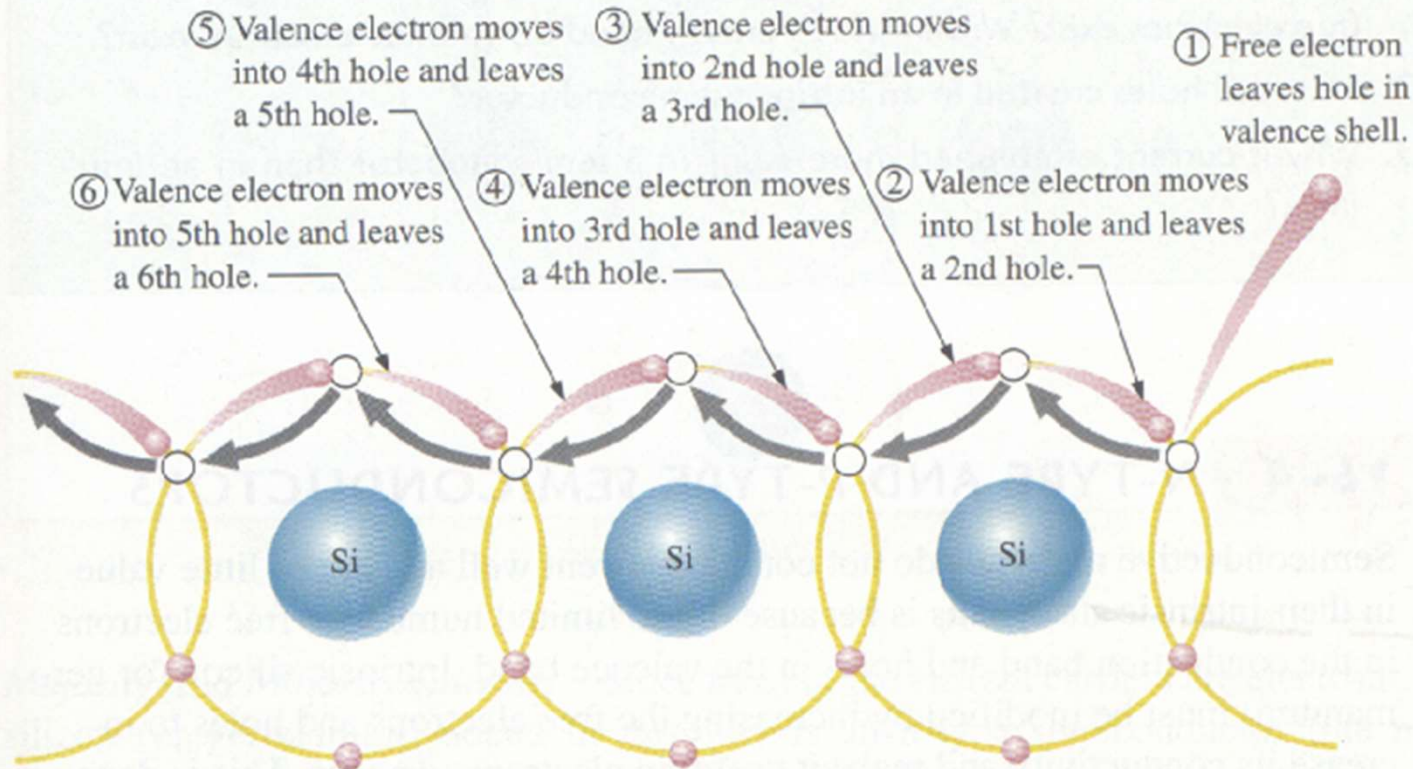
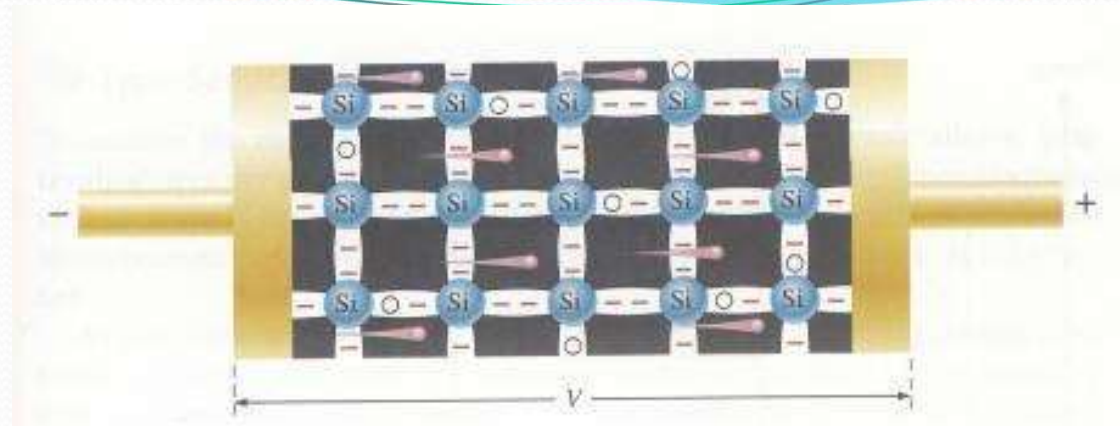
Intrinsic Semiconductors

- 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:**

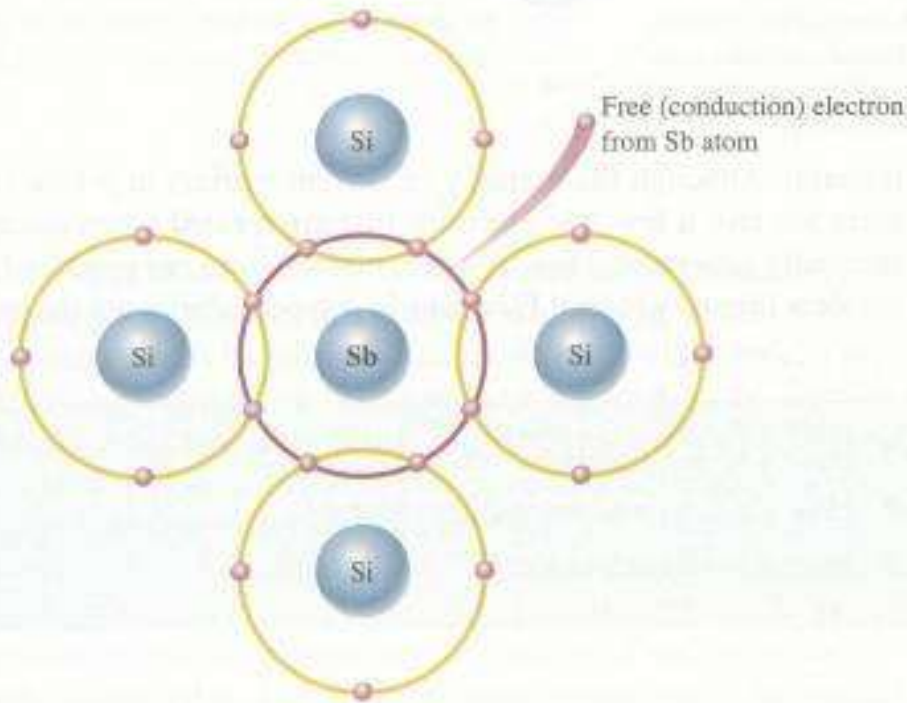
- An extrinsic semiconductor is a semiconductor material that has been intentionally doped with specific impurities to modify its electrical properties.
- Doping introduces additional charge carriers into the semiconductor, significantly affecting its conductivity. Extrinsic semiconductors are classified 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 semiconductor material.
- * *N-type*: adding Group V dopant (or donor) such as Phosphorus (P) and arsenic (As),...



electron the major charge carrier
hole the minor charge 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



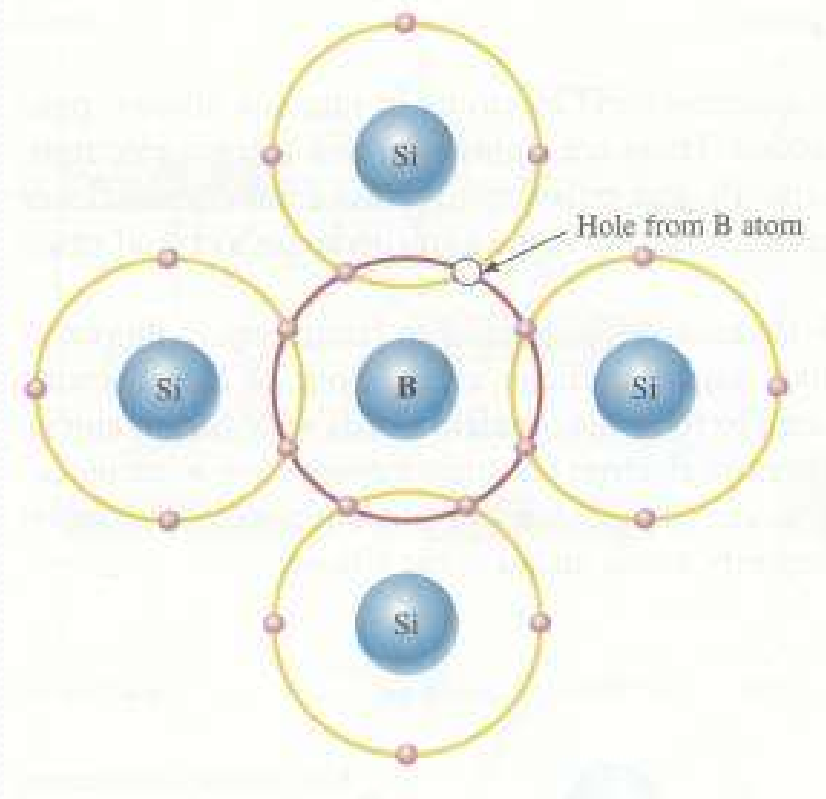
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PERIODIC TABLE OF ELEMENTS

GROUP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
PERIOD	1 H Hydrogen 1.008	2 He Helium 4.003																
2	Li Lithium 6.941	Be Beryllium 9.012											B Boron 10.81	C Carbon 12.011	N Nitrogen 14.007	O Oxygen 15.999	F Fluorine 18.998	Ne Neon 20.180
3	Na Sodium 22.990	Mg Magnesium 24.305											Al Aluminum 26.982	Si Silicon 28.086	P Phosphorus 30.974	S Sulfur 32.06	Cl Chlorine 35.45	Ar Argon 39.948
4	K Potassium 39.098	Ca Calcium 40.078	Sc Scandium 44.956	Ti Titanium 47.88	V Vanadium 50.942	Cr Chromium 52.00	Mn Manganese 54.938	Fe Iron 55.845	Co Cobalt 58.933	Ni Nickel 58.693	Cu Copper 63.546	Zn Zinc 65.38	Ga Gallium 69.723	Ge Germanium 72.64	As Arsenic 74.922	Se Selenium 78.96	Br Bromine 79.904	Kr Krypton 83.798
5	Rb Rubidium 85.468	Sr Strontium 87.62	Y Yttrium 88.906	Zr Zirconium 91.224	Nb Niobium 92.906	Mo Molybdenum 95.94	Tc Technetium 98.00	Ru Ruthenium 101.07	Rh Rhodium 102.91	Pd Palladium 106.36	Ag Silver 107.868	Cd Cadmium 112.415	In Indium 114.818	Sn Tin 118.710	Sb Antimony 121.757	Te Tellurium 127.6	I Iodine 126.905	Xe Xenon 131.29
6	Cs Cesium 132.905	Ba Barium 137.327	57-71 Lanthanides	Hf Hafnium 178.49	Ta Tantalum 180.948	W Tungsten 183.84	Re Rhenium 186.207	Os Osmium 190.23	Ir Iridium 192.222	Pt Platinum 195.084	Au Gold 196.967	Hg Mercury 200.59	Tl Thallium 204.383	Pb Lead 207.2	Bi Bismuth 208.98	Po Polonium 209	At Astatine 210	Rn Radon 222
7	Fr Francium 223	Ra Radium 226	89-103 Actinides	Rf Rutherfordium 261	Db Dubnium 262	Sg Seaborgium 266	Bh Bohrium 264	Hs Hassium 277	Mt Meitnerium 268	Ds Darmstadtium 271	Rg Roentgenium 272	Cn Copernicium 285	Nh Nihonium 286	Fl Flerovium 289	Mc Moscovium 290	Lv Livermorium 293	Ts Tennessine 294	Og Oganesson 294
	La Lanthanum 138.905	Ce Cerium 140.12	Pr Praseodymium 140.908	Nd Neodymium 144.24	Pm Promethium 145	Sm Samarium 150.36	Eu Europium 151.964	Gd Gadolinium 157.25	Tb Terbium 158.925	Dy Dysprosium 162.50	Ho Holmium 164.930	Er Erbium 167.259	Tm Thulium 168.930	Yb Ytterbium 173.054	Lu Lutetium 174.967			
	Ac Actinium 227	Th Thorium 232.038	Pa Protactinium 231.036	U Uranium 238.029	Np Neptunium 237.048	Pu Plutonium 244	Am Americium 243	Cm Curium 247	Bk Berkelium 247	Cf Californium 251	Es Einsteinium 252	Fm Fermium 257	Md Mendelevium 258	No Nobelium 259	Lr Lawrencium 262			

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 boron (B), aluminium (Al), and gallium (Ga)



hole the major charge carrier

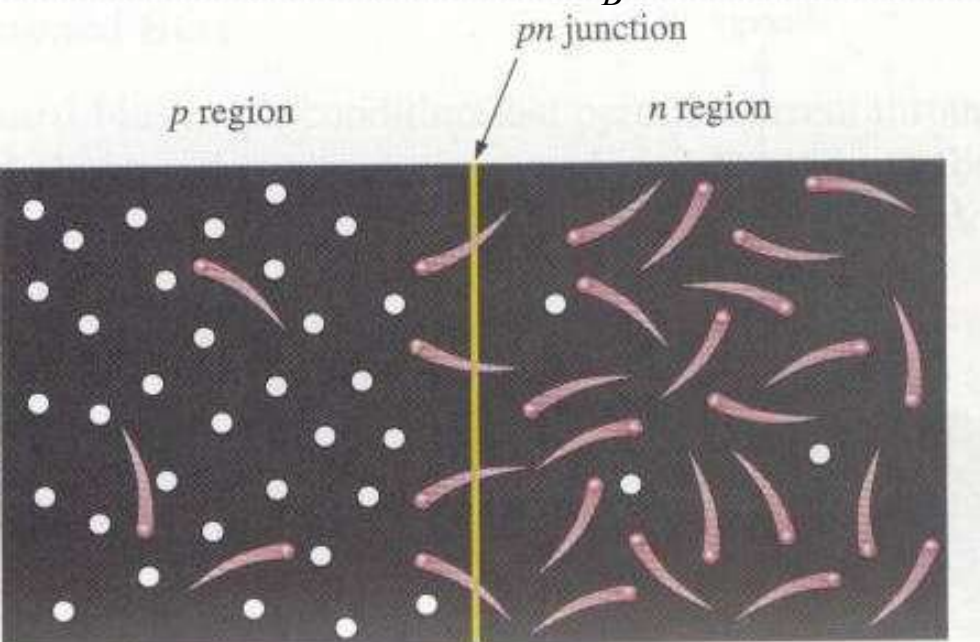
electron the minor charge carrier

The PN-Junction

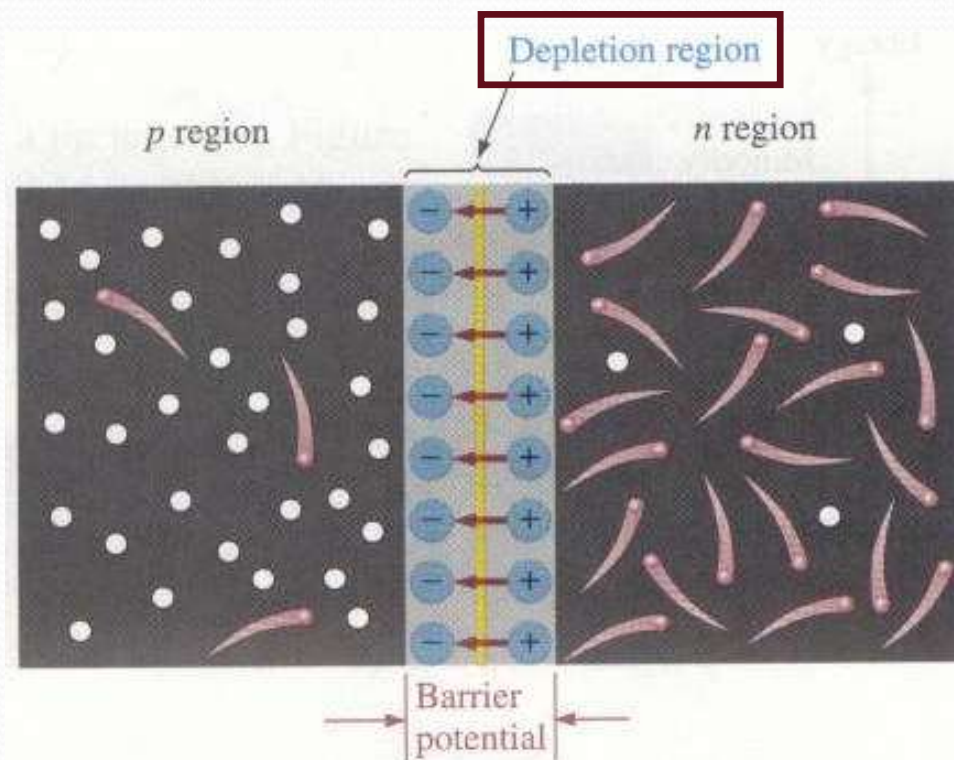
- * The interface between p-type and n-type material is called a *pn-junction*.

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.

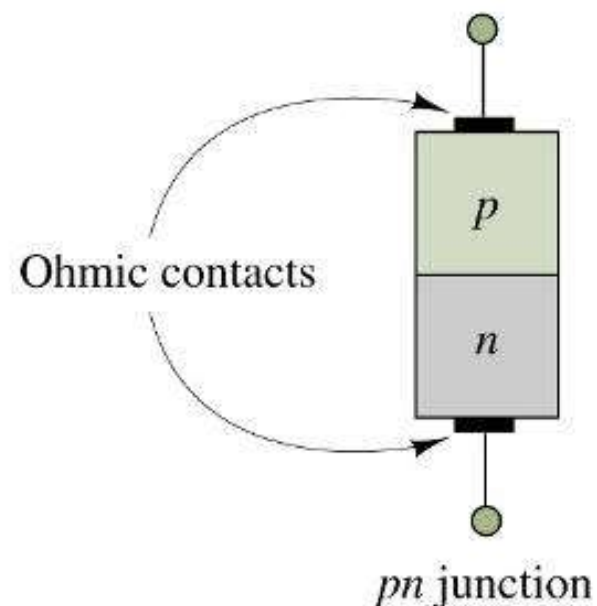
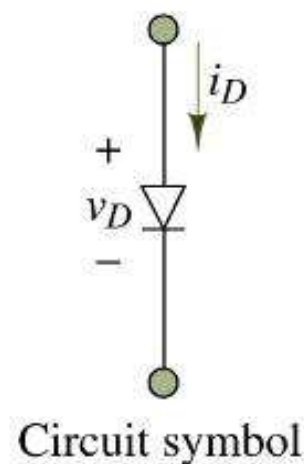


(b) For every electron that diffuses across the junction and combines with a hole, a positive charge is left in the *n* region and a negative charge is created in the *p* region, forming a **barrier potential**. This action continues until the voltage of the barrier repels further diffusion.

Biasing the PN-Junction

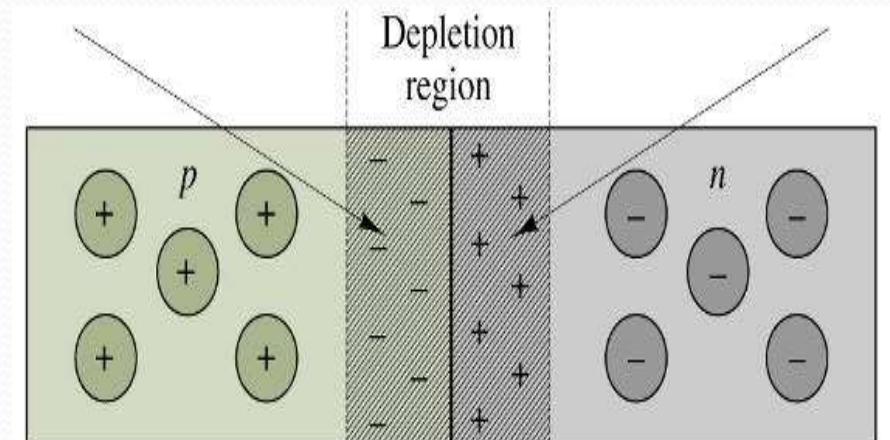
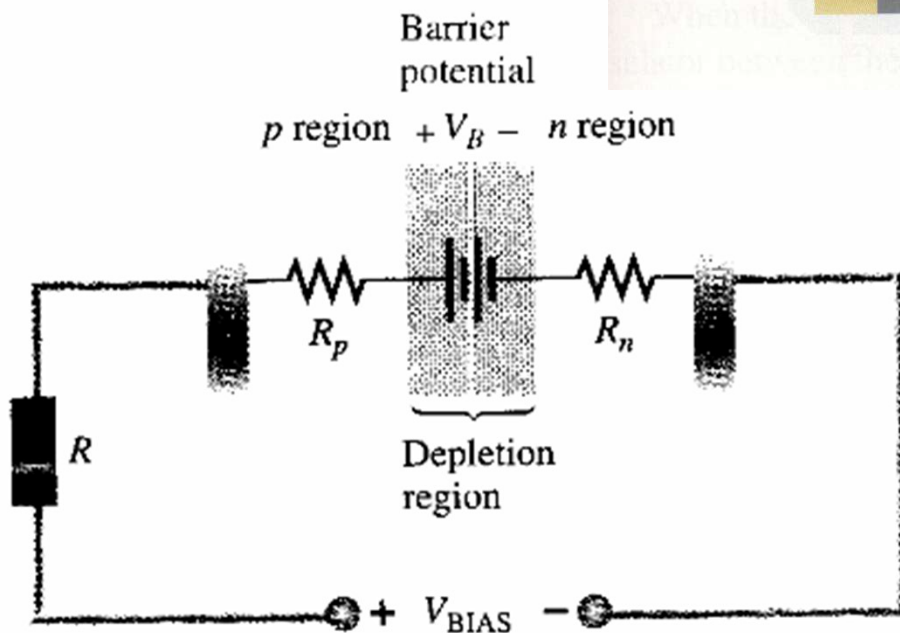
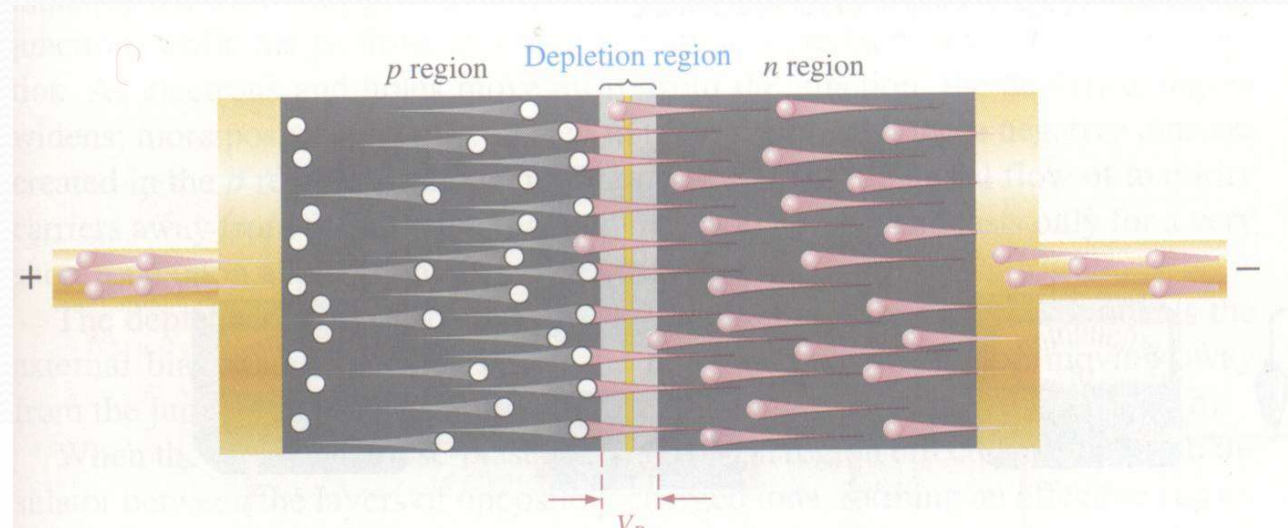
- * There is no movement of charge through a PN-junction at equilibrium.
- * The PN-junction form a *diode* which allows current in only one direction and prevent the current in the other direction as determined by the *bias*.

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



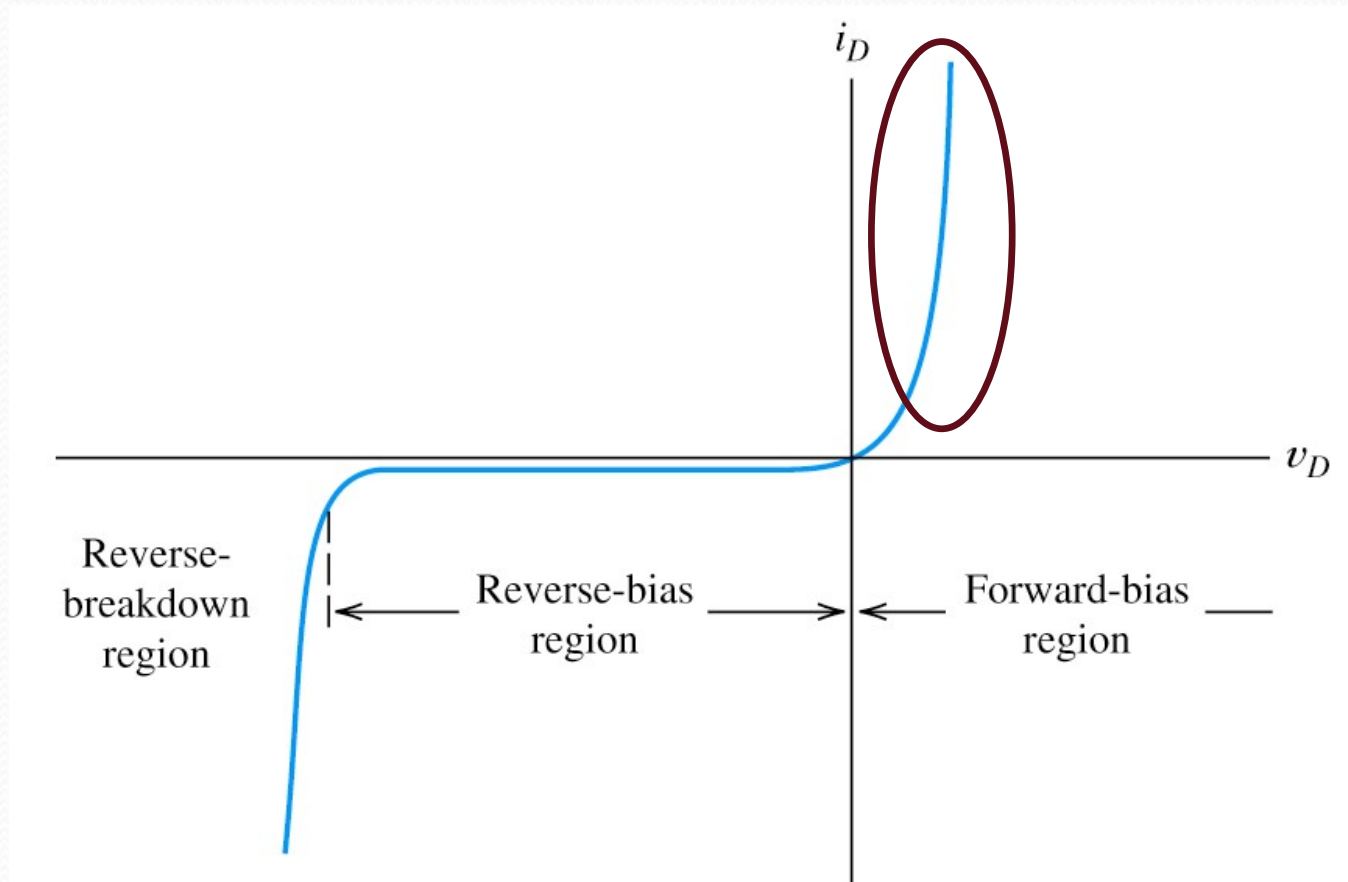
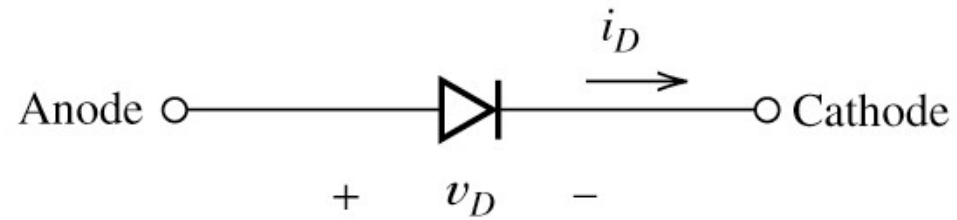
Biased the PN-Junction

***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.

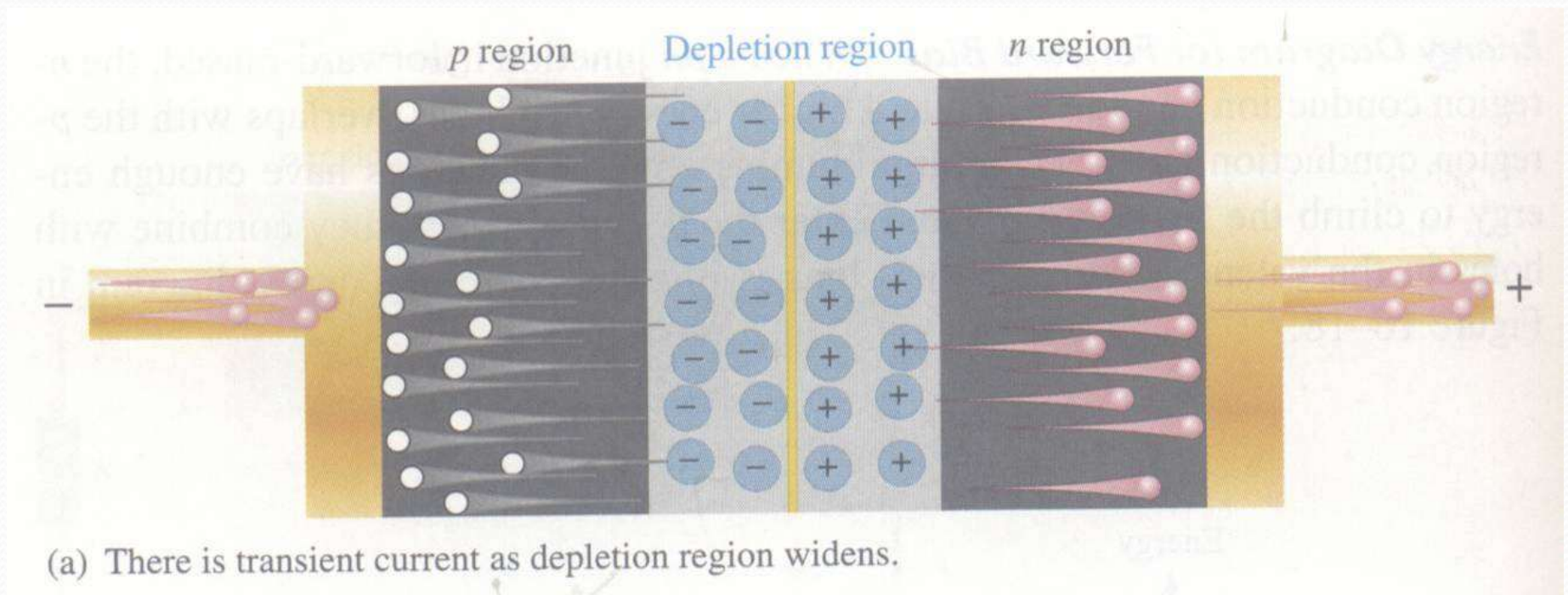


Biasing the PN-Junction

*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*.

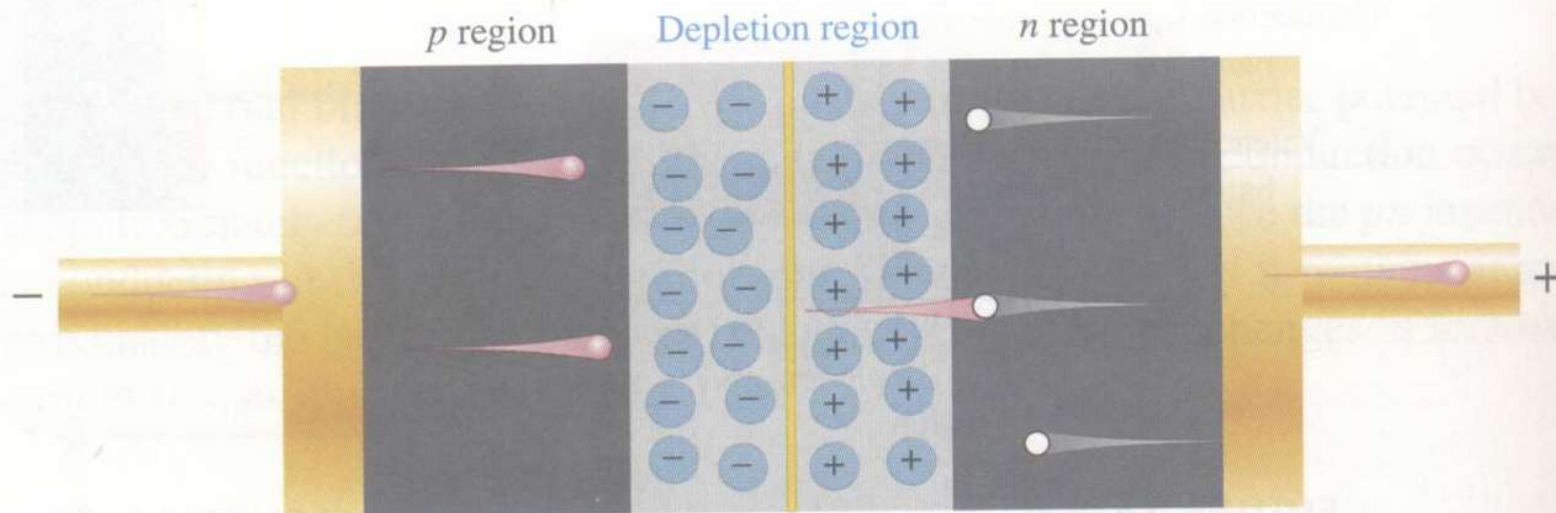
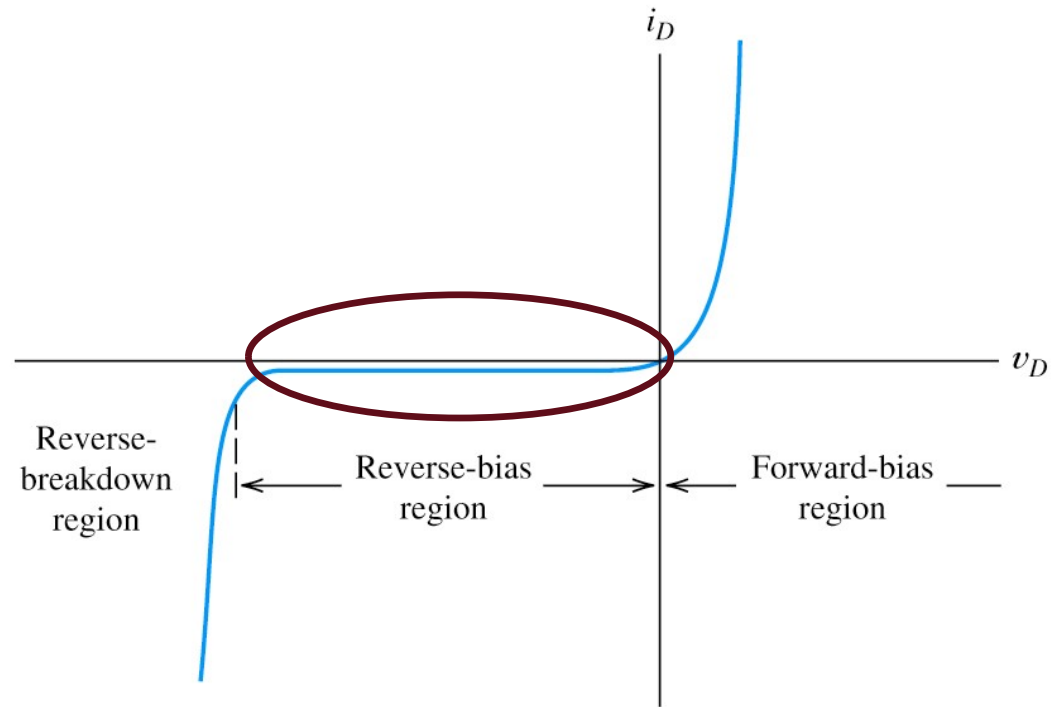


2. Diodes – Basic Diode Concepts

* **Reverse Bias:**

majority-carrier current ceases.

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



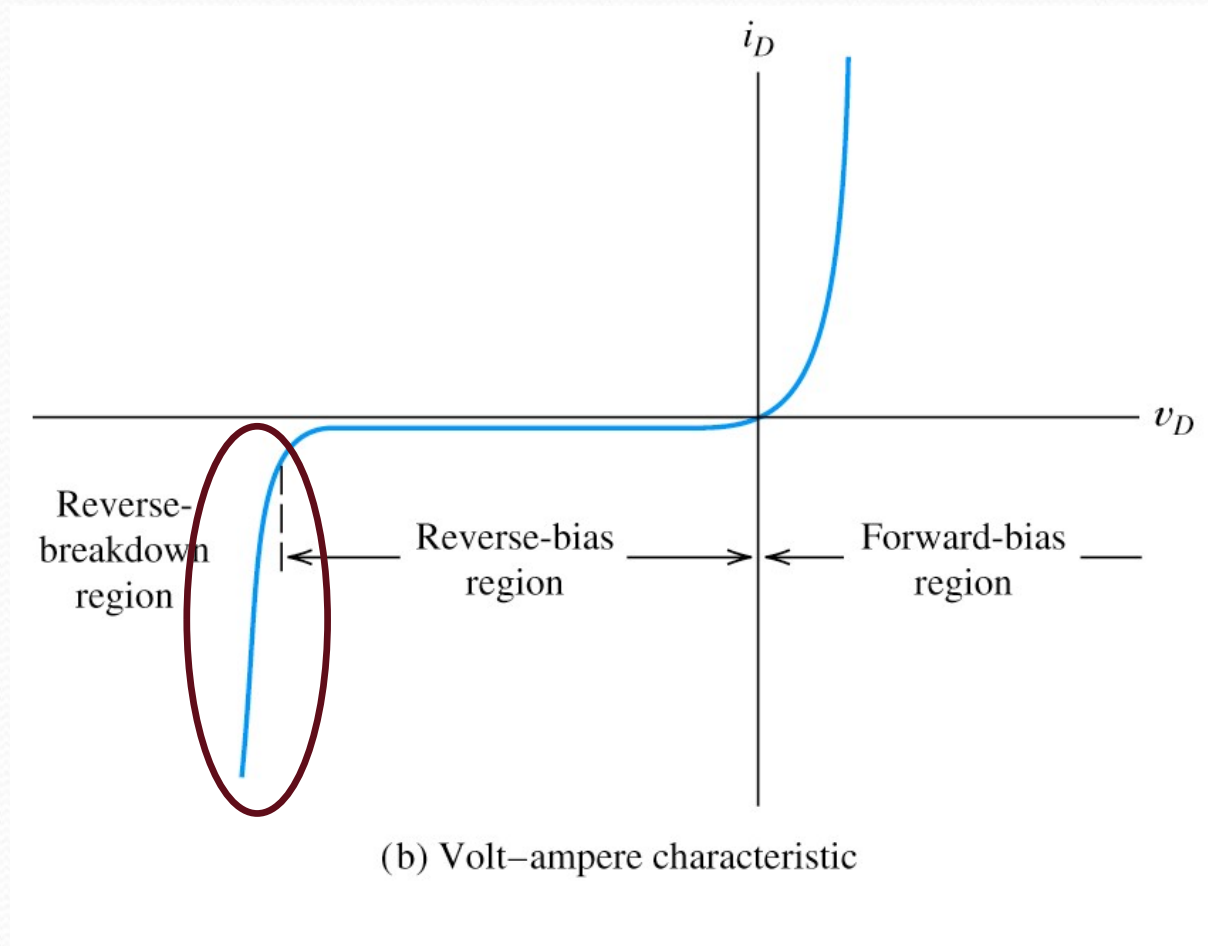
(b) Majority current ceases when barrier potential equals bias voltage. There is an extremely small reverse current due to minority carriers.

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



Shockley Equation

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

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

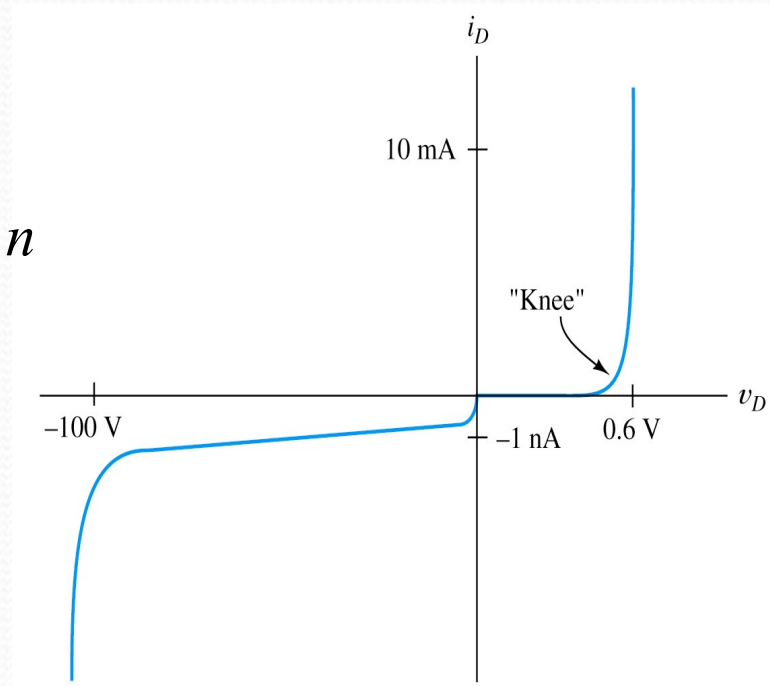
where $I_s \cong 10^{-14} A$ at 300K is the (reverse) saturation current, $n \cong 1$ to 2 is the emission coefficient,

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

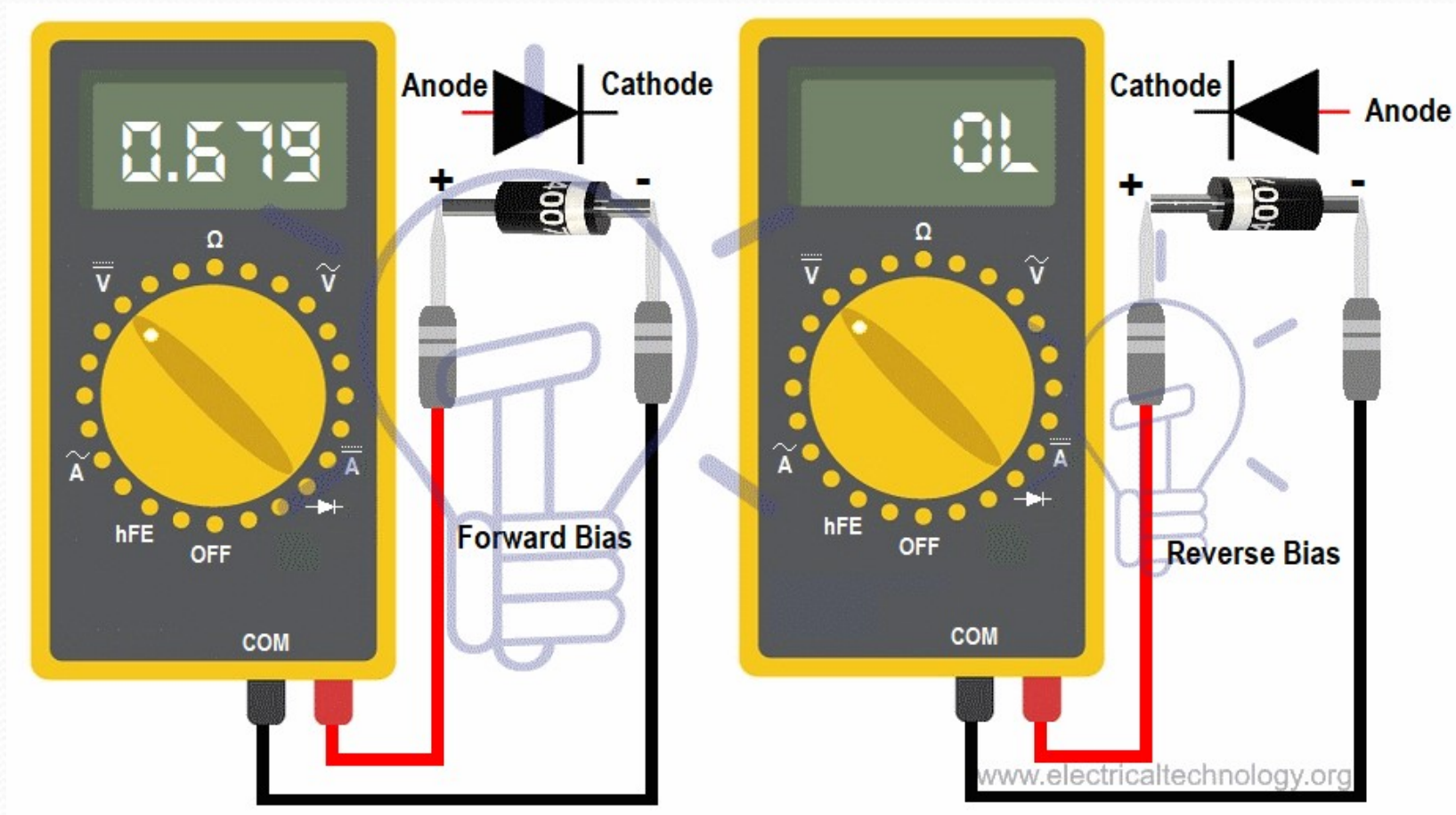
k is the Boltzmann's constant, $q = 1.60 \times 10^{-19} C$

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

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.

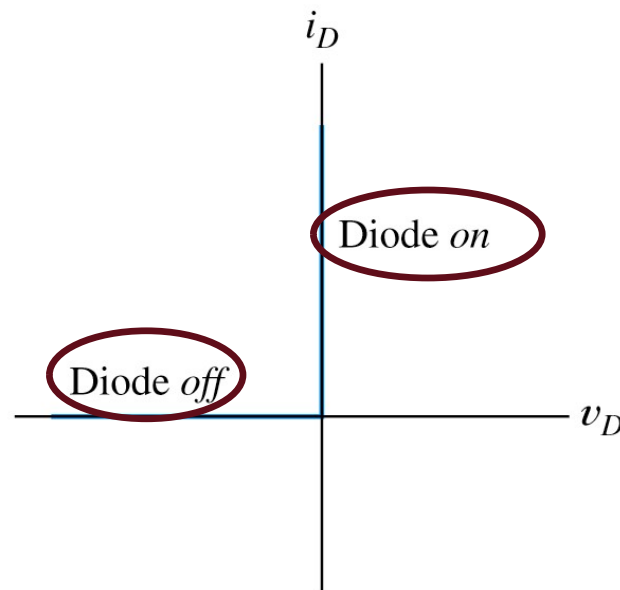


Figure 10.15 Ideal-diode volt–ampere characteristic.

2. Piecewise-Linear Diode Models

Modified Ideal-Diode Model

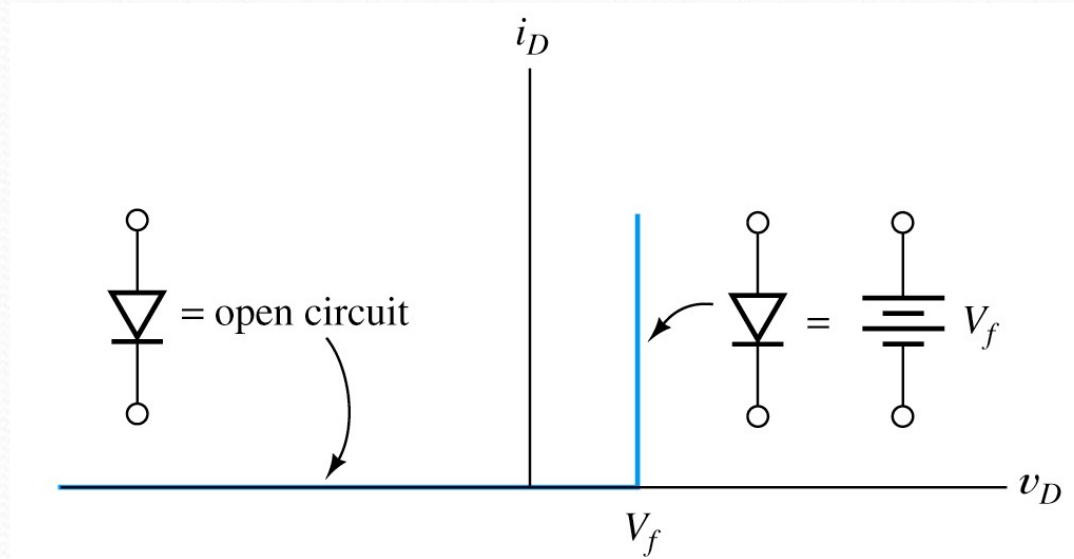
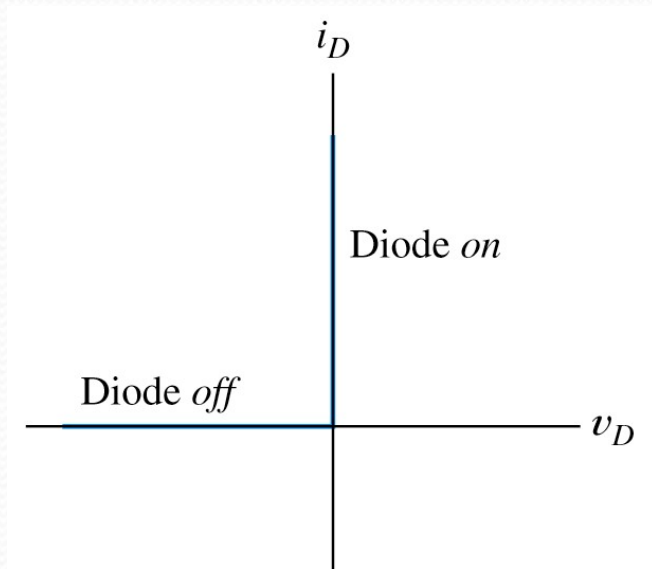


Figure 10.23 Simple piecewise-linear equivalent for the diode.

* 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

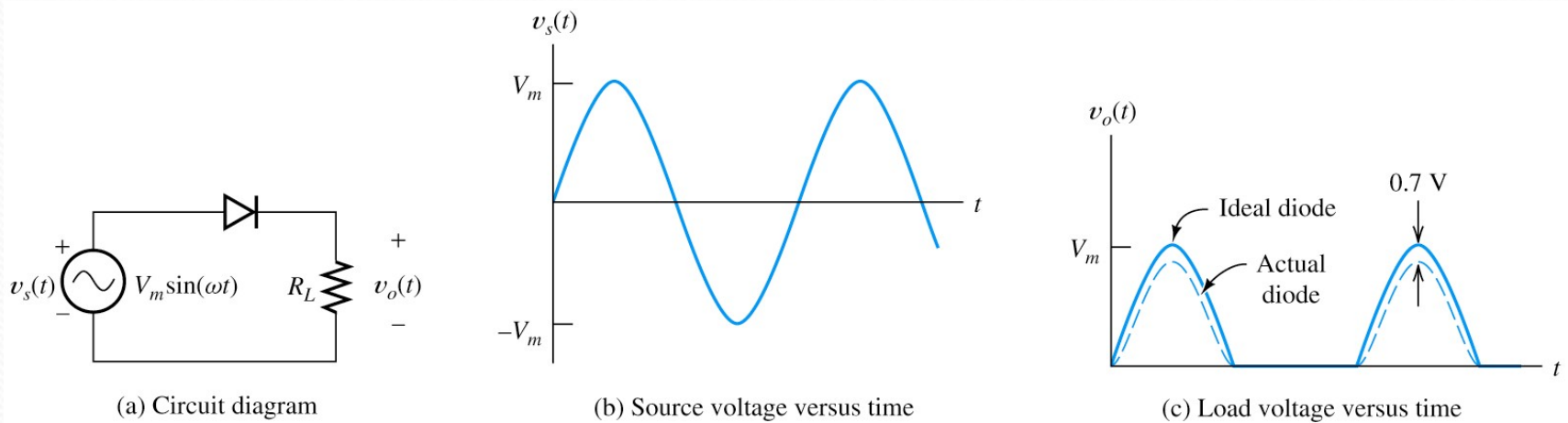
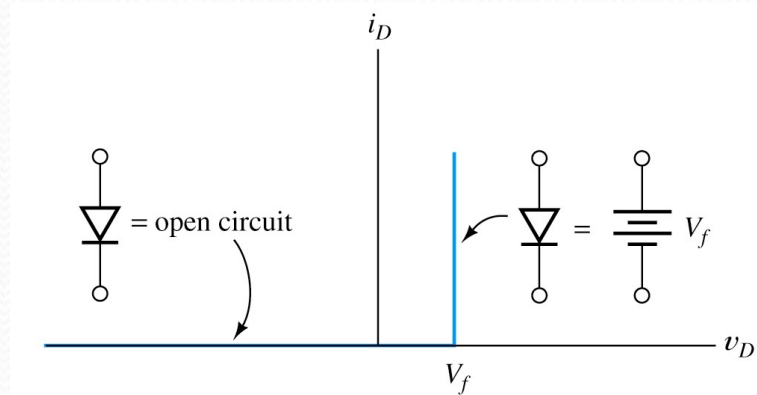
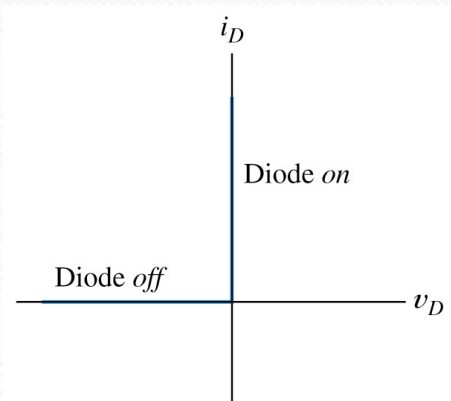
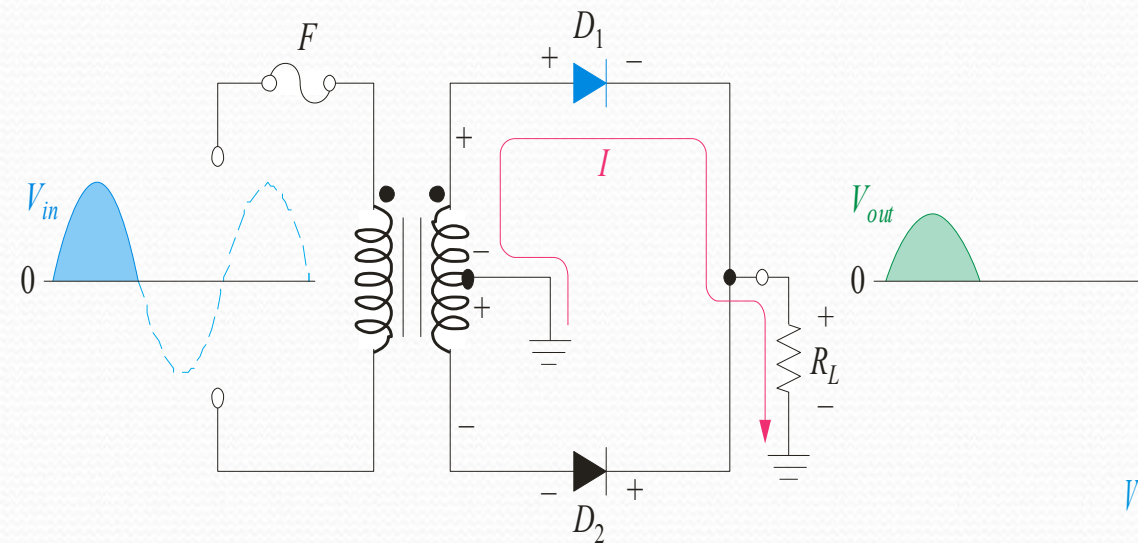


Figure 10.24 Half-wave rectifier with resistive load.



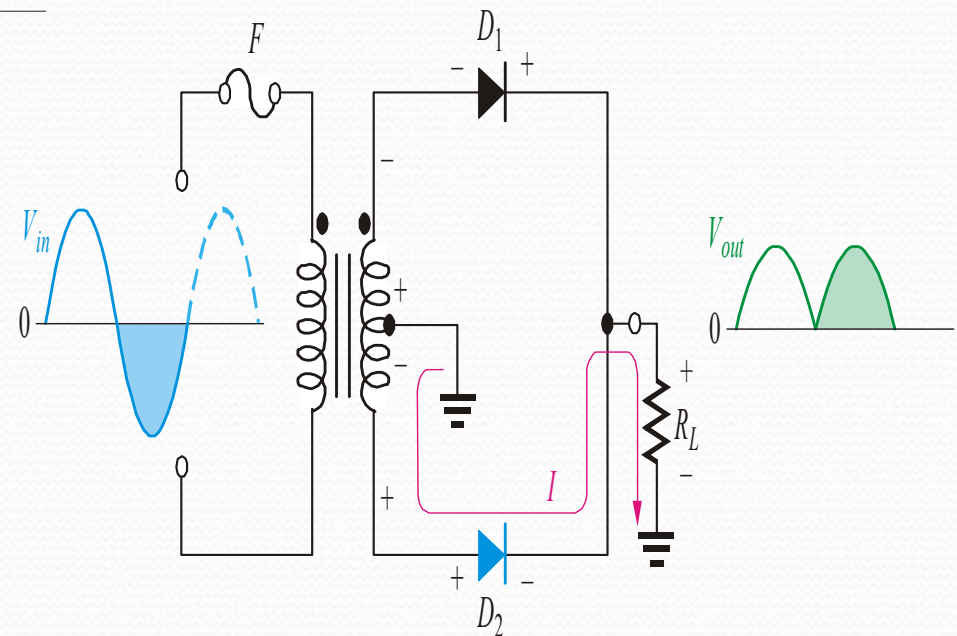
Center-Tapped Full wave rectifiers

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



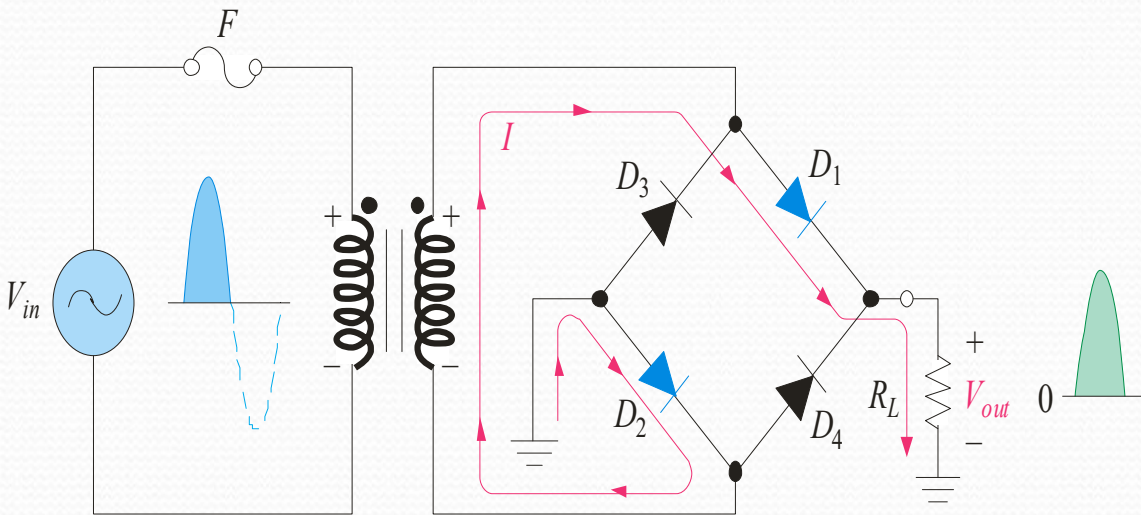
During the positive half-cycle, the upper diode is forward-biased and the lower diode is reverse-biased.

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



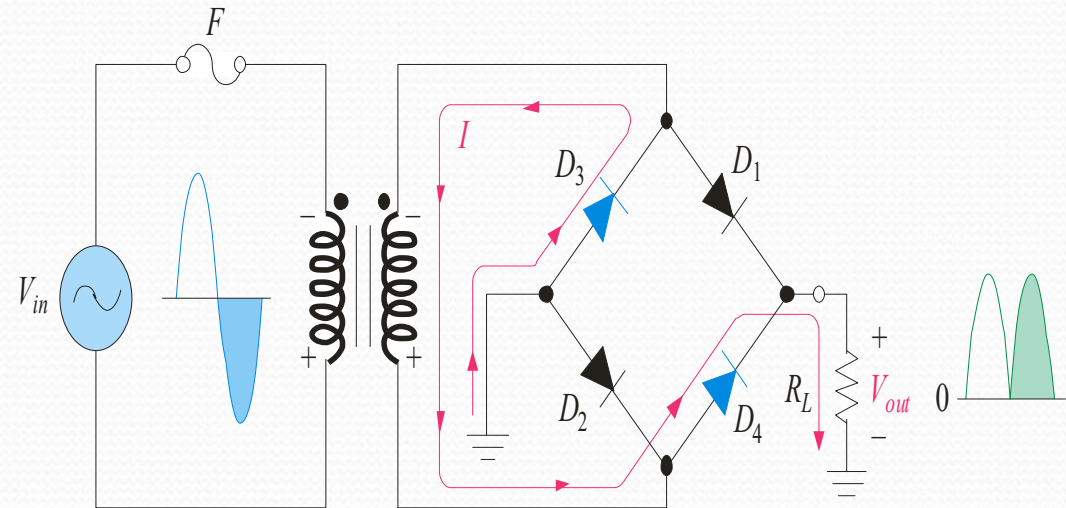
Bridge Full-wave rectifiers

- ❖ 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