Introduction to Basic Electronics


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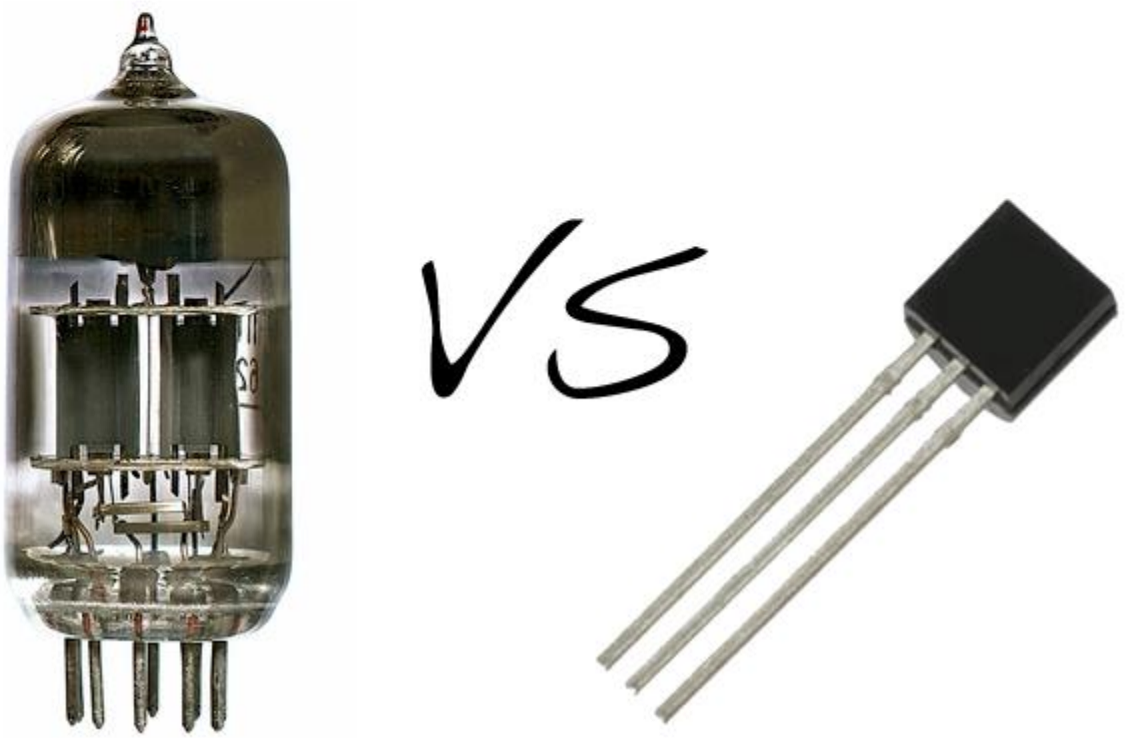
What is electronics?

- Electronics is the part of engineering aiming to use electricity with the purpose of controlling other devices or circuits

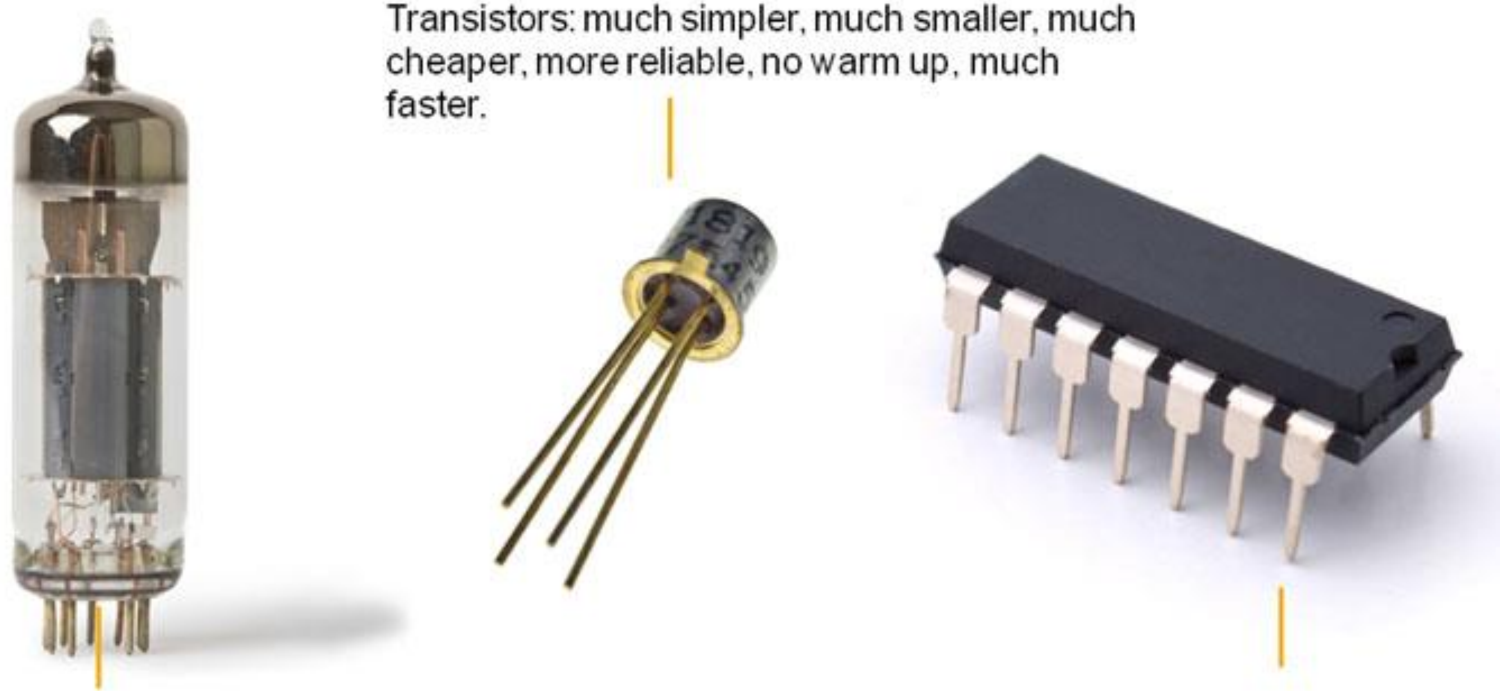
Index

Transistors Vs Vaccum tube



Integrated Circuits (ICs)

Transistors: much simpler, much smaller, much cheaper, more reliable, no warm up, much faster.



Vacuum tubes: slow, expensive, fragile

Integrated circuits: miniaturization added to all the existing benefits, enabled unthought-of possibilities

Integrated Circuits (ICs)

- The reduction in size of electronic systems is due primarily to an important innovation introduced in 1958—the **integrated circuit (IC).**
- Integrated circuits are fabricated (or made) on semiconductor wafers
- Integrated circuits are made of semiconductor devices such as **diodes** and **transistors**.
- An integrated circuit can now contain features less than 50 nanometers across.

A BRIEF HISTORY

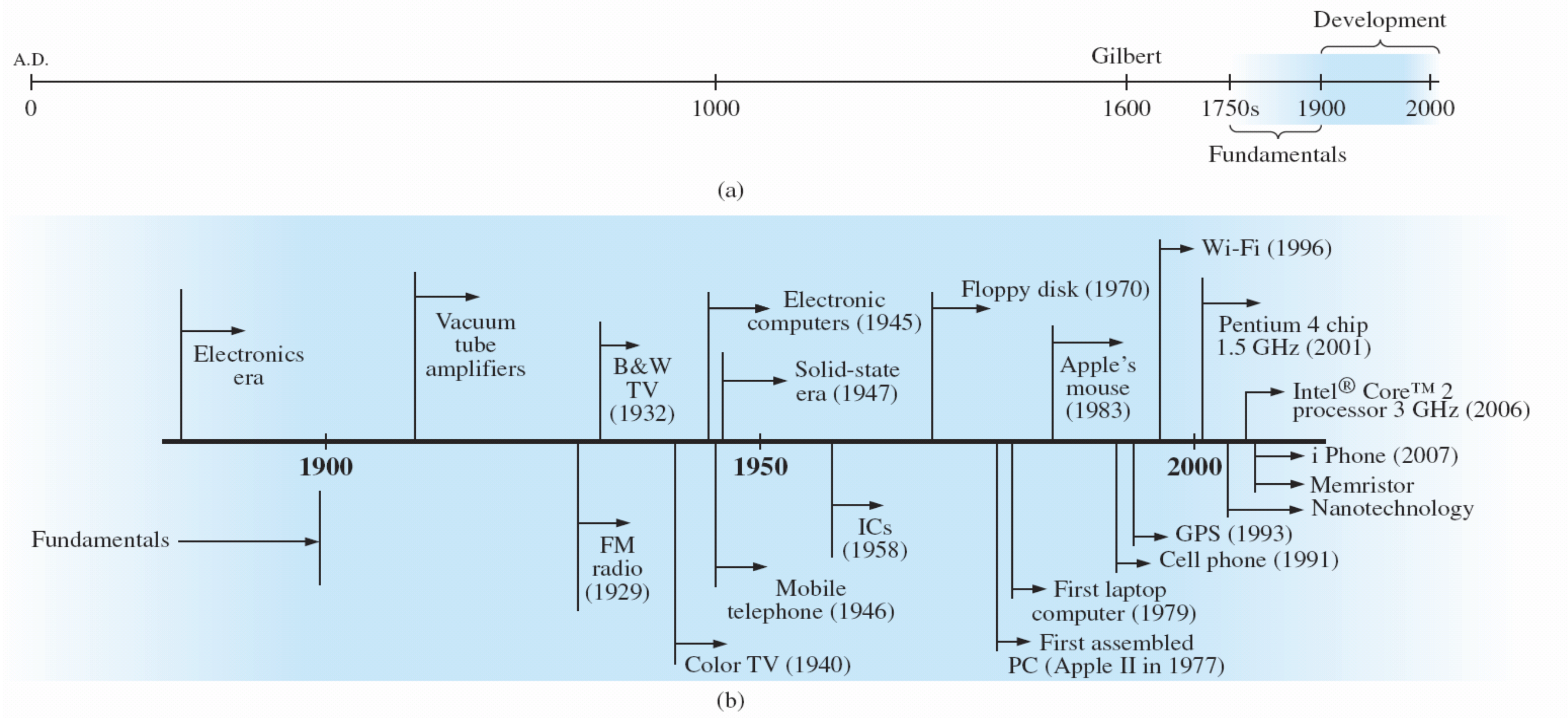


FIGURE: *Time charts: (a) long-range; (b) expanded.*

Integrated Circuits (ICs)

- The first integrated circuit (IC) was developed by Jack Kilby while working at Texas Instruments in 1958

Jack St. Clair Kilby, inventor of the integrated circuit and co-inventor of the electronic handheld calculator. (Courtesy of Texas Instruments.)

The first integrated circuit, a phase-shift oscillator, invented by Jack S. Kilby in 1958. (Courtesy of Texas Instruments.)

A BRIEF HISTORY
The Solid-State Era

- In 1947, physicists William Shockley, John Bardeen, and Walter H. Brattain of Bell Telephone Laboratories demonstrated the point-contact **transistor**
- It is an amplifier constructed entirely of solid-state materials
  - No requirement for a vacuum, glass envelope, or heater voltage for the filament

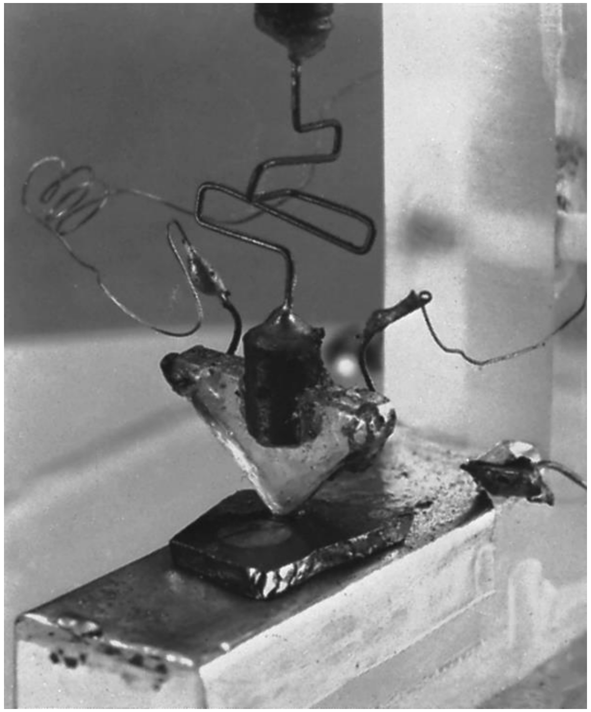


FIGURE. *The first transistor.* (Used with permission of Lucent Technologies Inc./ Bell Labs.)

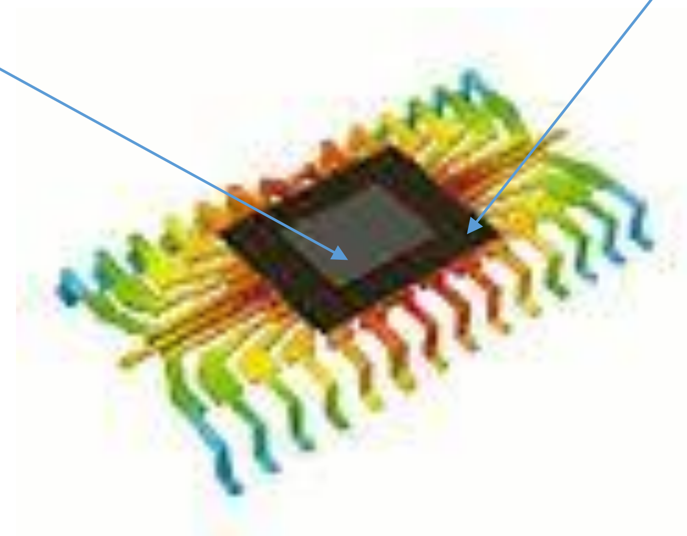
THE INTEGRATED CIRCUIT (IC)

- A modern single silicon chip may be on the order of 1 square centimeter and some ICs may have more than a hundred terminals.
- An IC can contain the arithmetic, logic, and memory functions on a single chip—the primary example of this type of IC is the microprocessor.
  - For example, the Intel ® Core TM i7 Extreme Edition Processor of Fig. 1.2 has 731 million transistors in a package that is only slightly larger than a 1.67 sq. inches.

FIG. 1.2
Intel® Core™ i7 Extreme Edition Processor.

IC Chips & Packages

IC Chip on a PCB (Printed Circuit Board)



A Simple DIP (Dual In-Line Package) IC Package with The Protective Casing Removed.

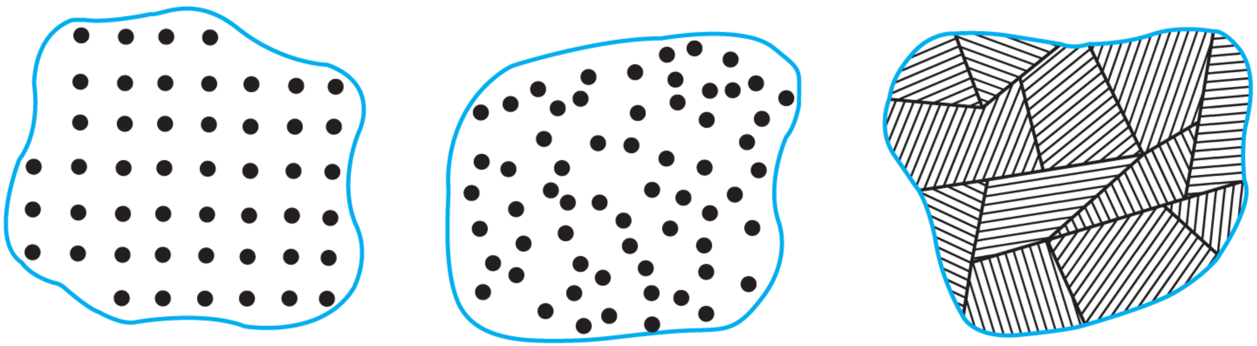
Conductors, Insulators and Semiconductors

- A conductor is a material that has loosely bound electrons that can be pulled away by an outside force to support current flow.
- An insulator is a material whose electrons are tightly bound and are not easily freed so that they do not easily support current flow.
- A semiconductor is a material that exhibits characteristics between conductors and insulators. Its ability to support current flow can be controlled.

Effect of Adding Controlled Impurities

- The electronic and optical properties of semiconductor materials are strongly affected by impurities
- Impurities are used to vary the conductivities of semiconductors over wide ranges
  - For example, an impurity concentration of 1 ppm can change a sample of Si from a poor conductor to a good conductor of electric current.
- This process of controlled addition of impurities, called doping

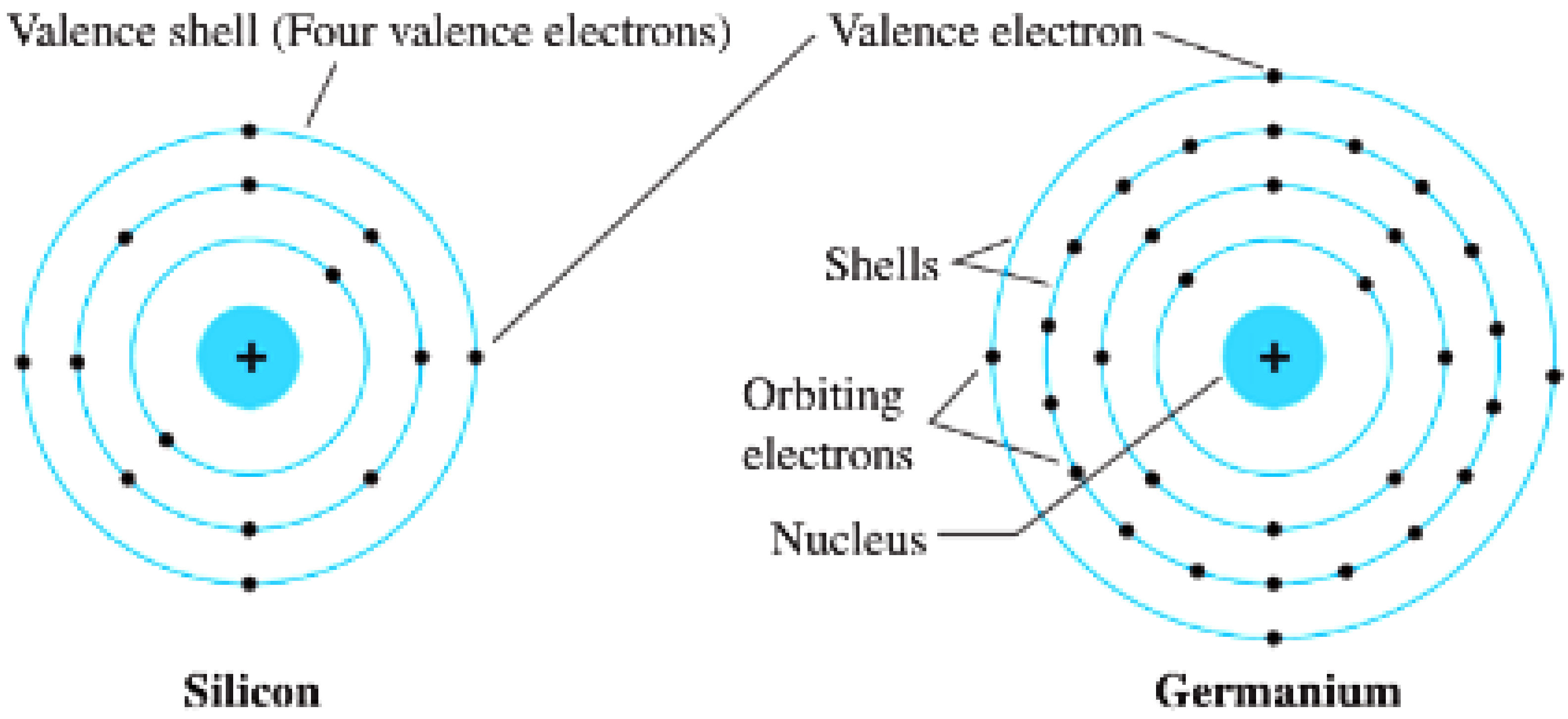
Three types of solids



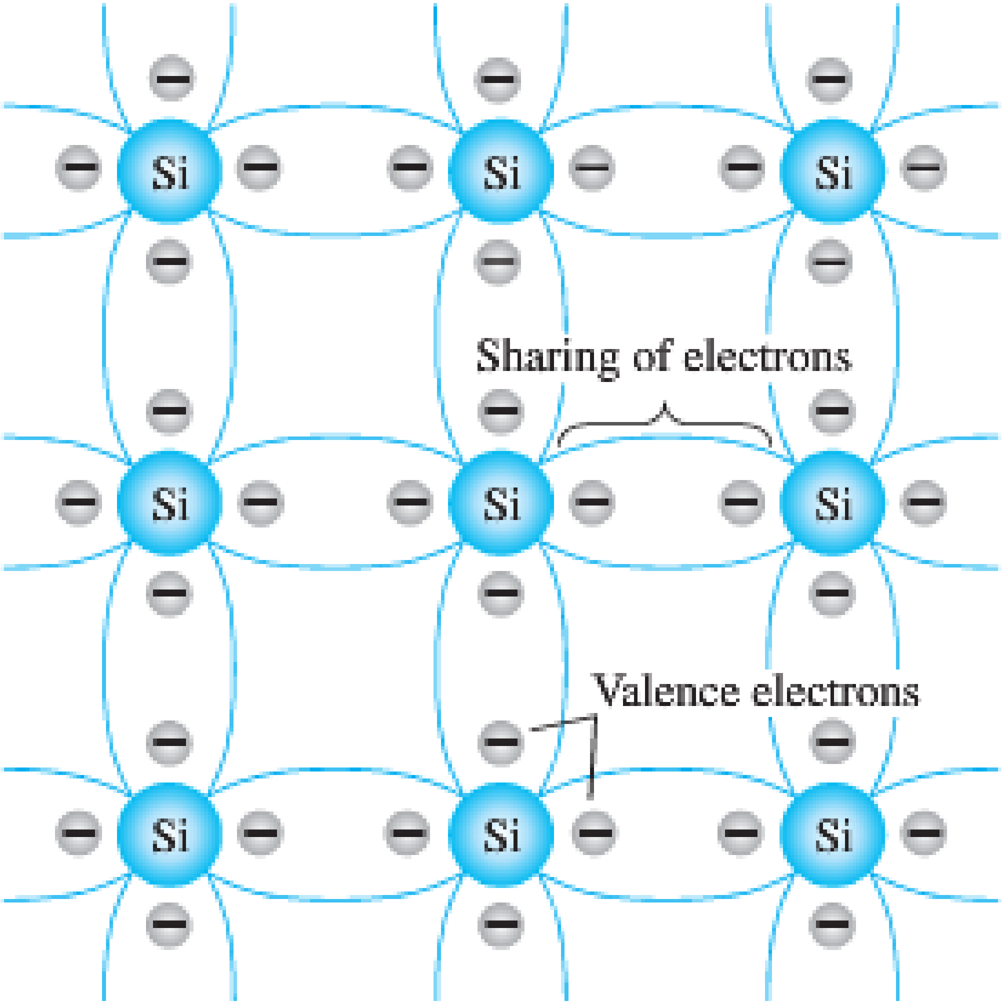
(a) Crystalline (b) Amorphous (c) Polycrystalline

- Solids are classified according to their atomic arrangement:
  a) **Crystalline**: the atoms are arranged in a periodic fashion
  b) **Amorphous**: no periodic structure at all
  c) **Polycrystalline**: many small regions of single-crystal material

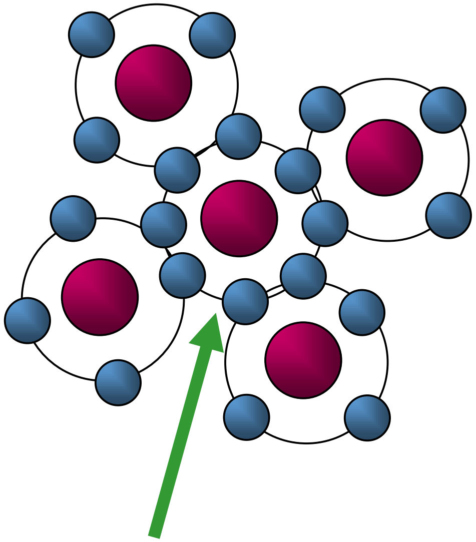
Atomic Structures of Semiconductors



Covalent bonding of the silicon atom



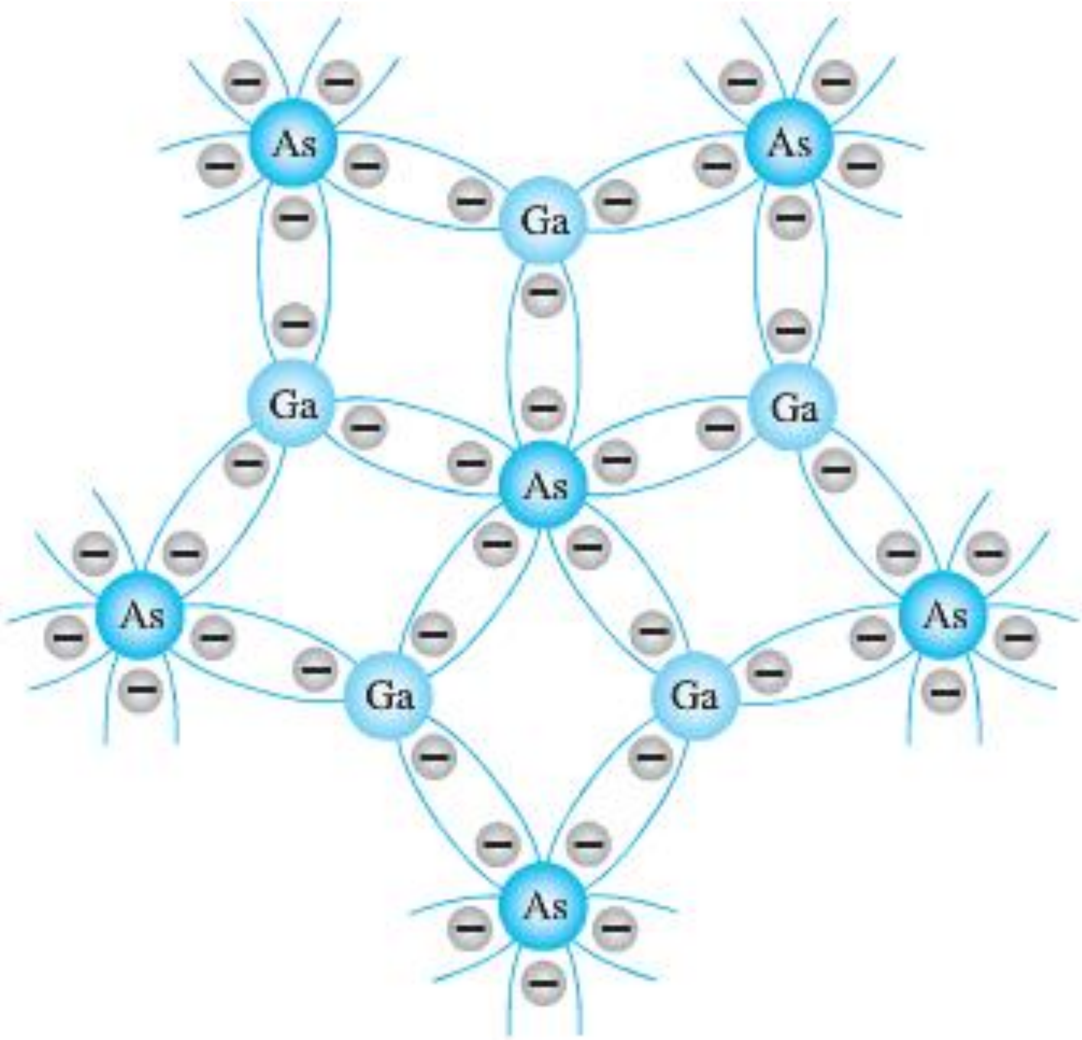
Silicon atoms in a crystal share electrons.



Valence saturation: n = 8

Because the valence electrons are bound, a silicon crystal at room temperature is almost a perfect insulator.

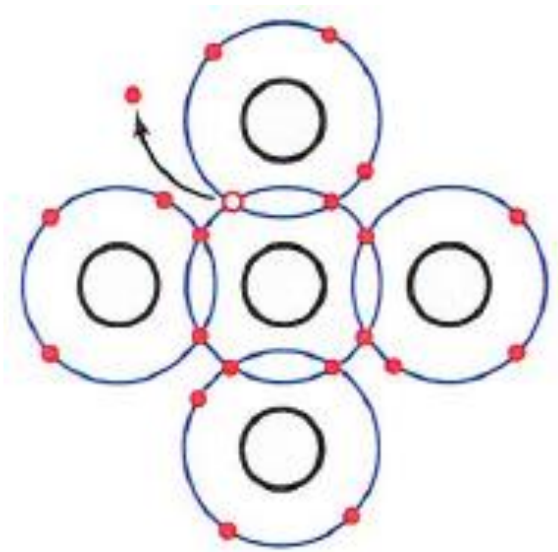
Covalent bonding of the GaAs crystal

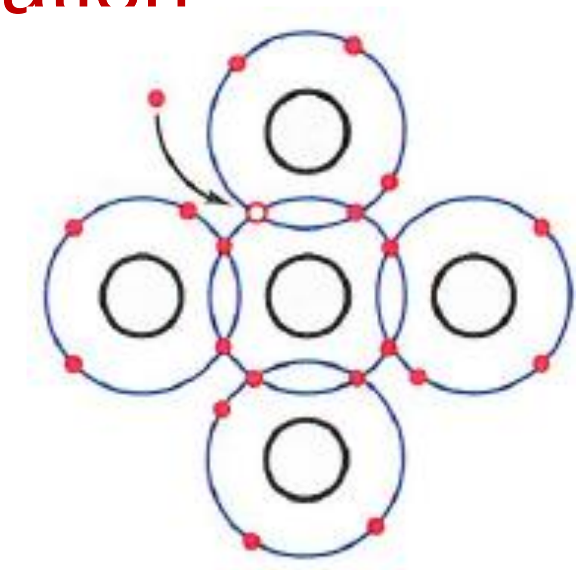


Intrinsic Semiconductors

- A pure semiconductor
- A silicon crystal is intrinsic if every atom in the crystal is a silicon atom
- Carefully refined to reduce the number of unintentional impurities to a very low level.

Electron Hole Pair Generation and Recombination

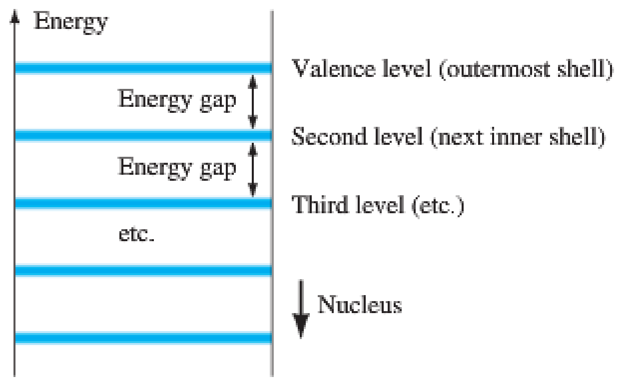




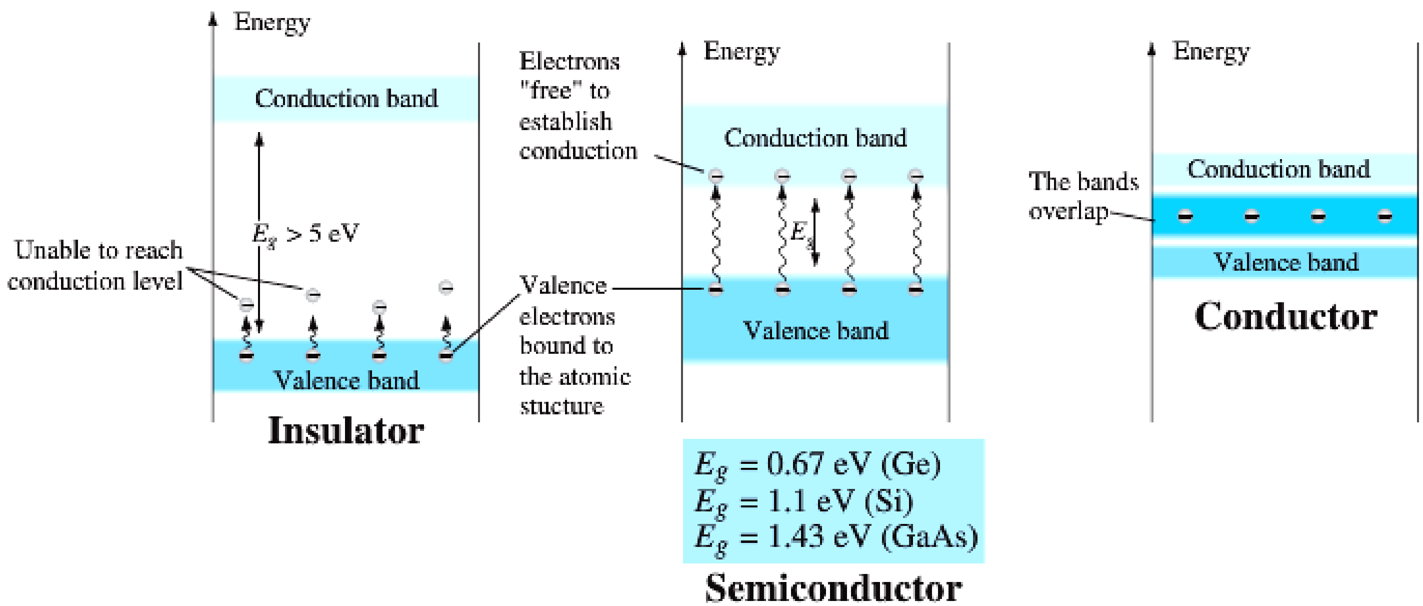
- Valence electrons can absorb sufficient energy (from light or heat) to break the covalent bonds and assume the “free” state.
  - These free electrons are called **intrinsic carriers**
- With higher temperatures, we get more intrinsic carriers – hence higher conductivity in semiconductors

Energy Levels

- The further an electron is from the nucleus, the higher is the energy state



(a) Discrete energy levels in isolated atomic structures



(b) conduction and valence bands of an insulator, a semiconductor, and a conductor.

Extrinsic Semiconductors

- The electrical properties of a semiconductor can be altered significantly by adding impurity atoms
  - This process is called **doping**
  - A **doped** semiconductor is called **extrinsic**

- **There are just two types of extrinsic semiconductor materials:**

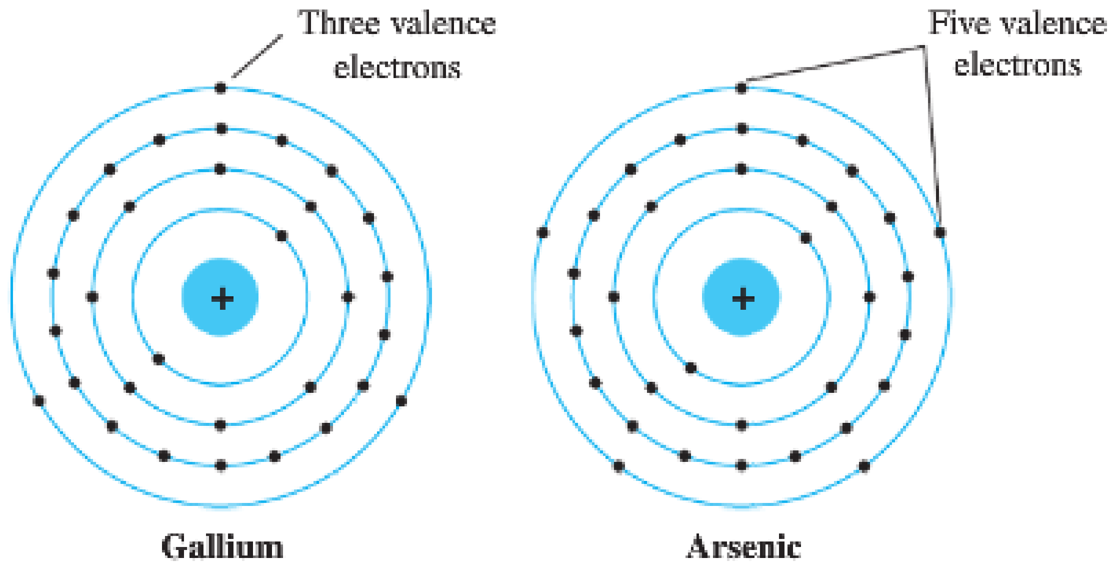
***n*-type**

***n*-type** materials contain an excess of conduction band electrons.

***p*-type**

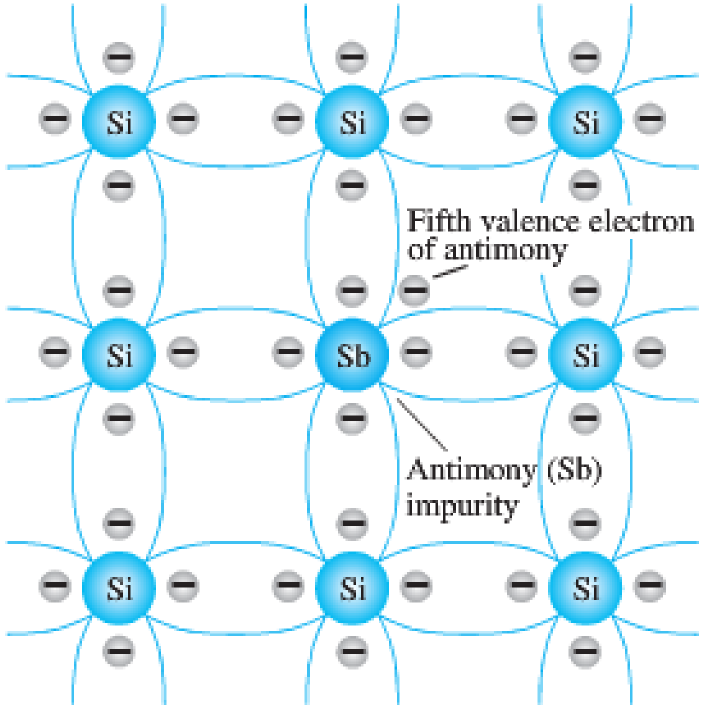
***p*-type** materials contain an excess of valence band holes.

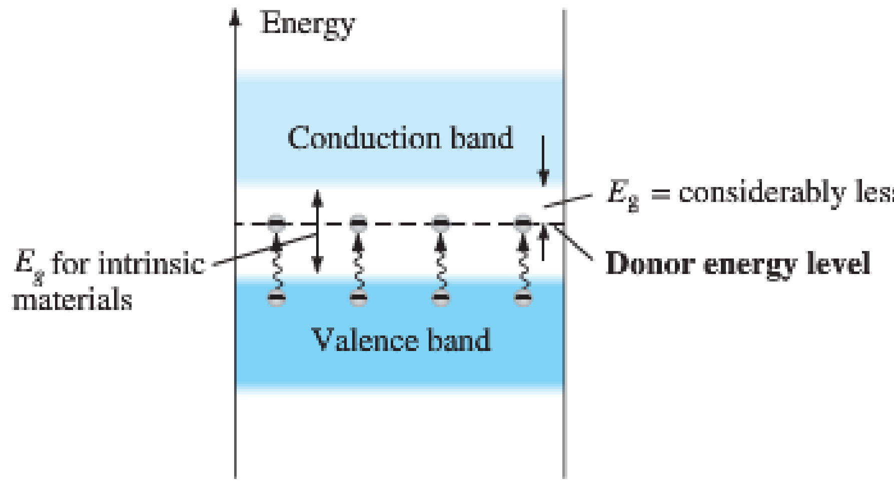
Atomic Structures of Impurities



- p-type material is created by adding impurity elements such as B, Ga, and In
- n-type material is created by adding impurity elements such as Sb, As, and Ph

n -Type Material



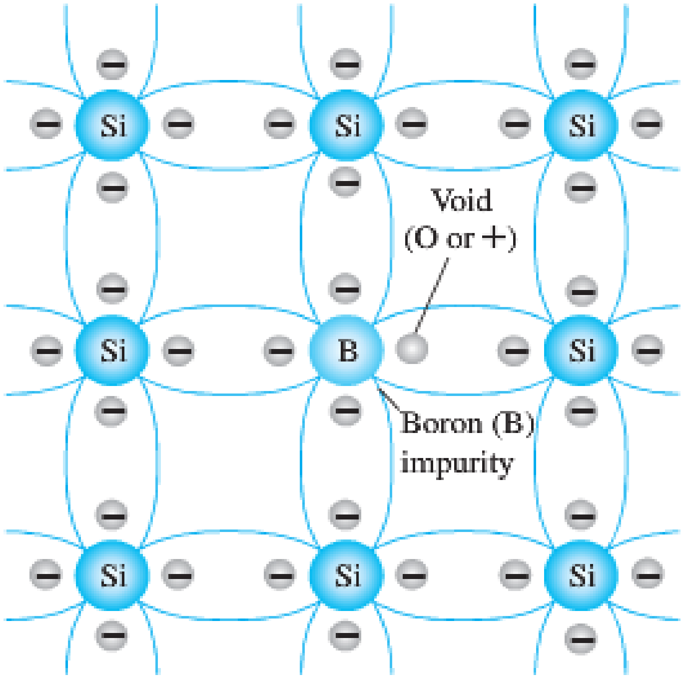


Effect of donor impurities on the energy band structure.

Antimony impurity in n-type material.

- Impurities with five valence electrons are called **donor** atoms, because the inserted impurity atom has donated a relatively “free” electron to the structure
- Still electrically neutral

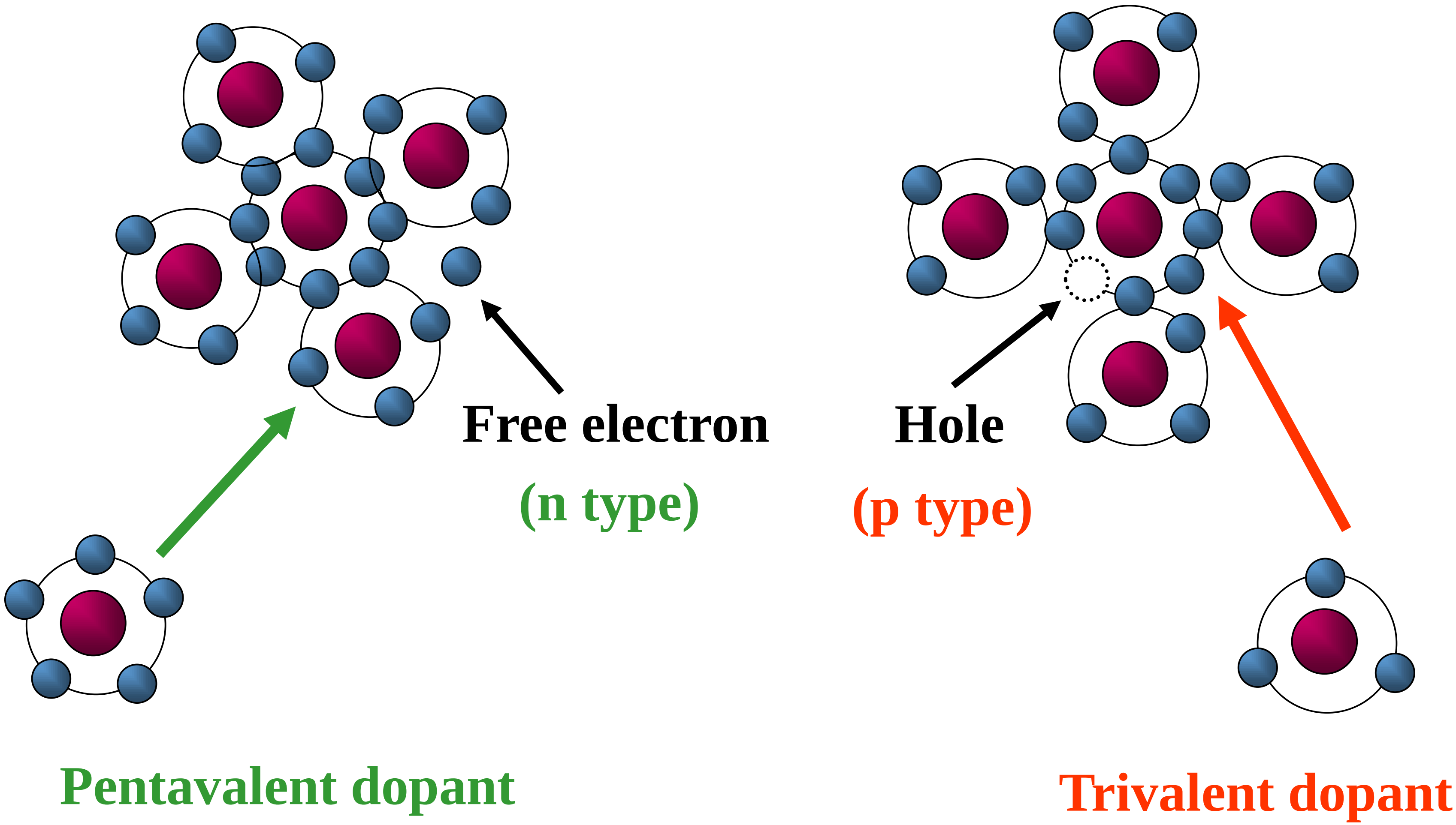
p-Type Material



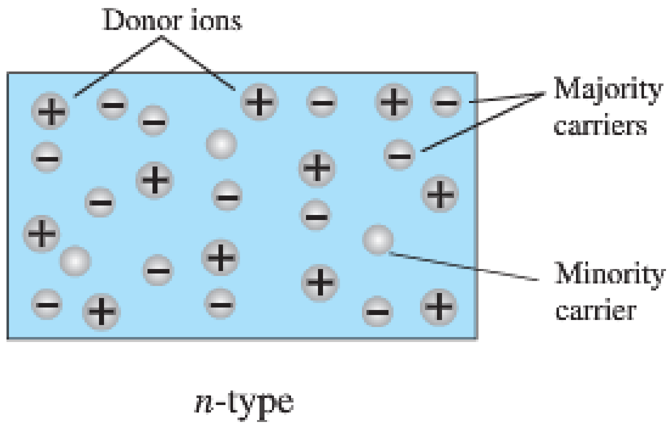
Boron impurity in p-type material.

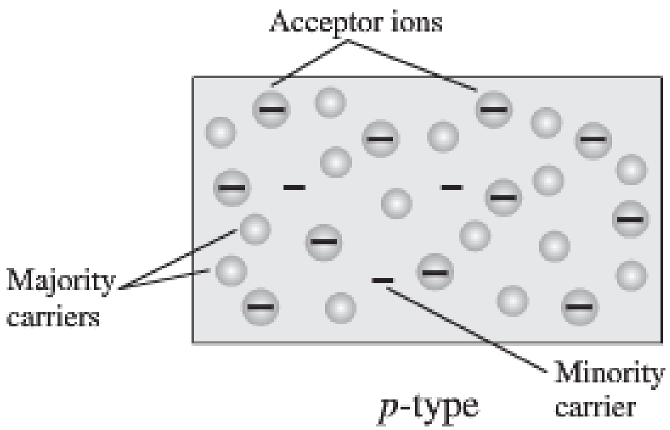
- There is now an insufficient number of electrons to complete the covalent bonds of the newly formed lattice.
  - The resulting vacancy is called a **hole**
- The diffused impurities with three valence electrons are called **acceptor** atoms, because the resulting vacancy will readily accept a free electron
- The resulting p-type material is electrically neutral

Silicon crystals are doped to provide permanent carriers.

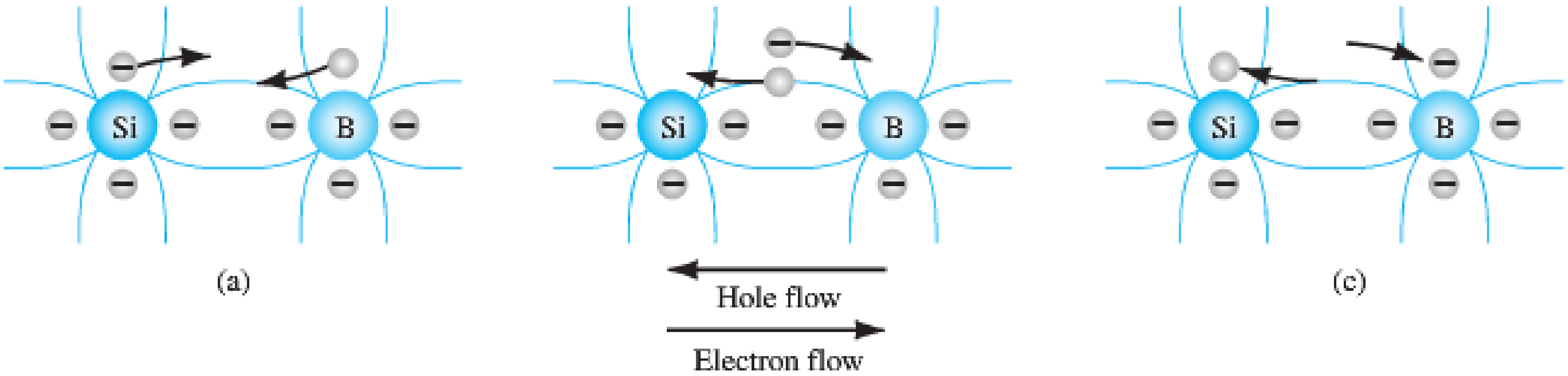


Majority and Minority Carriers





Electron versus Hole Flow

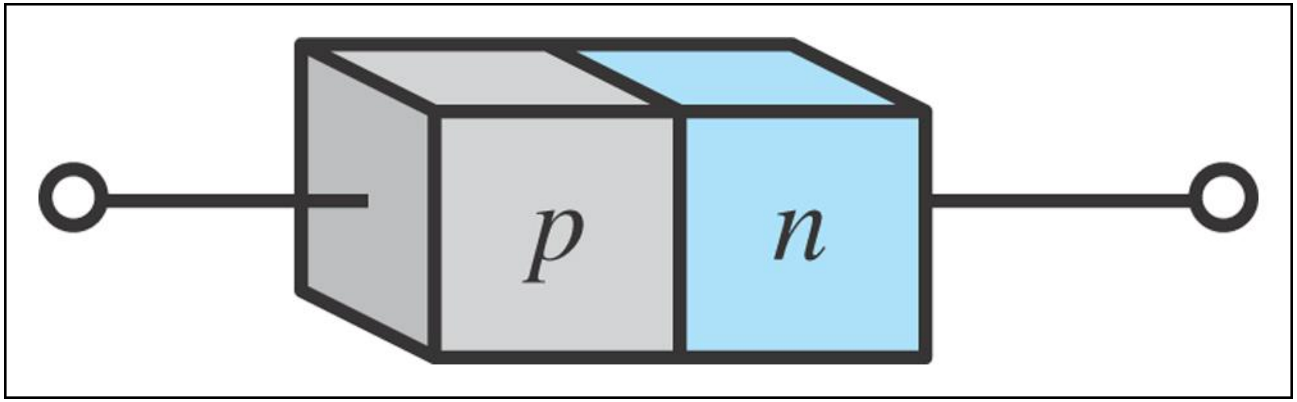


Semiconductors in Summary

- The most popular material is silicon.
- Pure crystals are intrinsic semiconductors.
- Doped crystals are extrinsic semiconductors.
- Crystals are doped to be n type or p type.
- A doped semiconductor will have mostly majority carriers and a few thermally generated *minority* carriers.
    - *Electrons* are majority carriers in n type
    - *Holes* are majority carriers in p type

SEMICONDUCTOR DIODE

One end of a silicon or germanium crystal can be doped as a *p*-type material and the other end as an *n*-type material.

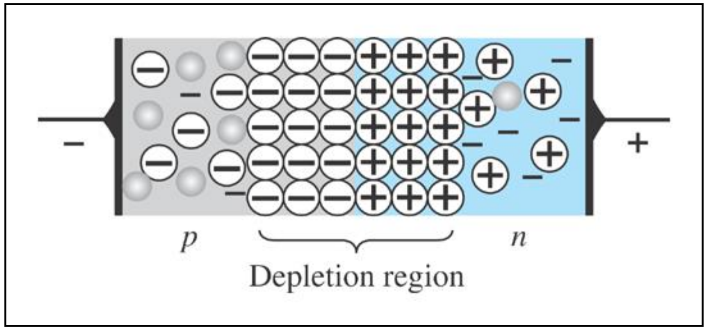


The result is a ***p-n* junction**

p-n Junctions

At the *p-n* junction, the excess conduction-band electrons on the *n*-type side are attracted to the valence-band holes on the *p*-type side.

The electrons in the *n*-type material migrate across the junction to the *p*-type material (electron flow).

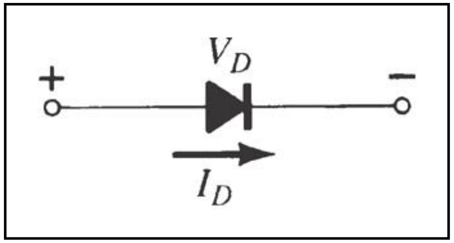


Electron migration results in a negative charge on the *p*-type side of the junction and a positive charge on the *n*-type side of the junction.

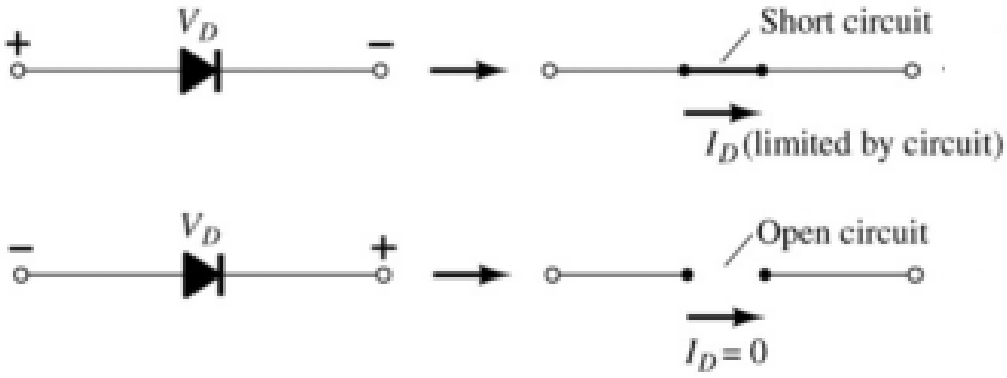
The result is the formation of a depletion region around the junction.

Diodes

The diode is a 2-terminal device.

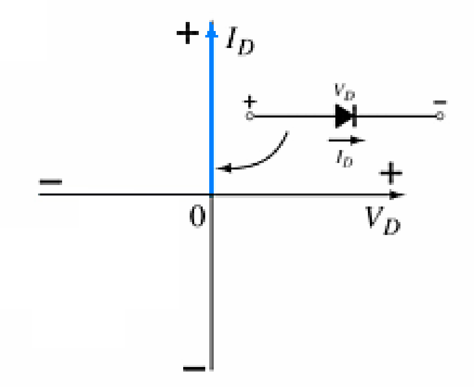


A diode ideally conducts in only one direction.



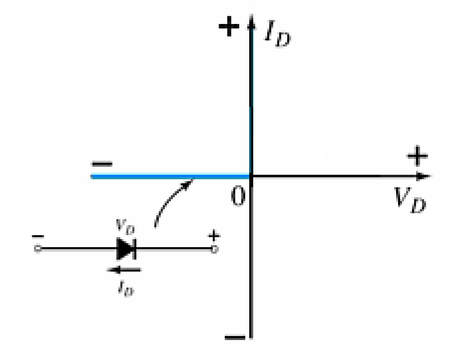
Diode Characteristics

Conduction Region



- The voltage across the diode is 0 V
- The diode acts like a short

Non-Conduction Region



- All of the voltage is across the diode
- The current is 0 A
- The diode acts like open

Diode Operating Conditions

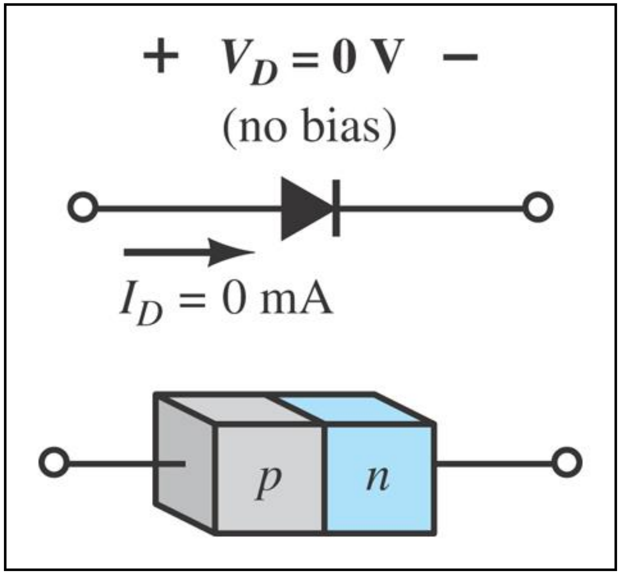
A diode has three operating conditions:

- **No bias**
- **Reverse bias**
- **Forward bias**

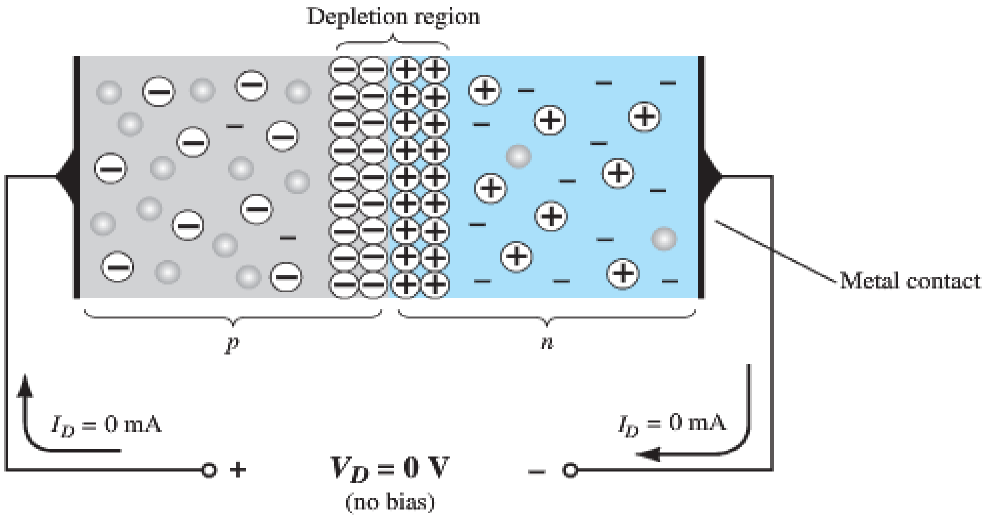
Diode Operating Conditions

No Bias

- No external voltage is applied: $V_D = 0$ V
- There is no diode current: $I_D = 0$ A
- Only a modest depletion region exists



No Applied Bias (V_D = 0 V)

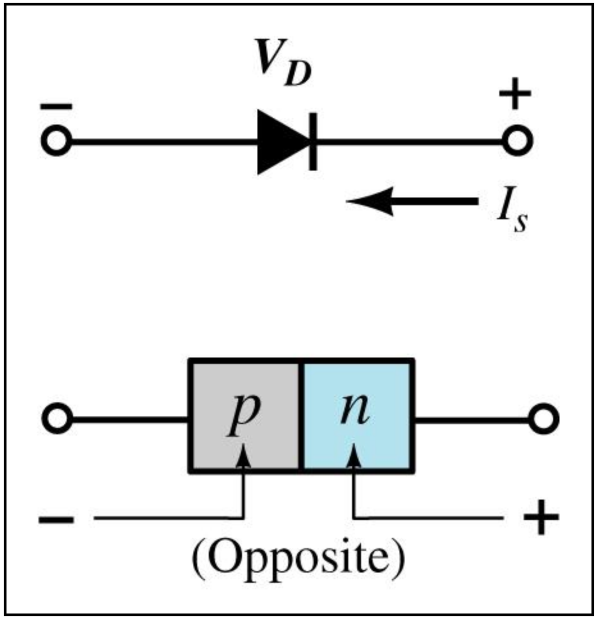


- This region of uncovered positive and negative ions is called the depletion region due to the "depletion" of free carriers in the region.
- In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero.

Diode Operating Conditions

Reverse Bias

External voltage is applied across the *p*-*n* junction in the opposite polarity of the *p*- and *n*-type materials.

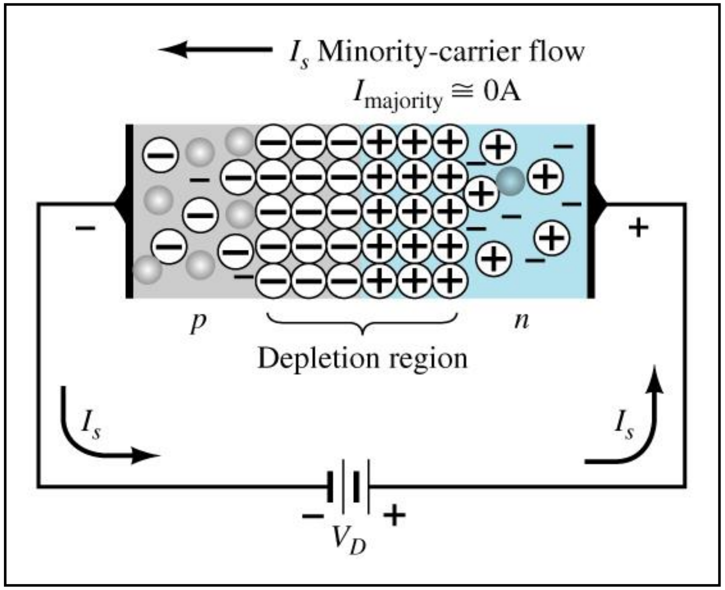


Diode Operating Conditions

Reverse Bias

The reverse voltage causes the depletion region to widen.

The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.



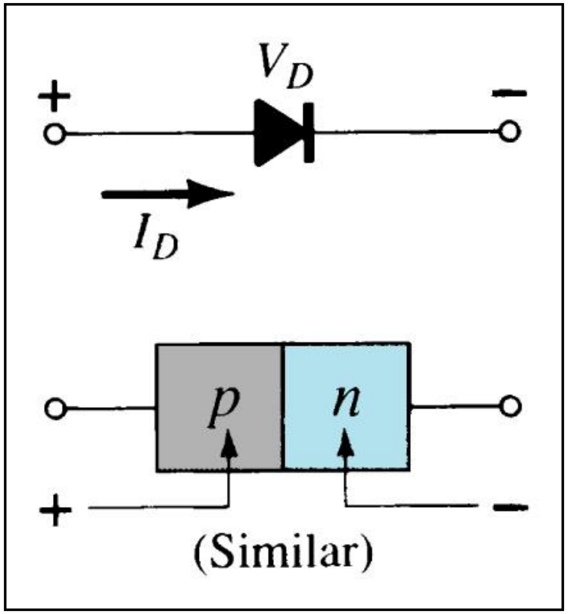
The current that exists under reverse bias conditions is called the reverse saturation current (Is). In the range of mA or nA.

- The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.
- The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by I_s .

Diode Operating Conditions

Forward Bias

- External voltage is applied across the *p*-*n* junction in the same polarity as the *p*- and *n*-type materials.
- The defined direction of conventional current for the positive voltage region matches the arrowhead in the diode symbol.

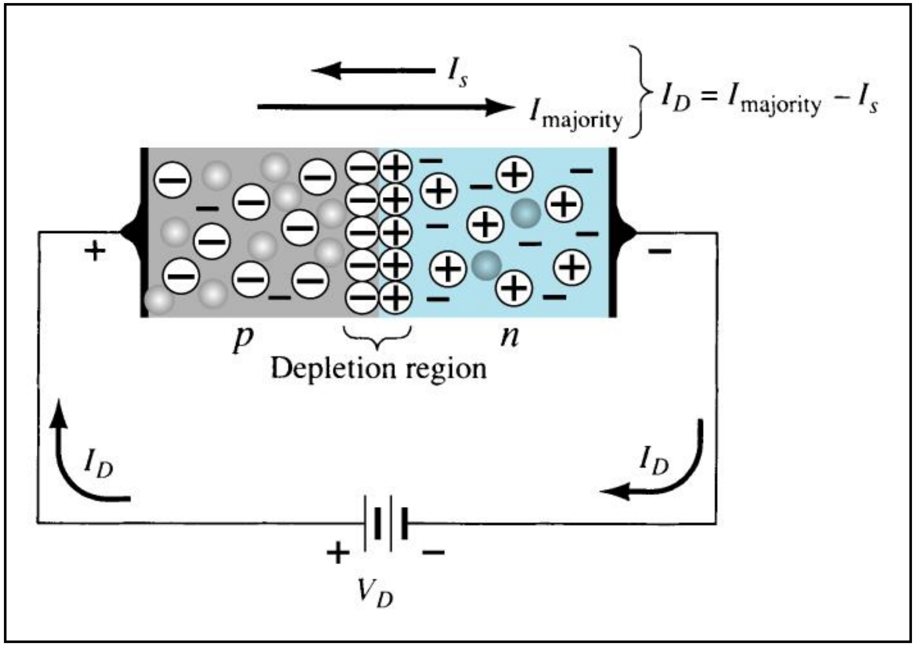


Diode Operating Conditions

Forward Bias

The forward voltage causes the depletion region to narrow.

The electrons and holes are pushed toward the *p-n* junction.

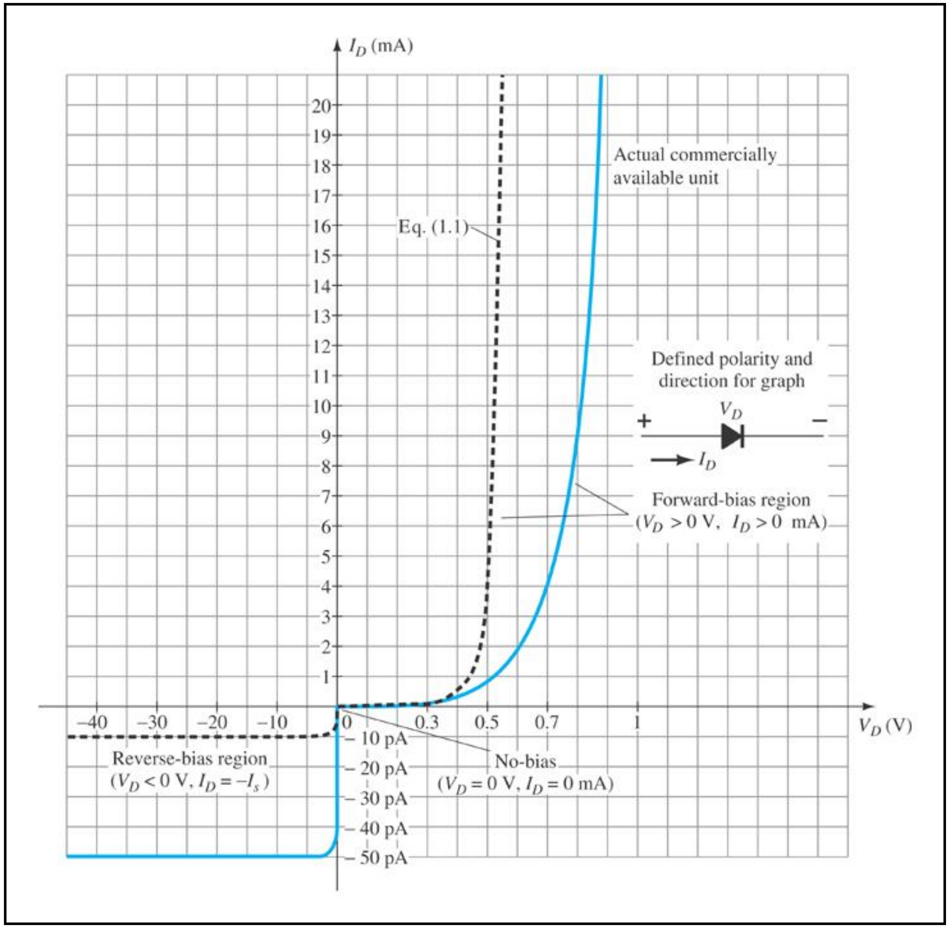


The electrons and holes have sufficient energy to cross the *p-n* junction.

Actual Diode Characteristics

Note the regions for no bias, reverse bias, and forward bias conditions.

Carefully note the scale for each of these conditions.



Diode Current Equation

It can be demonstrated through the use of solid-state physics that the general characteristics of a semiconductor diode can be defined by the following equation, referred to as Shockley's equation, for the forward- and reverse-bias regions:

$$\boxed{I_D = I_s(e^{V_D/nV_T} - 1)} \quad \text{(A)} \qquad \textbf{(1.2)}$$

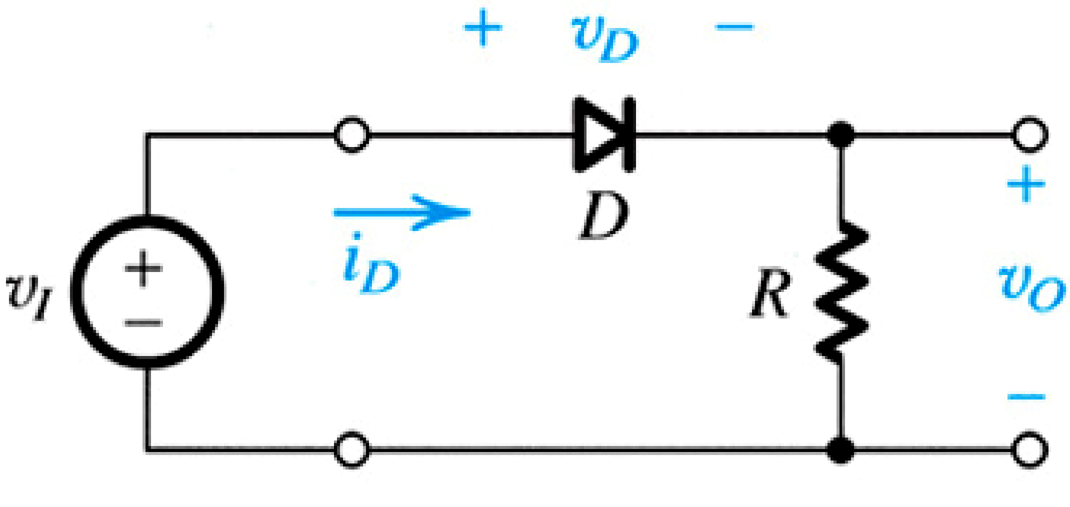
where I_s is the reverse saturation current
V_D is the applied forward-bias voltage across the diode
n is an ideality factor, which is a function of the operating conditions and physical construction; it has a range between 1 and 2 depending on a wide variety of factors ($n = 1$ will be assumed throughout this text unless otherwise noted).

The voltage V_T in Eq. (1.1) is called the *thermal voltage* and is determined by

$$\boxed{V_T = \frac{kT_K}{q}} \quad \text{(V)} \qquad \textbf{(1.3)}$$

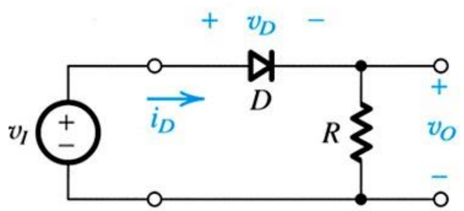
where k is Boltzmann's constant $= 1.38 \times 10^{-23}$ J/K
T_K is the absolute temperature in kelvins $= 273 +$ the temperature in °C
q is the magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

A Simple Application – The Rectifier

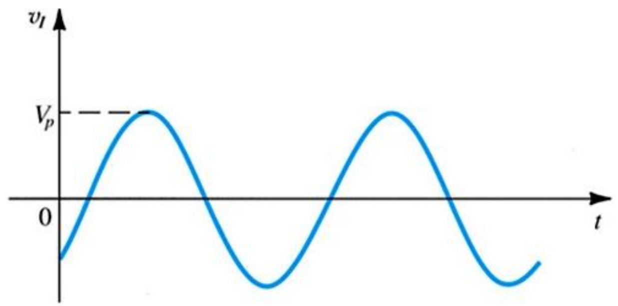


- One fundamental application of diode behavior is the rectifier.
  - A **rectifier** is a circuit which converts AC into DC

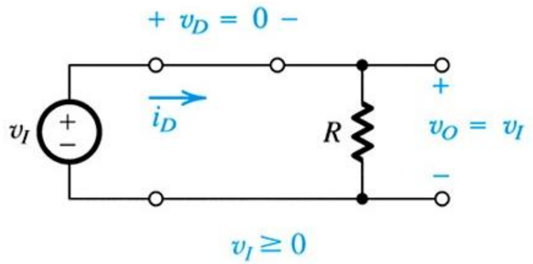
The Rectifier Operation – Using Ideal Diode



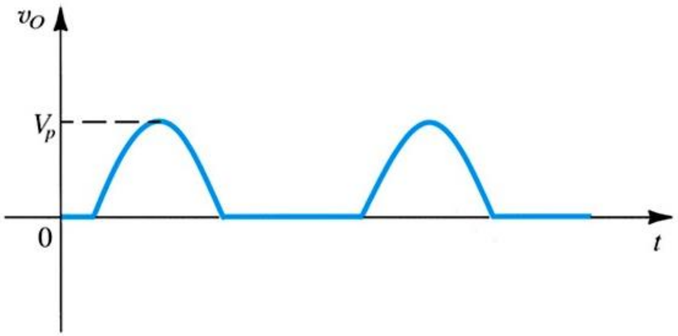
Rectifier circuit



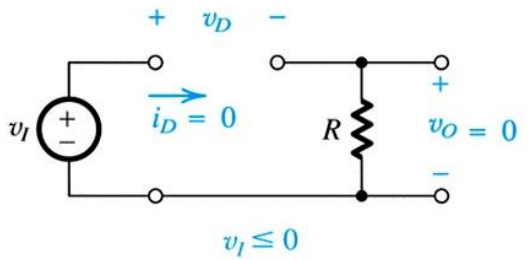
Input waveform



Equivalent circuit when Vi >/= 0



Output waveform

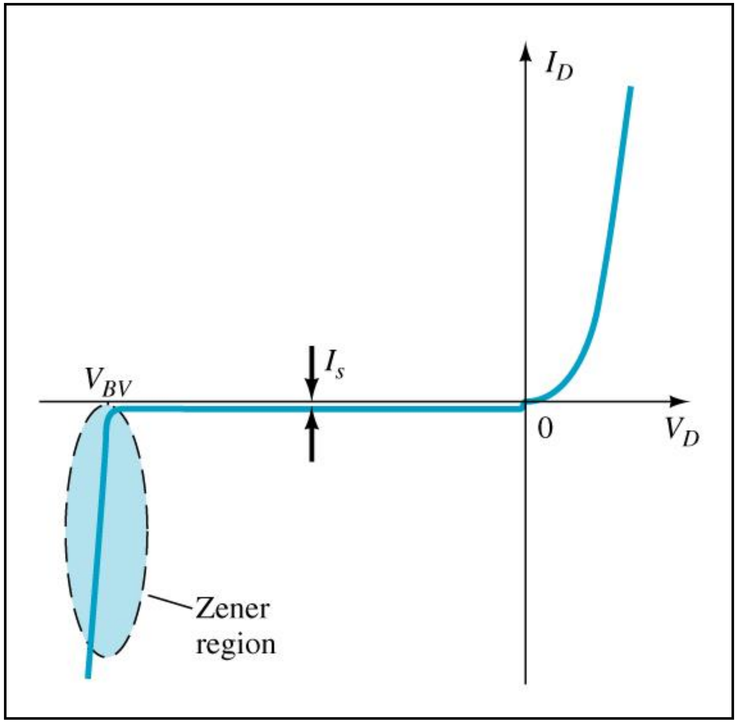


Equivalent circuit when Vi < 0

Breakdown Region

The breakdown region is in the diode's reverse-bias region.

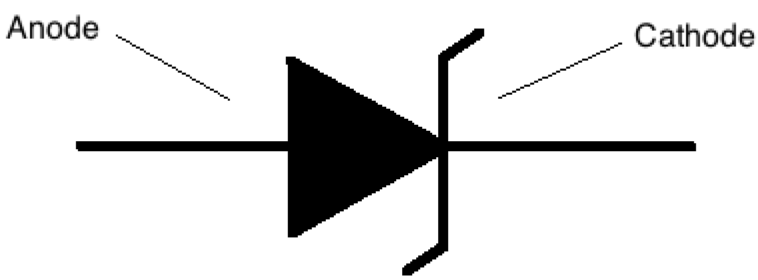
- At some point the reverse bias voltage is so large (at breakdown voltage V_{BV}) the diode breaks down and the reverse current increases dramatically.
- This can be destructive if the power dissipated exceeds the "safe" level
- The maximum reverse voltage that won't take a diode into the zener region is called the **peak inverse voltage** or **peak reverse voltage.**



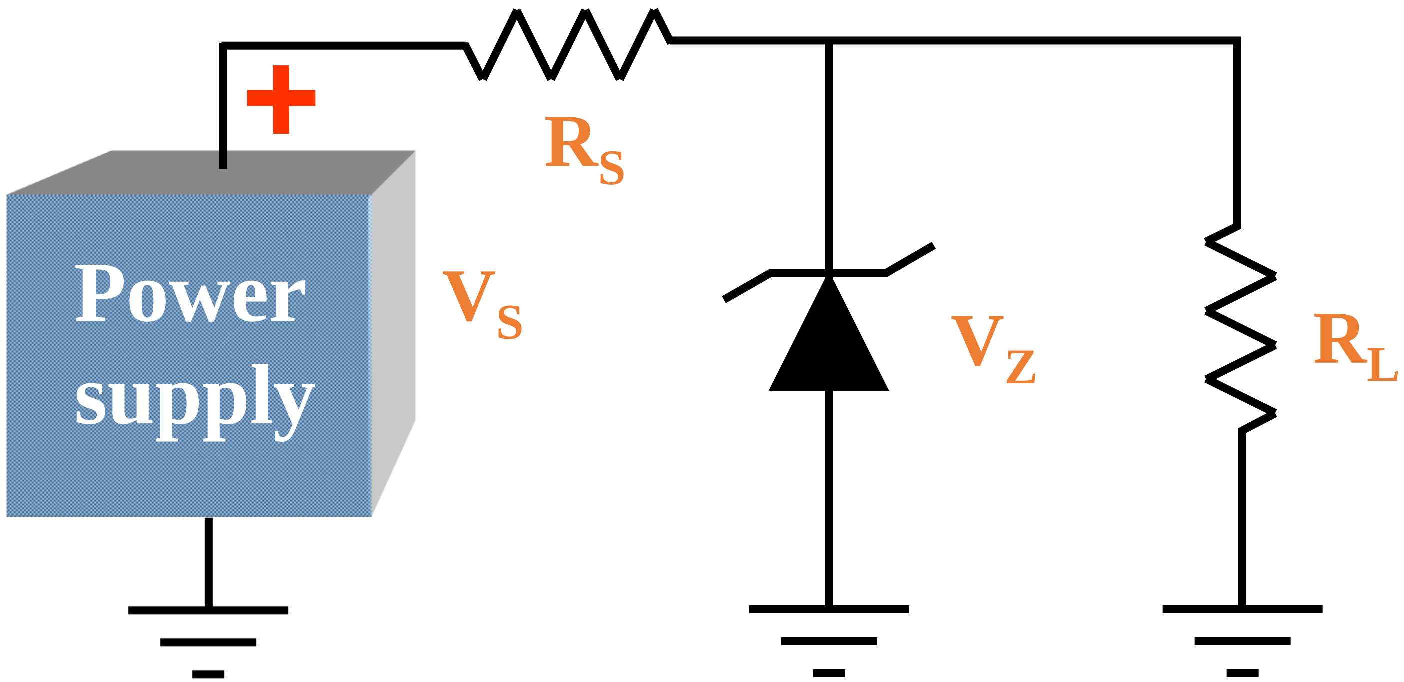
- **Two mechanisms:**
  - ***Zener breakdown:*** Due to high electric field at the depletion region (up to about 5V)
  - ***Avalanche breakdown:*** Due to high kinetic energy of electrons (5V and above)

Zener Voltage

- The breakdown voltage (V_{BV}) can be reduced by increasing the doping levels in the p - and n -type materials.
- As V_{BV} decreases to low levels, such as ~5V, Zener breakdown becomes the dominant factor compared to avalanche breakdown.
  - The strong electric field in the region of the junction can disrupt the bonding forces within the atom and “generate” carriers.
- This sharp change in the characteristic at any breakdown voltage is called the Zener region
  - Diodes employing this unique portion of the characteristic of a p–n junction are called **Zener diodes**
    - **The actual breakdown mechanism can be either zener or avalanche**
- The voltage that causes a diode to enter the zener region of operation is called the **zener voltage (V_Z).**



A zener diode voltage regulator



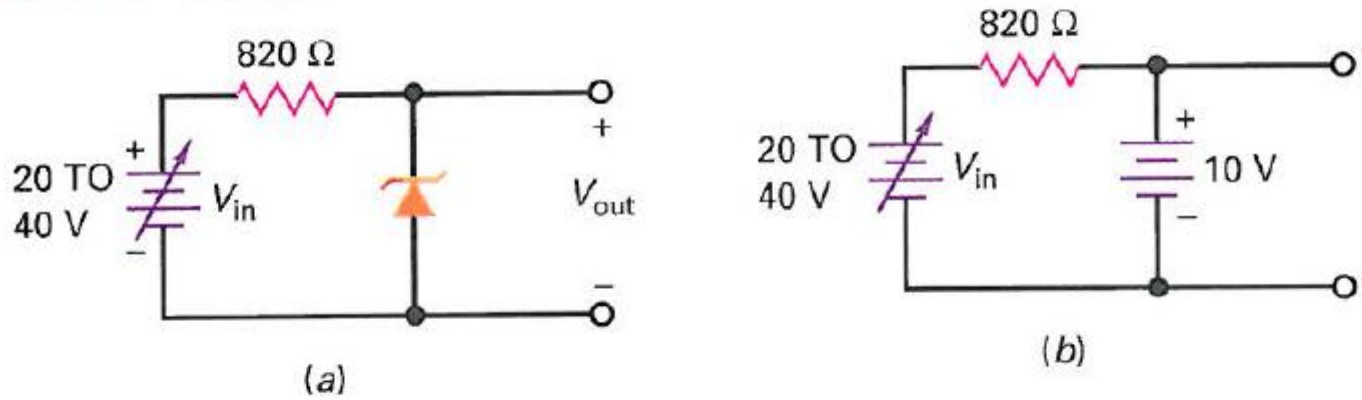
This circuit will regulate when the Thevenin voltage facing the zener diode is <u>greater</u> than the zener voltage.

$$V_{TH} = \frac{R_L}{R_S + R_L} V_S$$

Example 5-1

Suppose the zener diode of Fig. 5-4*a* has a breakdown voltage of 10 V. What are the minimum and maximum zener currents?

Figure 5-4 Example.



SOLUTION The applied voltage may vary from 20 to 40 V. Ideally, a zener diode acts like the battery shown in Fig. 5-4*b*. Therefore, the output voltage is 10 V for any source voltage between 20 and 40 V.

$$I_S = \frac{10\text{ V}}{820\ \Omega} = 12.2\text{ mA} \qquad I_S = \frac{30\text{ V}}{820\ \Omega} = 36.6\text{ mA}$$

Forward Bias Voltage

The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons and holes are given sufficient energy to cross the p-n junction. This energy comes from the external voltage applied across the diode.

The forward bias voltage required for a:

gallium arsenide diode ≅ 1.2 V

silicon diode ≅ 0.7 V

germanium diode ≅ 0.3 V

EXAMPLE 1.3 Determine the dc resistance levels for the diode of Fig. 1.24 at

a. $I_D = 2$ mA (low level)
b. $I_D = 20$ mA (high level)
c. $V_D = -10$ V (reverse-biased)

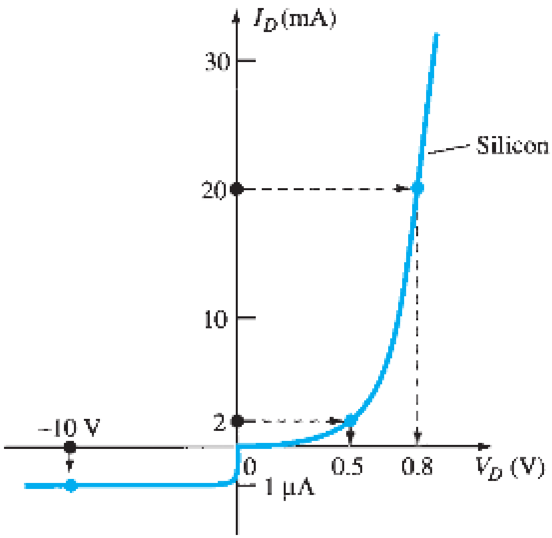


FIG. 1.24
Example 1.3.

Solution:

a. At $I_D = 2$ mA, $V_D = 0.5$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.5\text{ V}}{2\text{ mA}} = \mathbf{250\ \Omega}$$

b. At $I_D = 20$ mA, $V_D = 0.8$ V (from the curve) and

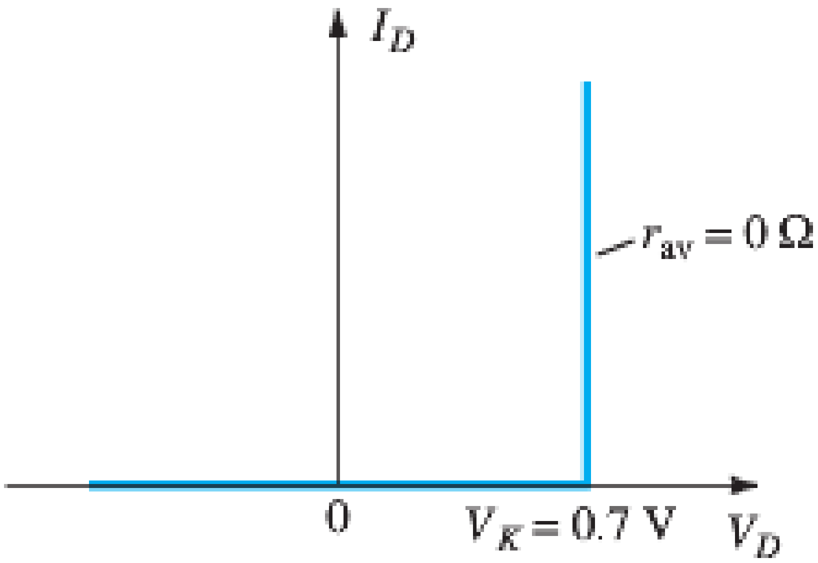
$$R_D = \frac{V_D}{I_D} = \frac{0.8\text{ V}}{20\text{ mA}} = \mathbf{40\ \Omega}$$

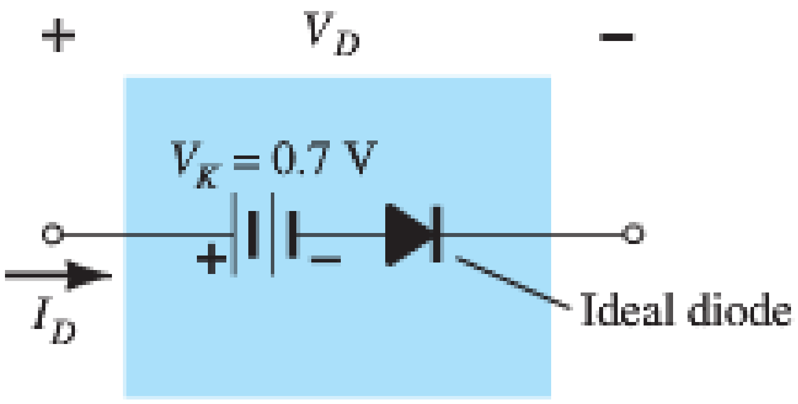
c. At $V_D = -10$ V, $I_D = -I_s = -1\ \mu$A (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{10\text{ V}}{1\ \mu\text{A}} = \mathbf{10\ M\Omega}$$

Diode Equivalent Circuit

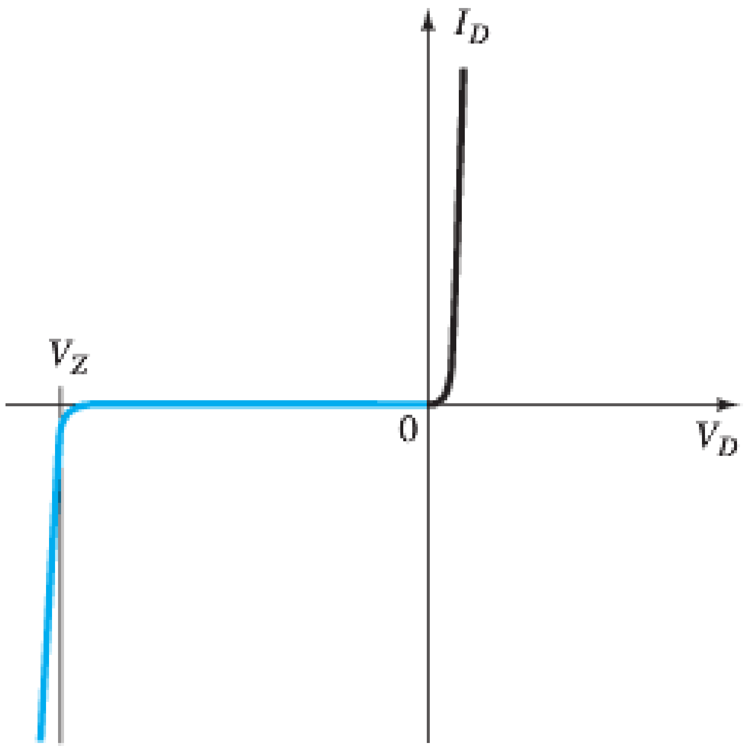
Simplified Equivalent Circuit

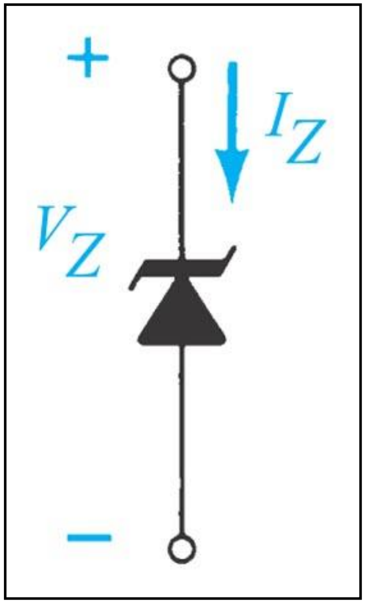




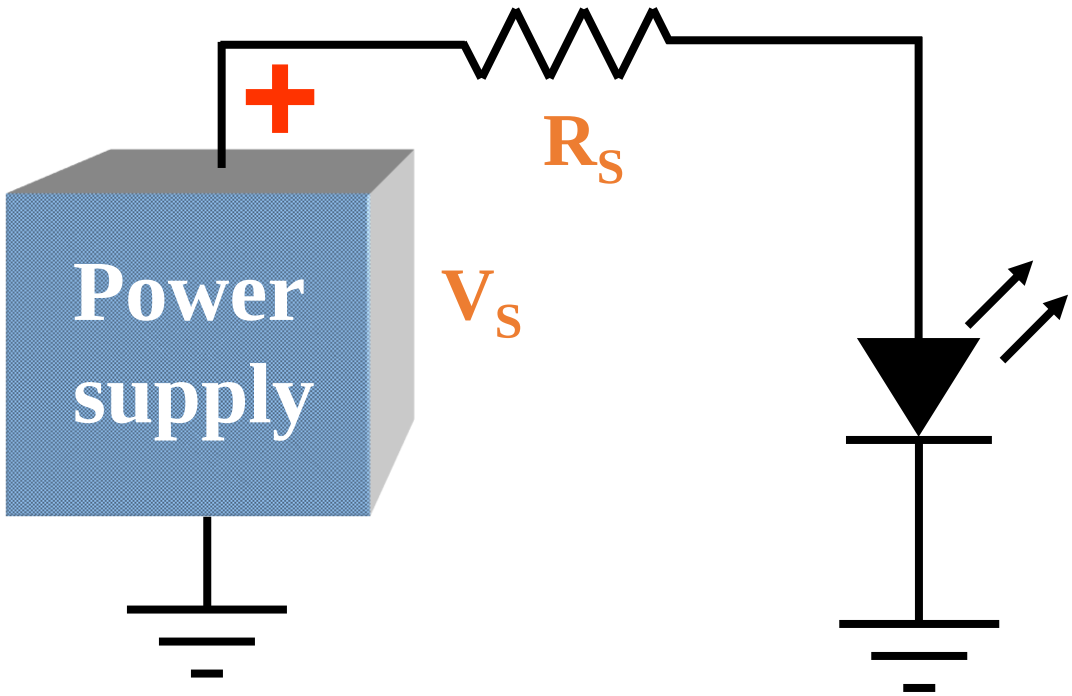
Zener Diode

A **Zener diode** is one that is designed to safely operate in its zener region; i.e., biased at the Zener voltage (V_Z).





Common zener diode voltage ratings are between 1.8 V and 200 V



Light-emitting diode

$$I_S = \frac{V_S - V_D}{R_S}$$

- **The brightness of a LED depends on the current.**
- **LEDs have very low breakdown voltages, typically between 3 and 5 V.**

Continue to next slide ……..