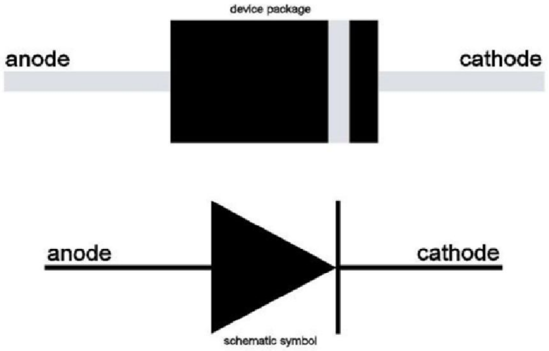
DIODE BASICS AND APPLICATIONS AND SPECIAL DIODES



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1-1 ATOMIC STRUCTURE

- All matter is made of atoms; and all atoms consists of electrons, protons, and neutrons.

  ‘An atom is the smallest particle of an element that retains the characteristics of that element. Each of the known 109 elements has atoms that are different from the atoms of all other elements.’

- The nucleus consists of positively charged particles called **protons** and uncharged particles called **neutrons**. The basic particles of negative charge are called **electrons**

Figure 1–1 The Bohr model of an atom showing electrons in orbits around the nucleus, which consists of protons and neutrons. The “tails” on the electrons indicate motion.

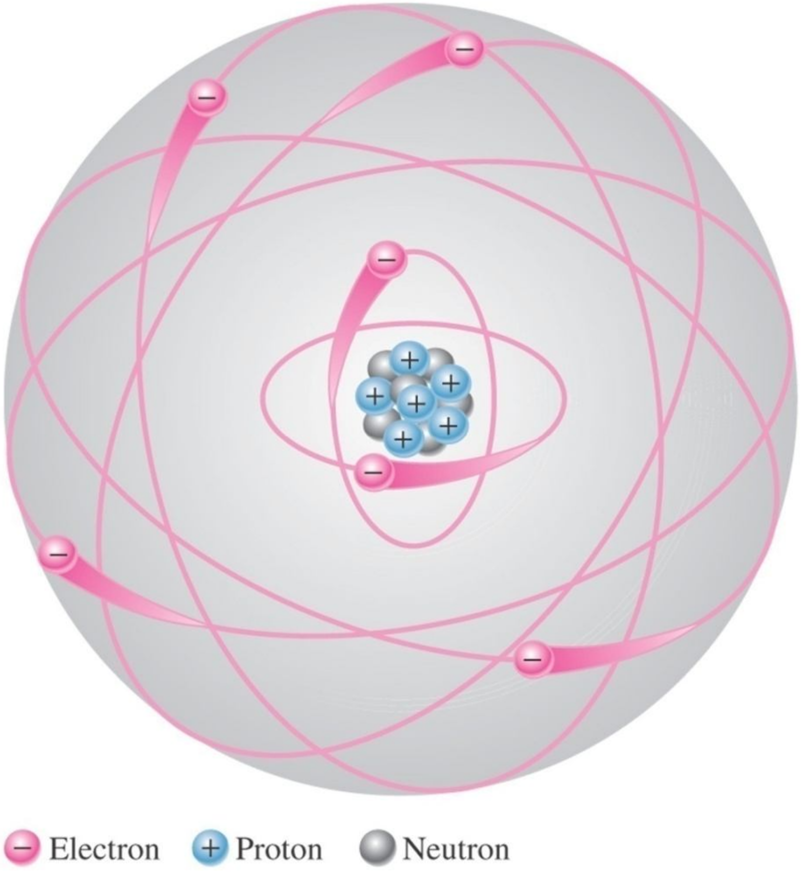
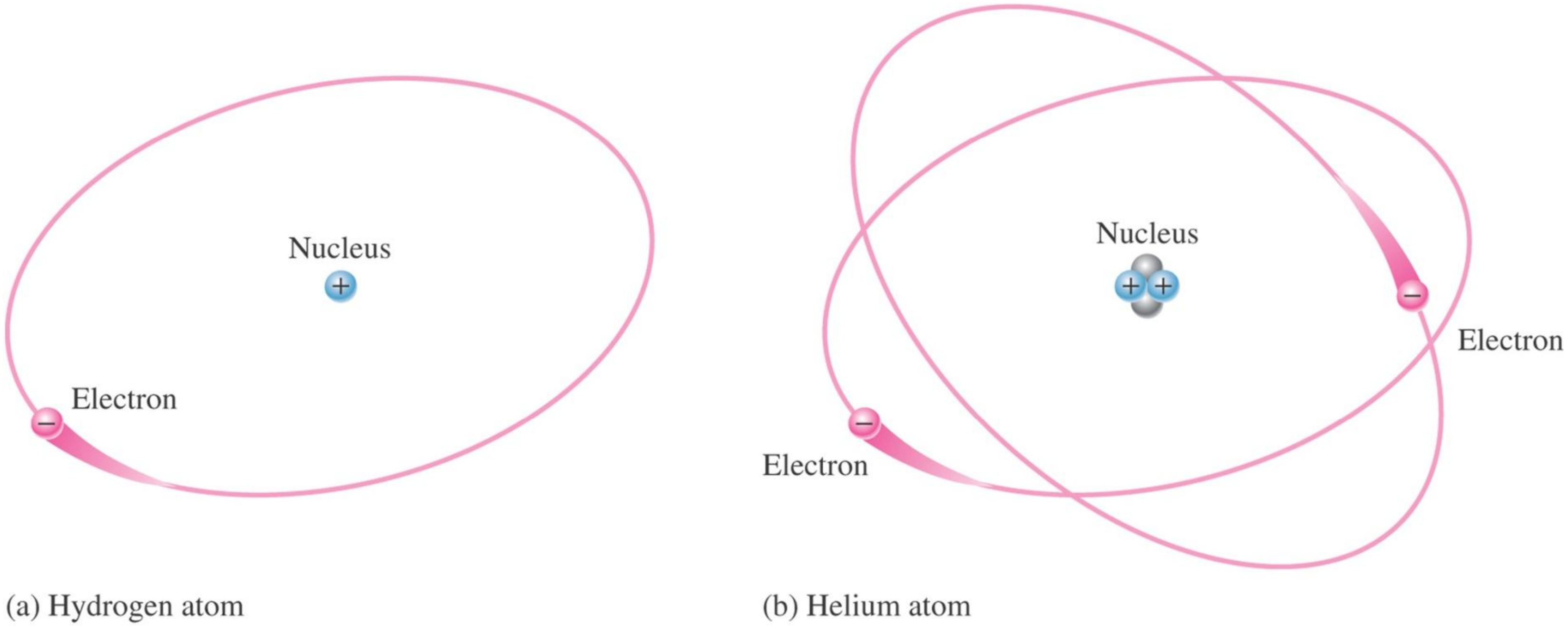


Figure 1–2 Two simple atoms, hydrogen and helium.



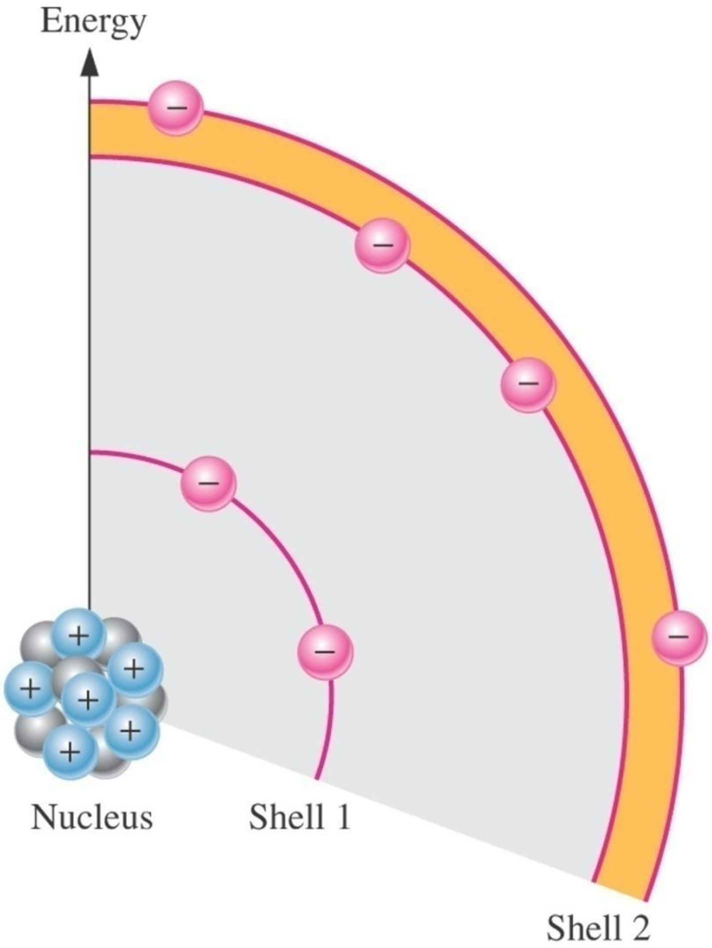
ATOMIC NUMBER

- All elements are arranged in the periodic table of the elements in order according to their atomic number. The atomic number equals the number of protons in the nucleus, which is the same as the number of electrons in an electrically balanced (neutral) atom.

ELECTRON SHELLS AND ORBITS

- Electrons orbit the nucleus of an atom at certain distances from the nucleus. Electrons near the nucleus have less energy than those in more distant orbits. It is known that only discrete (separate and distinct) values of electron energies exists within atomic structures. Therefore, electrons must orbit only at discrete distances from the nucleus.

Figure 1–3 Energy increases as the distance from the nucleus increases.



VALENCE ELECTRONS

- Electrons with the highest energy exist in the outermost shell of an atom and are relatively loosely bound to the atom. This outermost shell is known as the valence shell and electrons in this shell are called valence electrons.

IONIZATION

- The departure of a valence electron leaves a previously neutral atom with an excess of positive charge (more protons than electrons). The process of losing a valence electron is known as ionization

THE NUMBER OF ELECTRONS IN EACH SHELL

- The maximum number of electrons (N_e) that can exist in each shell of an atom is a fact of nature and can be calculated by the formula,
- $N_e = 2n^2$
- Where n is the number of shell.

1-2 SEMICONDUCTORS, CONDUCTORS, AND INSULATORS

CONDUCTOR

- Low resistance for easy current flow.
- Atom is tend to release valence electron and it flow freely from one atom to another.
- Conduction and valence band overlap,electron easily move

INSULATOR

- High resistance so current cannot flow.
- Atom is tend to absorb valence electron to valence layer to make it stable and try avoid electrical of chemical activity.
- The energy gap is big, so electron cannot easily move.

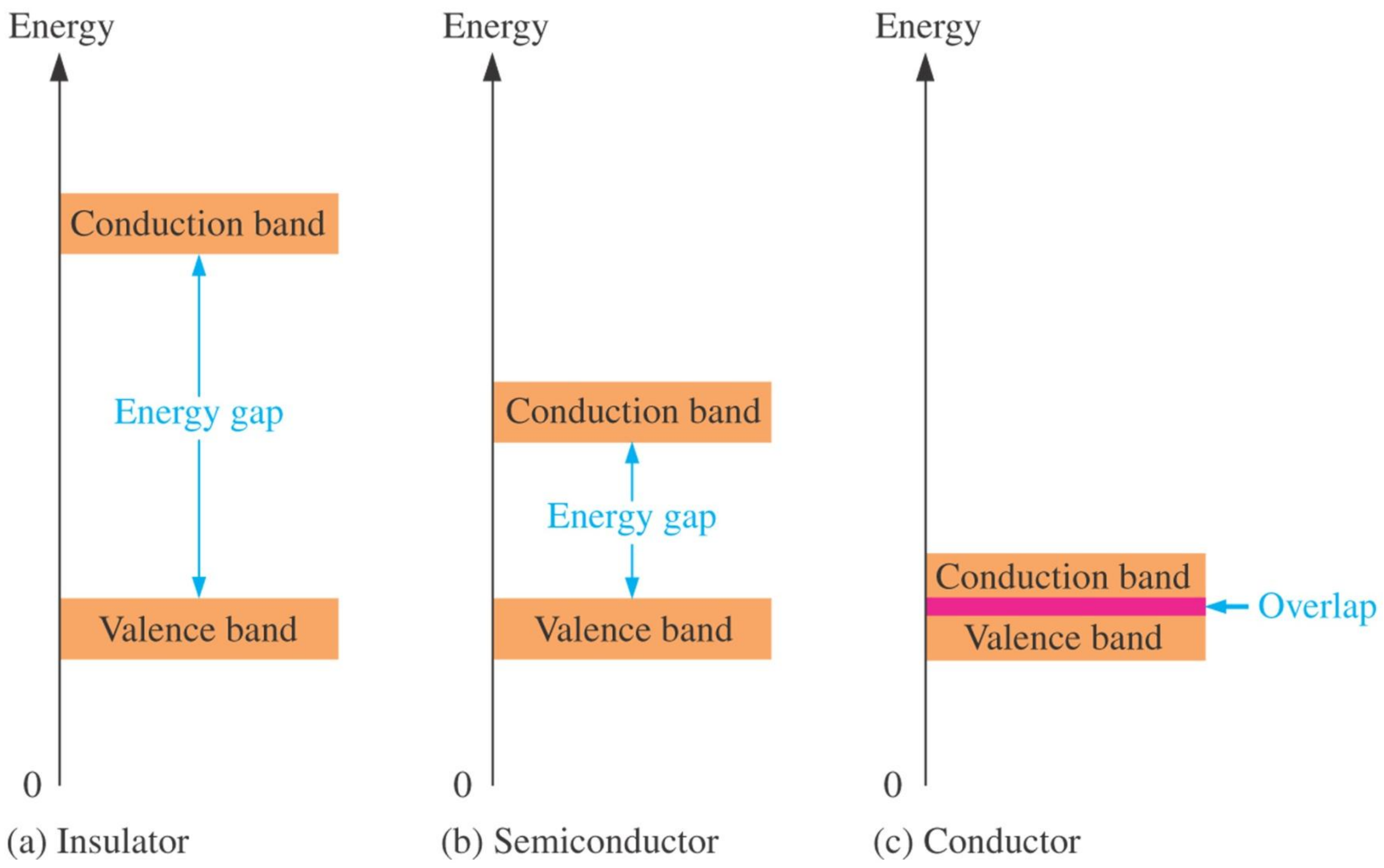
SEMICONDUCTOR

- Between conductor and insulator.
- Difficult to free or accept valence electron from other atom

ENERGY BANDS

- The difference in energy between the valence band and the conduction band is called an energy gap.

Figure 1–5 Energy diagrams for the three types of materials.

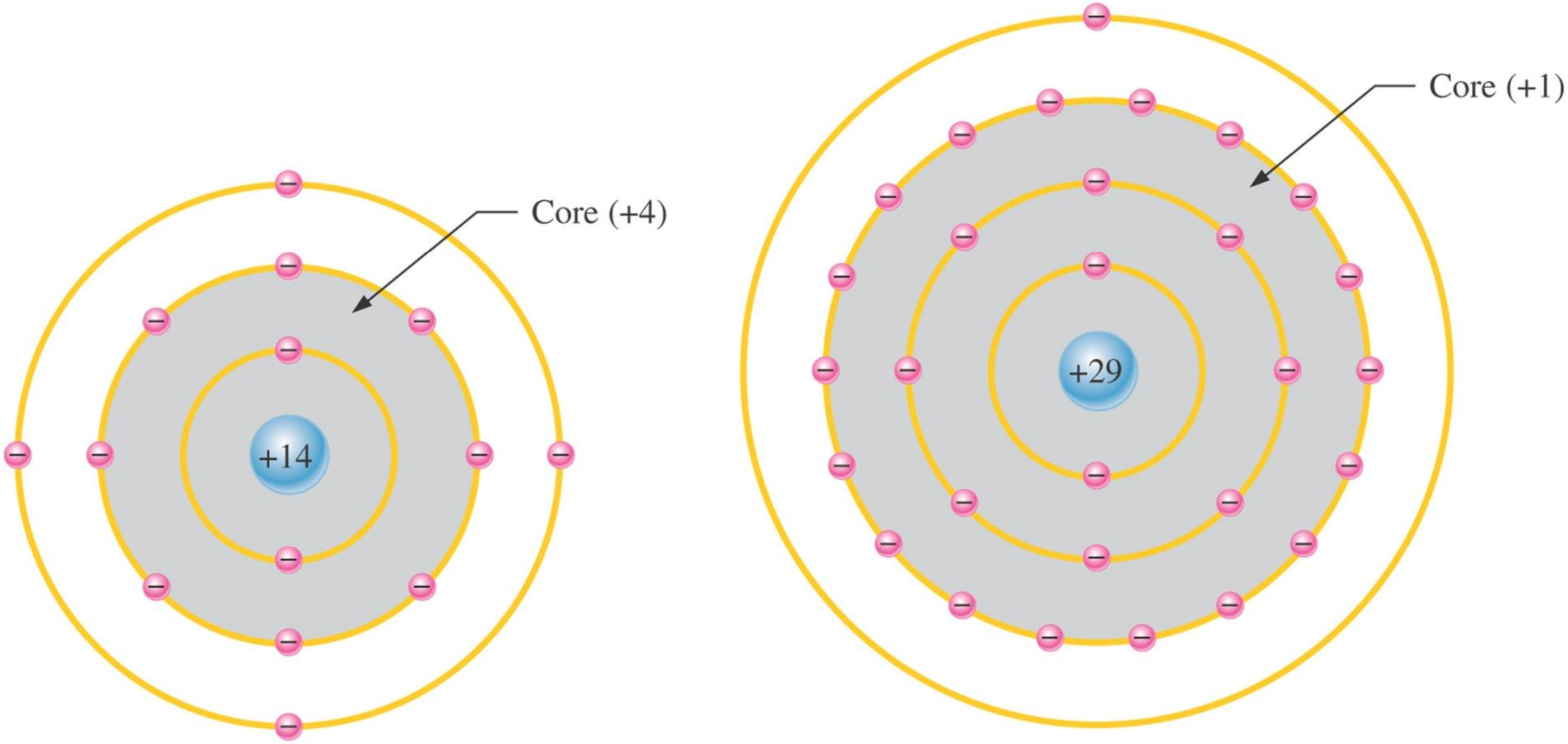


(a) Insulator (b) Semiconductor (c) Conductor

COMPARISON OF A SEMICONDUCTOR ATOM TO A CONDUCTOR ATOM

Silicon is a semi conductor	Copper is a conductor
Core of the Silicon atom has a net charge of +4	Core of the Copper atom has a net charge of +1

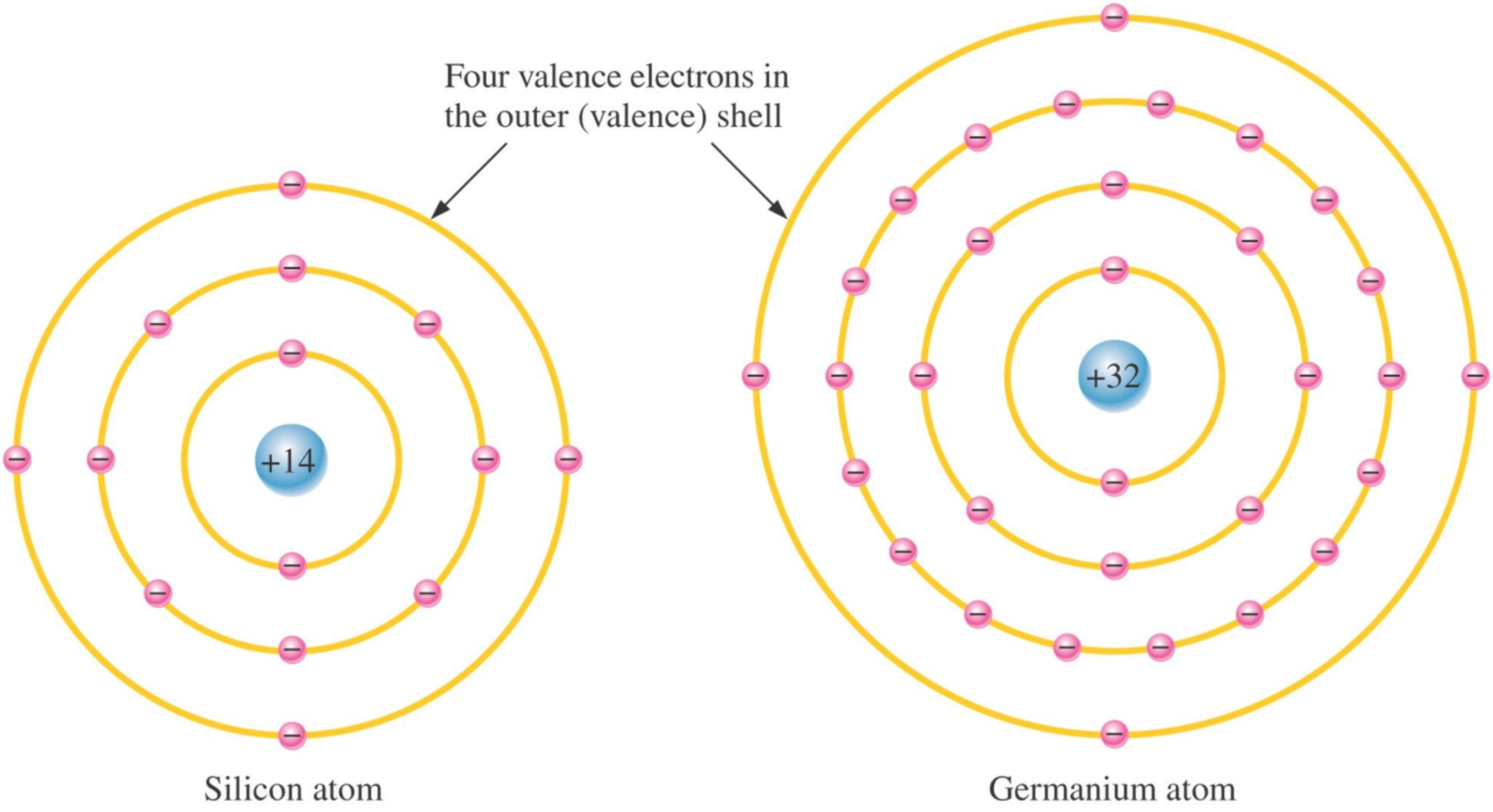
FIGURE 1–6 DIAGRAMS OF THE SILICON AND COPPER ATOMS.



(a) Silicon atom (b) Copper atom

SILICON AND GERMANIUM

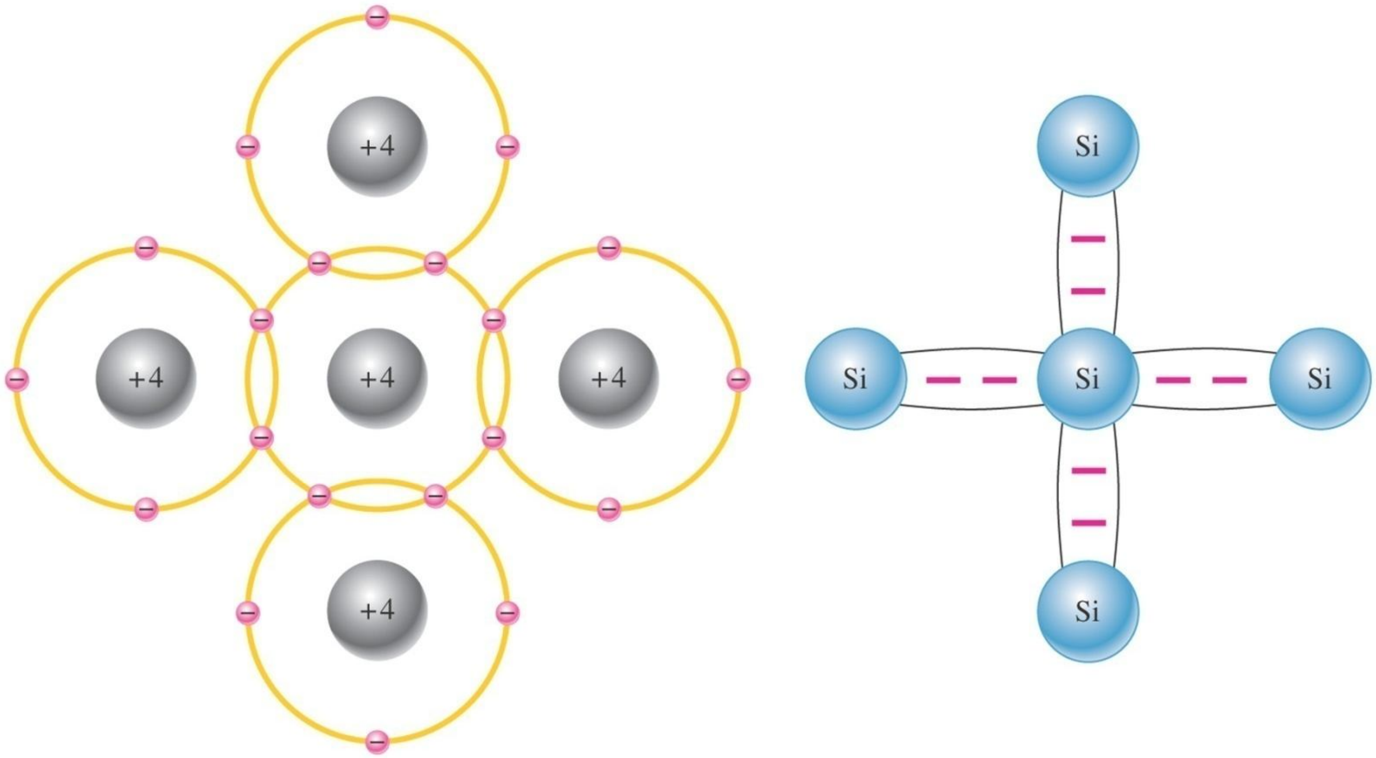
Figure 1–7 Diagrams of the silicon and germanium atoms.



1-3 COVALENT BONDS

- When atoms combine to form a solid, crystalline material, they arrange themselves in a symmetrical pattern. the atoms within the crystal structure are held together by covalent bonds, which are created by the interactions of the valence electrons of the atoms. Silicon is a crystalline material.

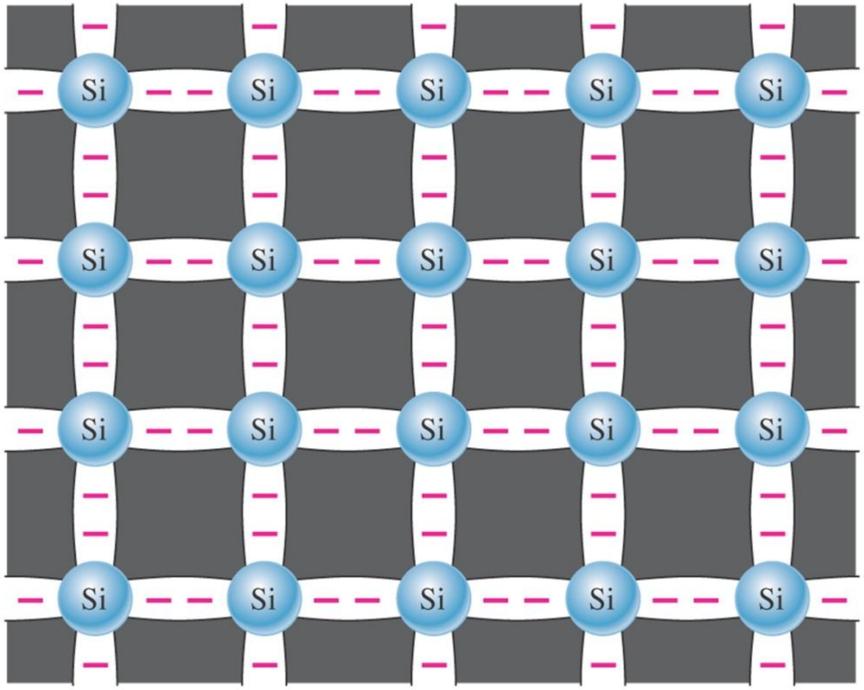
FIGURE 1–8 ILLUSTRATION OF COVALENT BONDS IN SILICON.



(a) The center silicon atom shares an electron with each of the four surrounding silicon atoms, creating a covalent bond with each. The surrounding atoms are in turn bonded to other atoms, and so on.

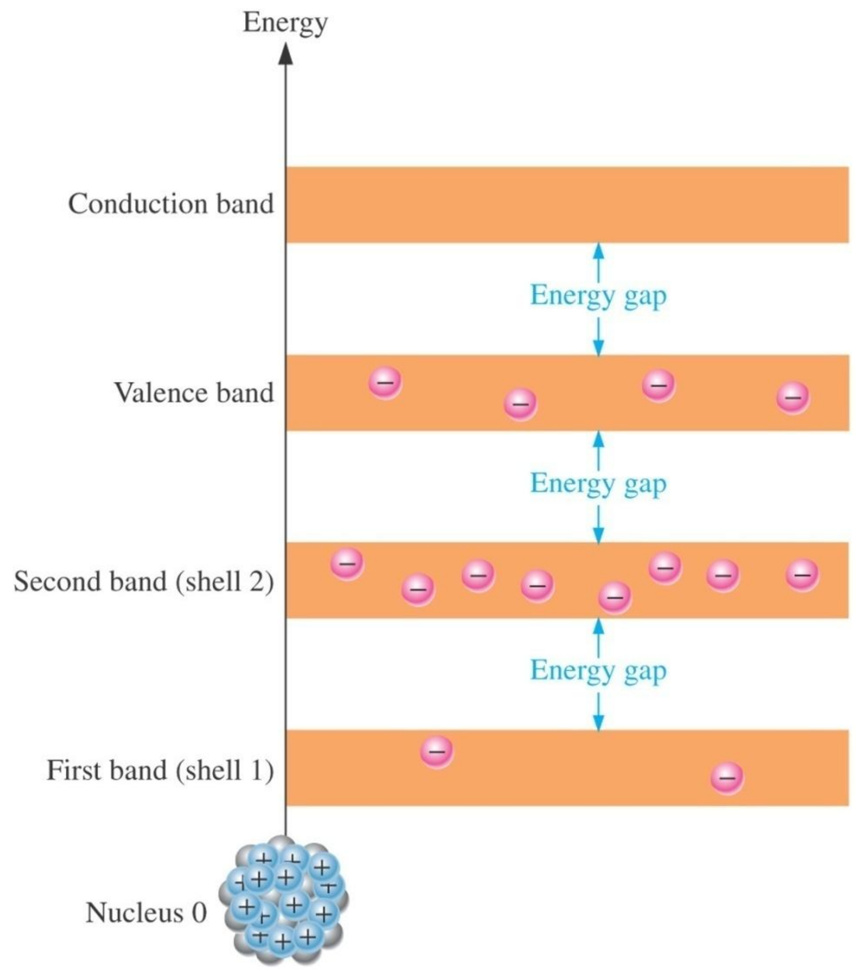
(b) Bonding diagram. The red negative signs represent the shared valence electrons.

Figure 1–9 Covalent bonds in a silicon crystal.



1-4 CONDUCTION IN SEMICONDUCTORS

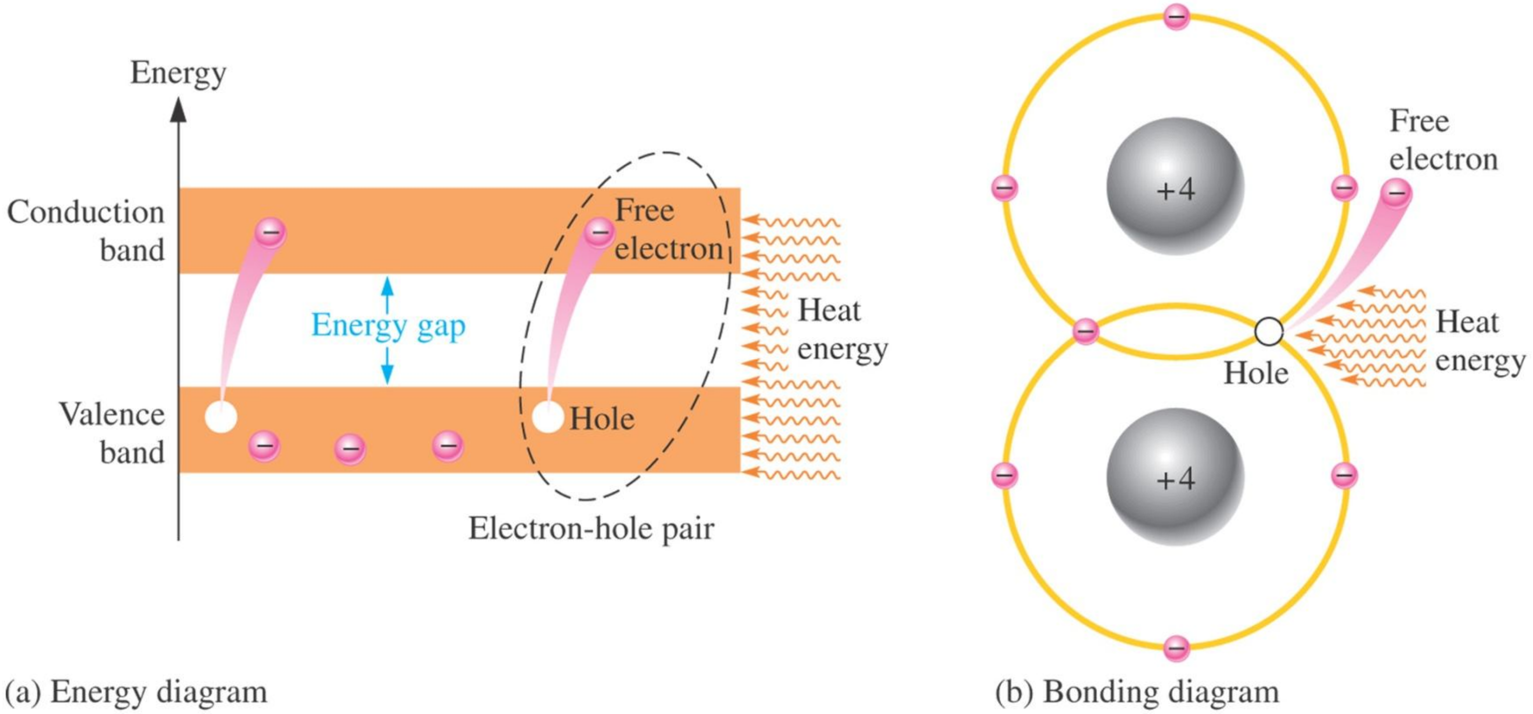
Figure 1–10 Energy band diagram for an unexcited atom in a pure (intrinsic) silicon crystal. There are no electrons in the



CONDUCTION ELECTRONS AND HOLES

- An intrinsic (pure) silicon crystal at room temperature has sufficient heat (thermal energy) for some valence electrons to jump the gap from the valence band into the conduction band, becoming free electrons, free electrons are also called conduction electrons.

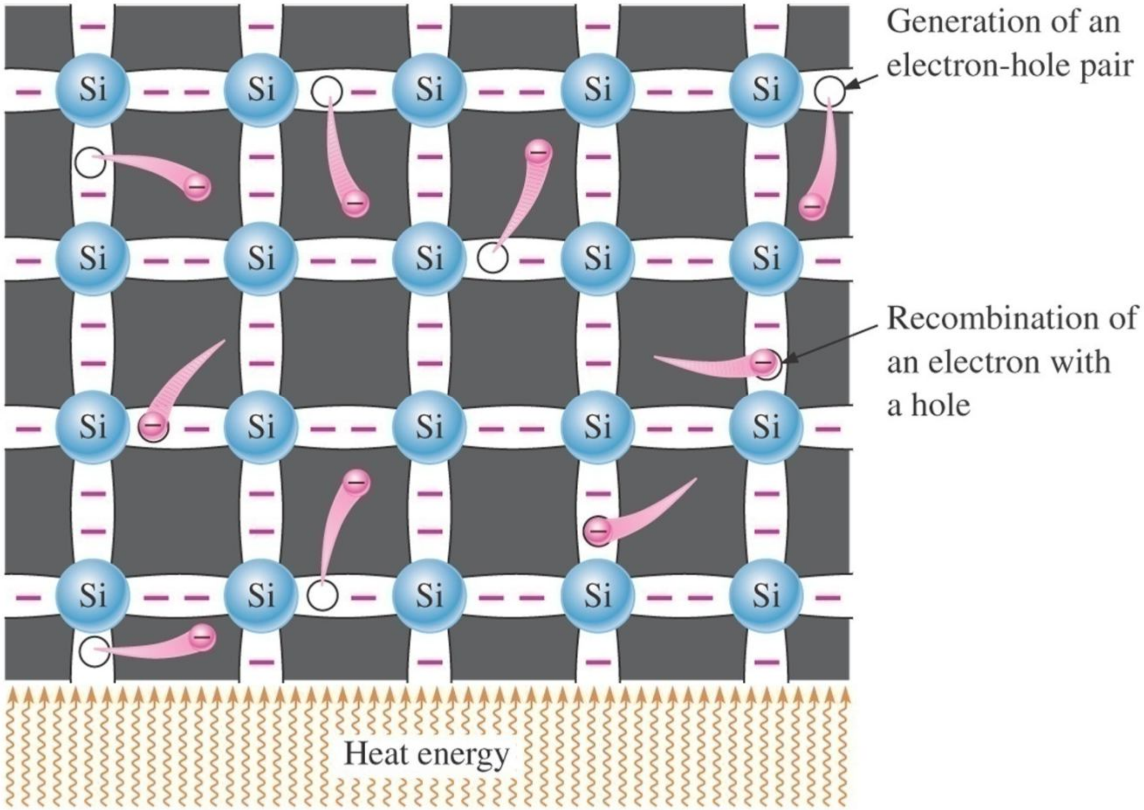
FIGURE 1–11 CREATION OF ELECTRON-HOLE PAIRS IN A SILICON CRYSTAL. ELECTRONS IN THE CONDUCTION BAND ARE FREE ELECTRONS.



(a) Energy diagram

(b) Bonding diagram

Figure 1–12 Electron-hole pairs in a silicon crystal. Free electrons are being generated continuously while some recombine with holes.



ELECTRON AND HOLE CURRENT

Figure 1–13 Electron current in intrinsic silicon is produced by the movement of thermally generated free electrons.

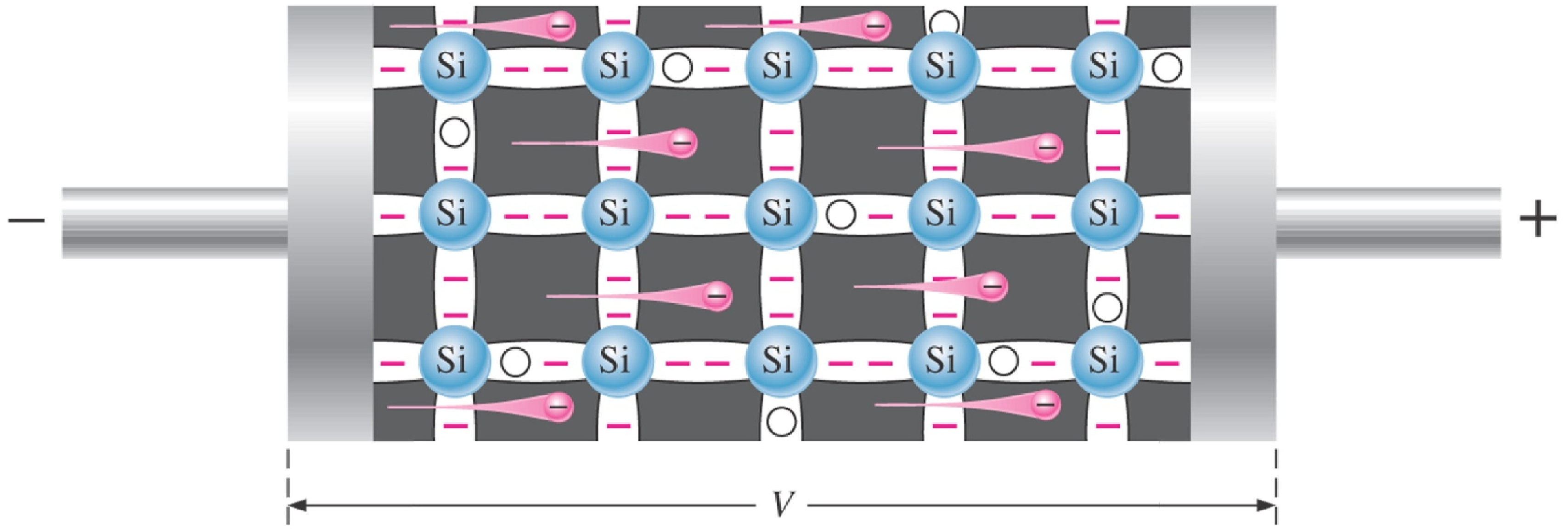
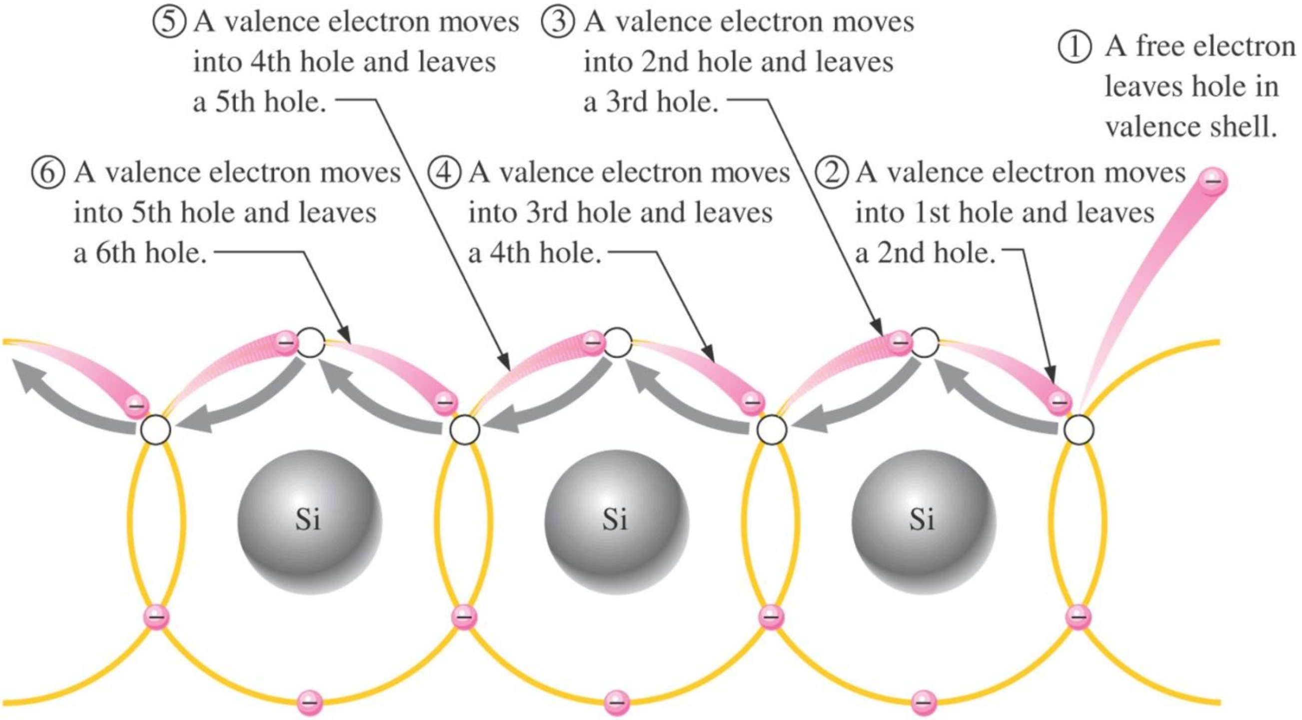


Figure 1–14 Hole current in intrinsic silicon.



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

DOPING

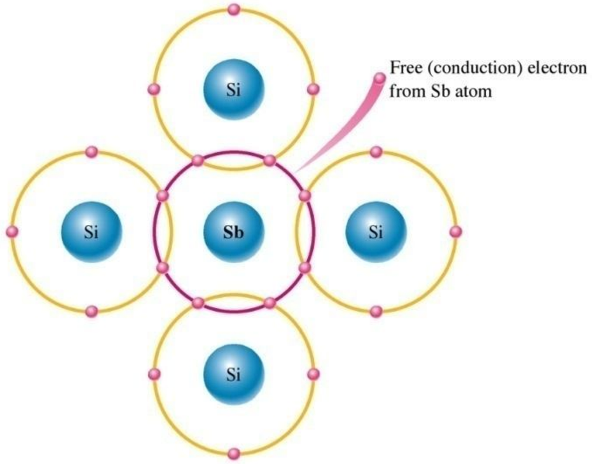
- The conductivity of silicon and germanium can be drastically increased by the controlled addition of impurities to the intrinsic (pure) semiconductive material. This process, called doping, increases the number of current carriers (electrons or holes). The two categories of impurities are n-type and p-type.

N-type and P-type Semiconductors

The process of creating N- and P-type materials is called doping.

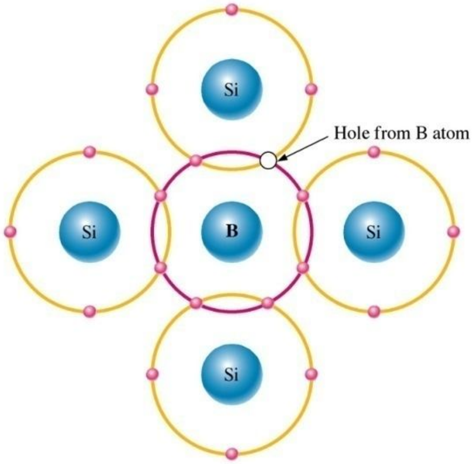
Other atoms with 5 electrons such as Antimony are added to Silicon to increase the free electrons.

N-type



Other atoms with 3 electrons such as Boron are added to Silicon to create a deficiency of electrons or hole charges

P-type



MAJORITY AND MINORITY CARRIRS

- Mot of the current carriers and holes, silicon (or germanium) doped with trivalent atoms is called a p-type semiconductor. Holes can be thought of as positive charges because the absence of an electron leaves a net positive charge on the atom. The holes are the majority carriers in p-type material. Although the majority of current carriers in p-type material are holes, there are also a few free electrons that are created when electron electron-hole pairs are thermally generated. These free electrons are not produced by the addition of the trivalent impurity atoms. Electrons in p-type material are the minority carriers.

1-6 THE DIODE

- A diode is a device that conducts current in only one direction. The pn junction is the feature that allows diode, certain transistors, and other devices to work.

FORMATION OF THE DEPLETION REGION

Figure 1–17 The basic diode structure at the instant of junction formation showing only the majority and minority carriers.

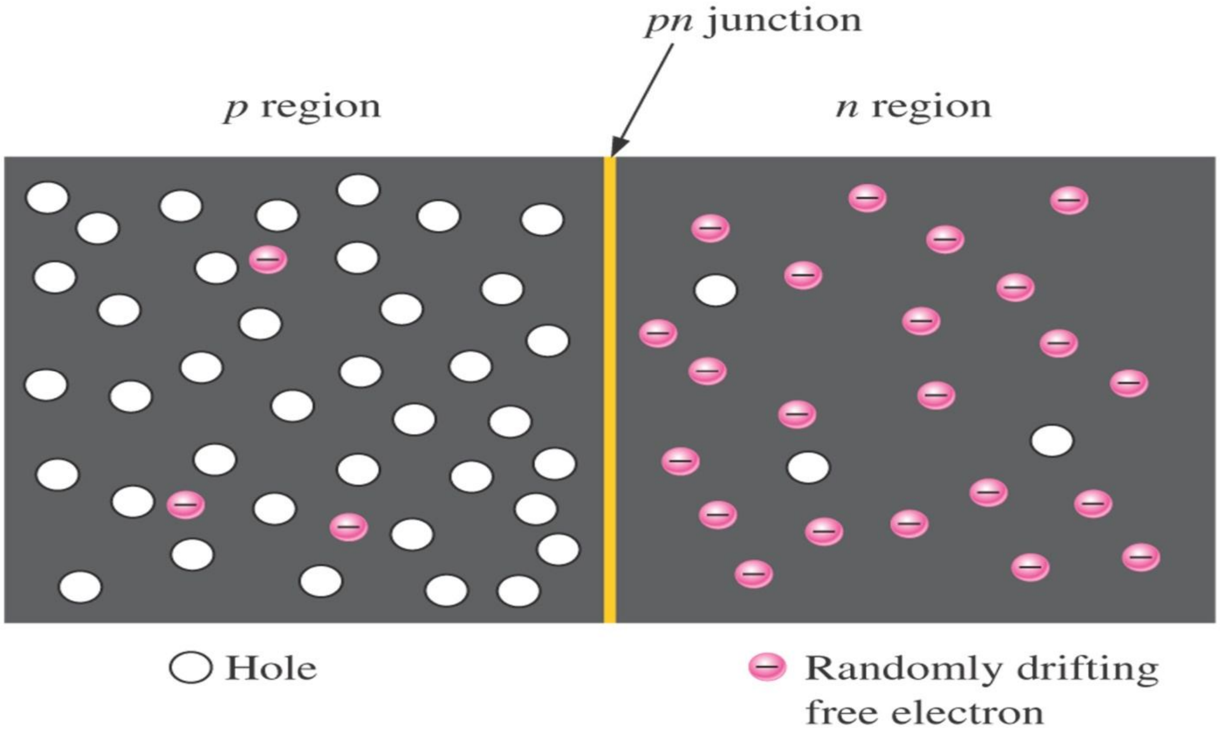
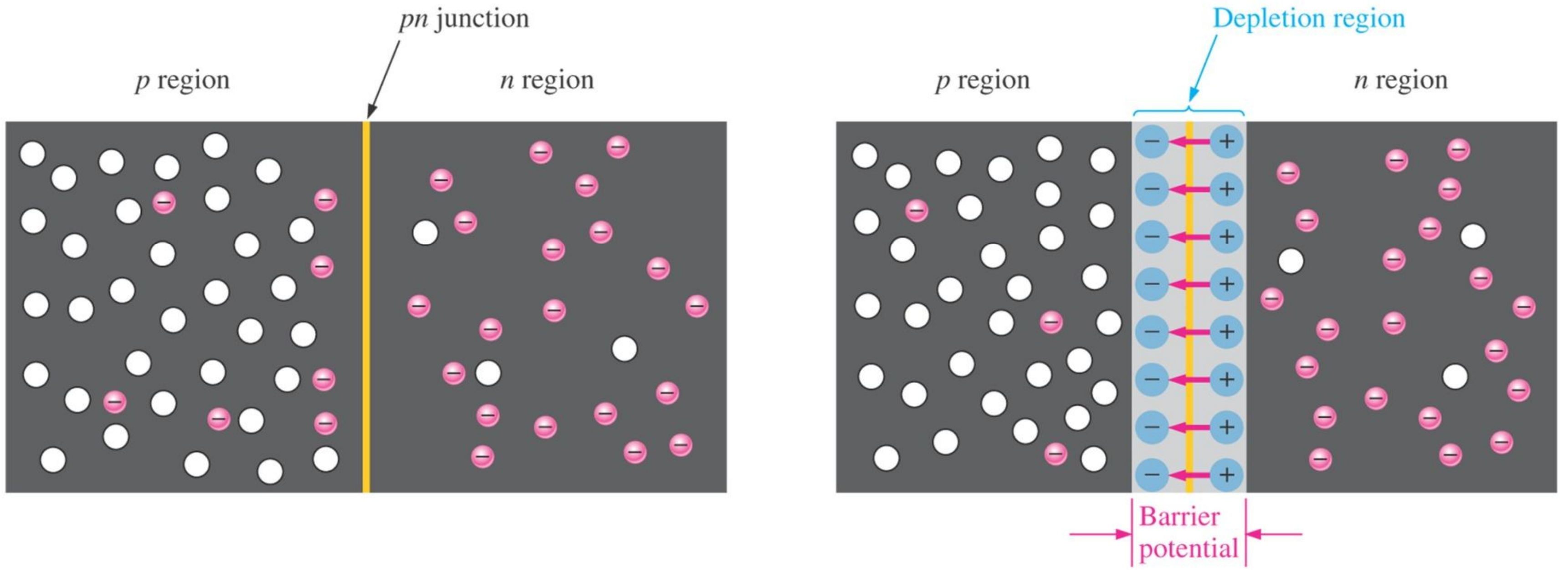


Figure 1–18 Formation of the depletion region. The width of the depletion region is exaggerated for illustration purposes.



(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.

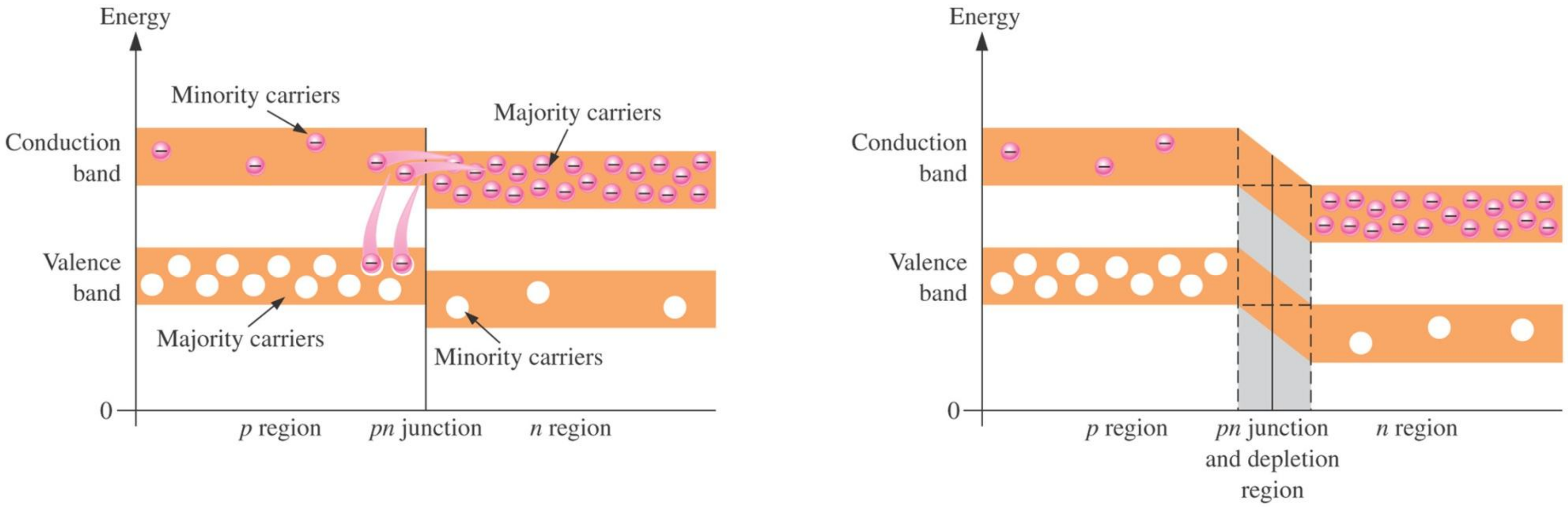
BARRIER POTENTIAL

- The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field. This potential difference is called barrier potential and is expressed in volts.
- The barrier potential of a pn junction depends on several factors, including the type semiconductive material, the amount of doping, and the temperature.

ENERGY DIAGRAMS OF THE PN JUNCTION AND DEPLETION REGION

- The valence and conduction bands in an n-type material are at slightly lower energy levels than the valence and conduction bands in a p-type material. This is due to differences in the atomic characteristics of the pentavalent and the trivalent impurity atoms

Figure 1–19 Energy diagrams illustrating the formation of the pn junction and depletion region.

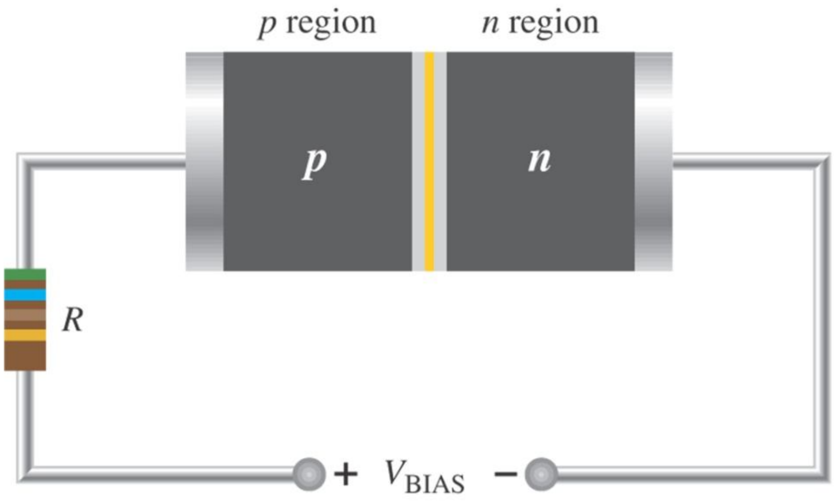


(a) At the instant of junction formation

(b) At equilibrium

1-7 BIASING A DIODE

- The term bias refers to the use of a dc voltage to establish certain operating conditions for an electronic device. In relation to a diode, there are two bias conditions: forward and reverse.



A forward-biased diode showing the flow of majority carriers and the voltage due to the barrier potential across the depletion region.

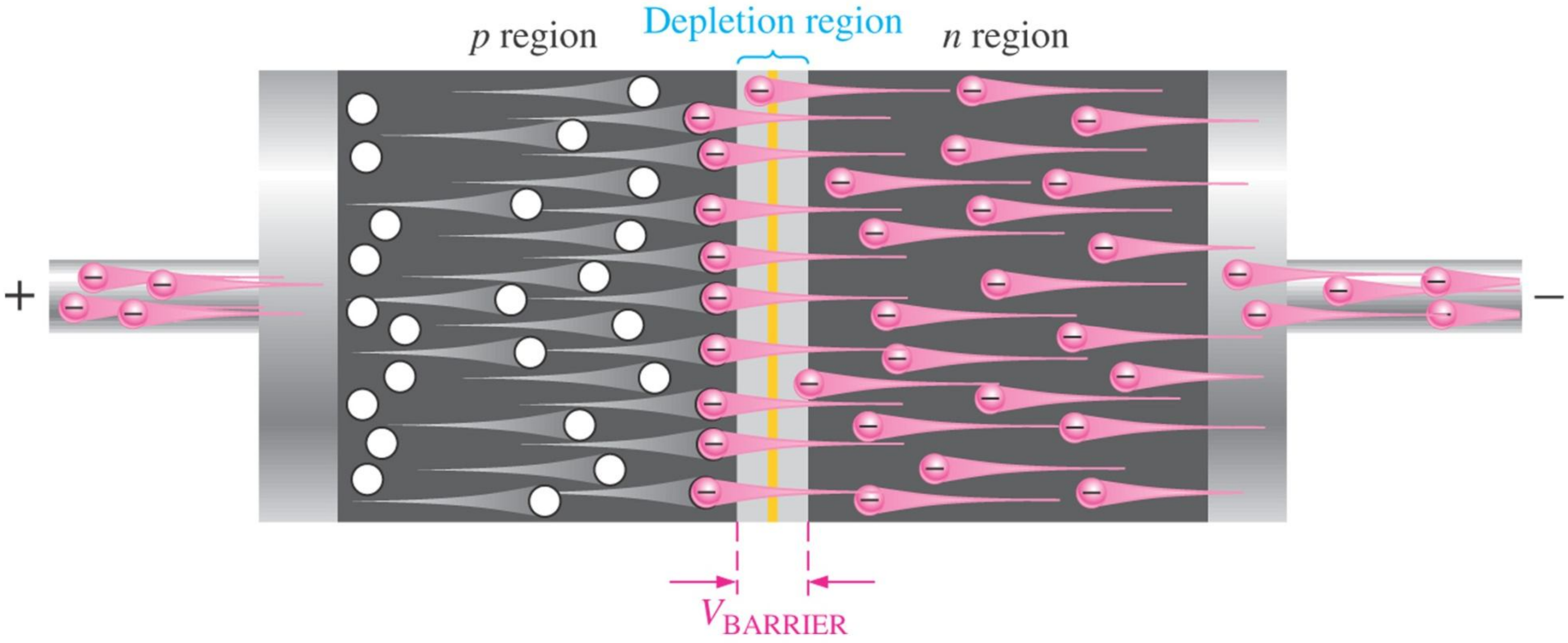
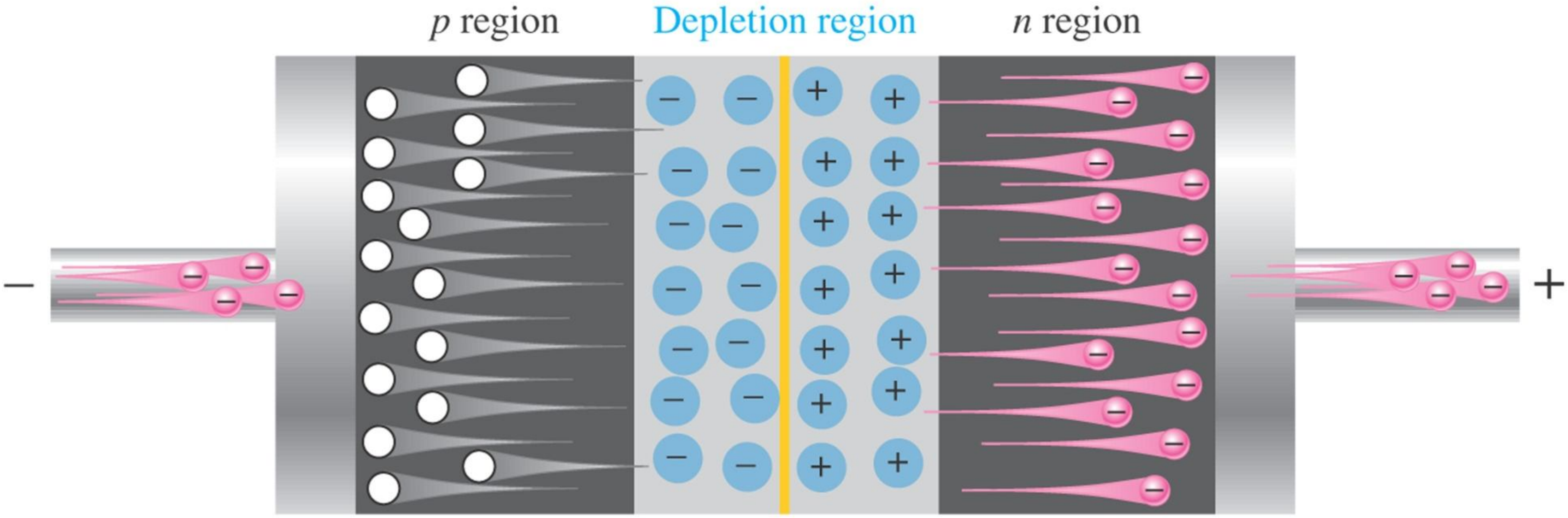
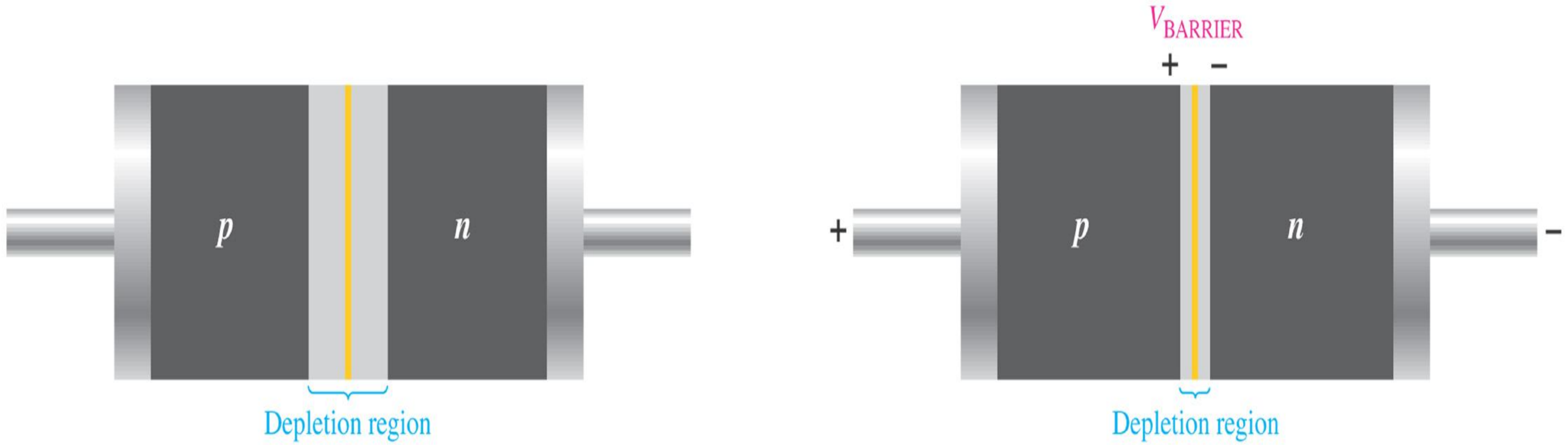


Figure 1–24 The diode during the short transition time immediately after reverse-bias voltage is applied.



THE EFFECT OF FORWARD BIAS ON DEPLETION REGION

Figure 1–22 The depletion region narrows and a voltage drop is produced across the pn junction when the diode is forward-biased.



(a) At equilibrium (no bias)

(b) Forward bias narrows the depletion region and produces a voltage drop across the *pn* junction equal to the barrier potential.

THE EFFECT OF REVERSE BIAS ON DEPLETION REGION

Figure 1–23 A diode connected for reverse bias. A limiting resistor is shown although it is not important in reverse bias because there is essentially no current.

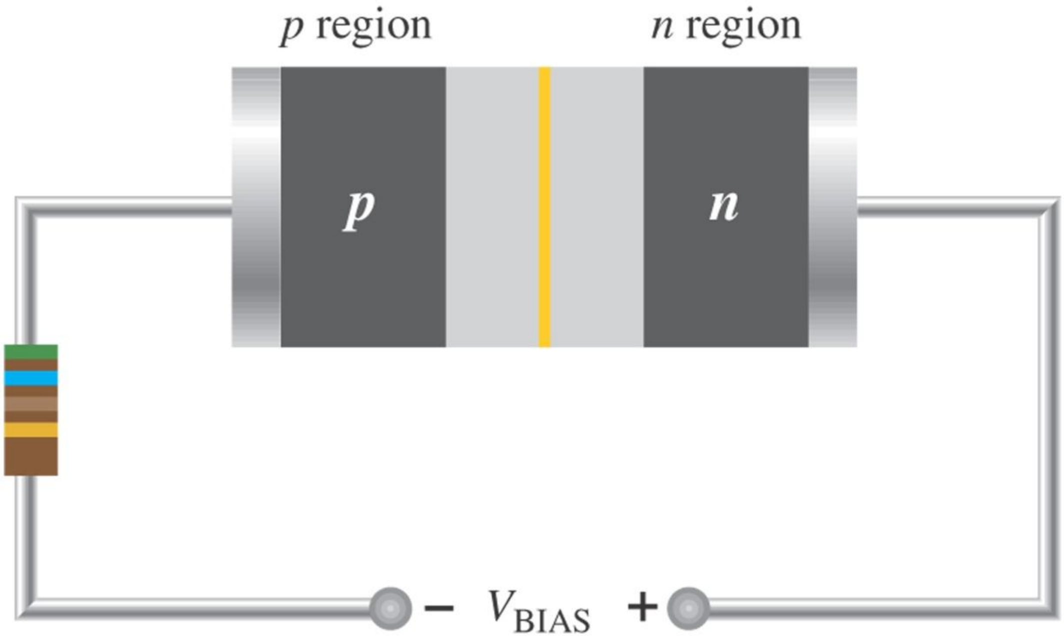
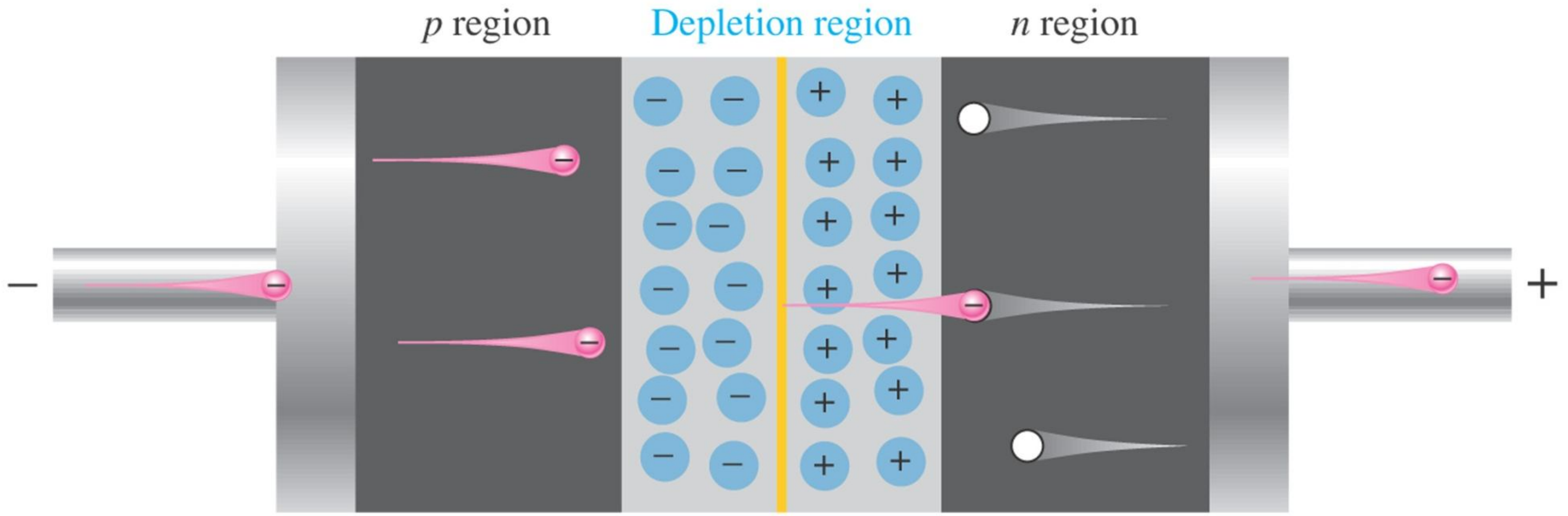
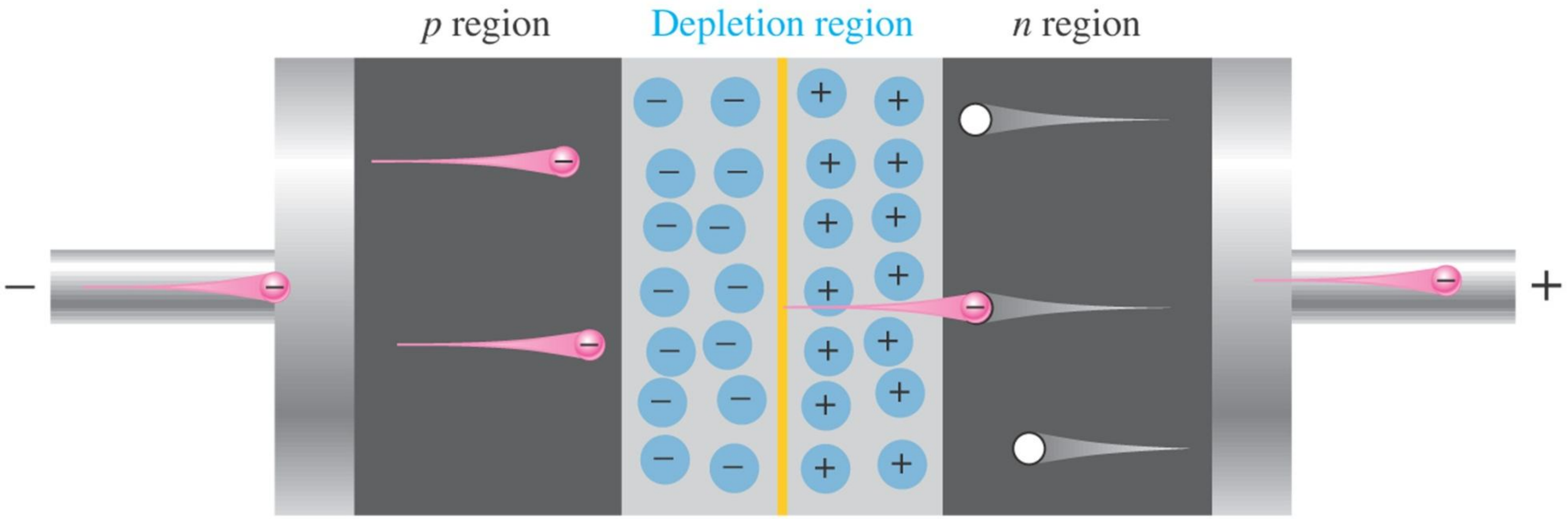


Figure 1–25 The extremely small reverse current in a reverse-biased diode is due to the minority carriers from thermally generated electron-hole pairs.



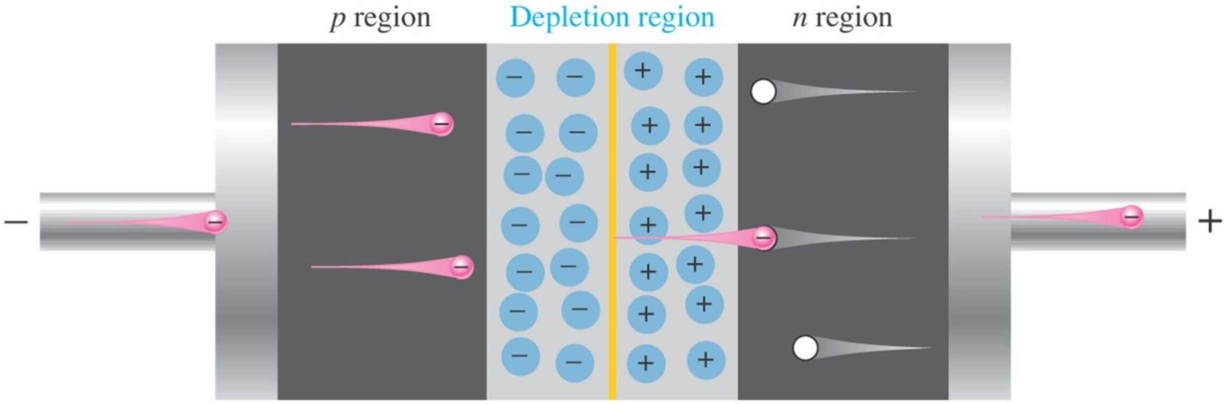
REVERSE CURRENT

Figure 1–25 The extremely small reverse current in a reverse-biased diode is due to the minority carriers from thermally generated electron-hole pairs.



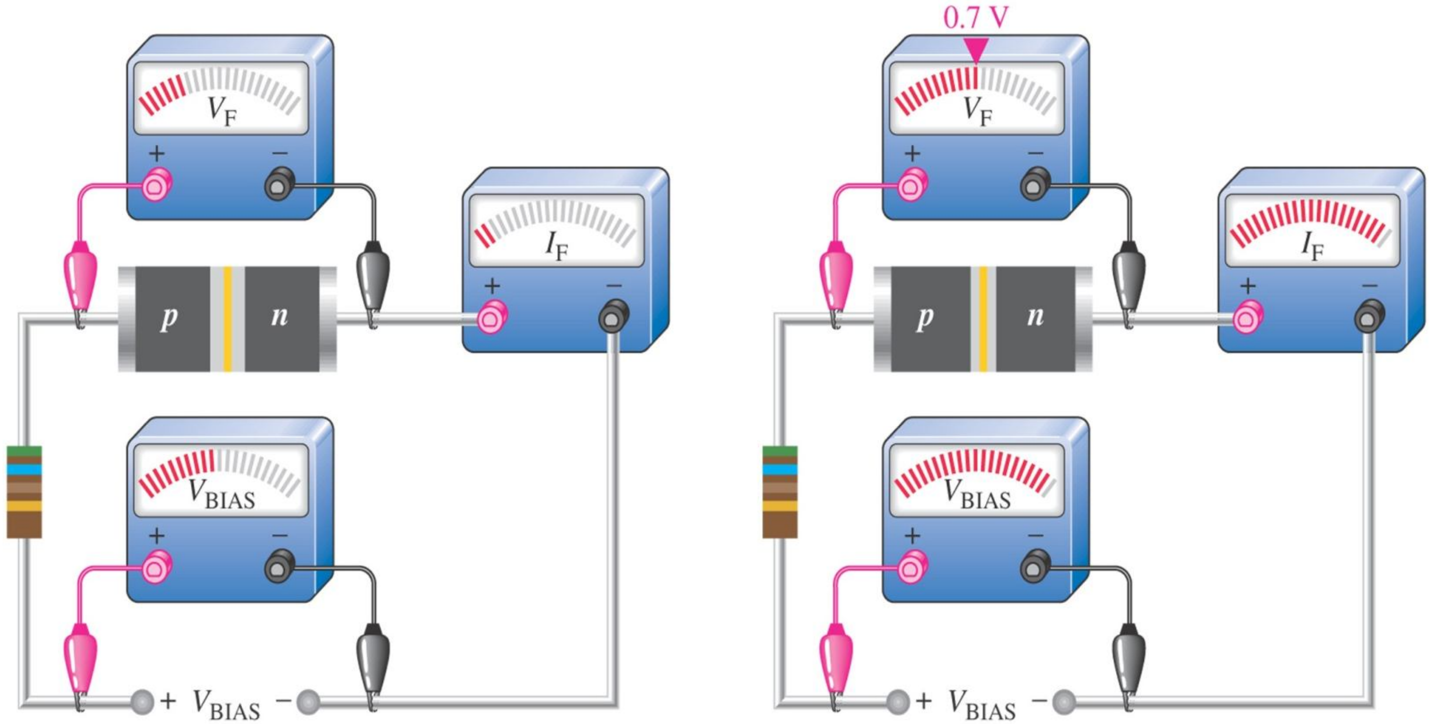
REVERSE BREAKDOWN

- Normally, the reverse current is so small that it can be neglected. However, if the external reverse bias voltage is increased to a value called the breakdown voltage, the reverse current will drastically increase.
- **Figure 1–25** The extremely small reverse current in a reverse-biased diode is due to the minority carriers from thermally generated electron-hole pairs.



1-8 VOLTAGE-CURRENT CHARACTERISTIC OF A DIODE

V-I characteristic for forward bias

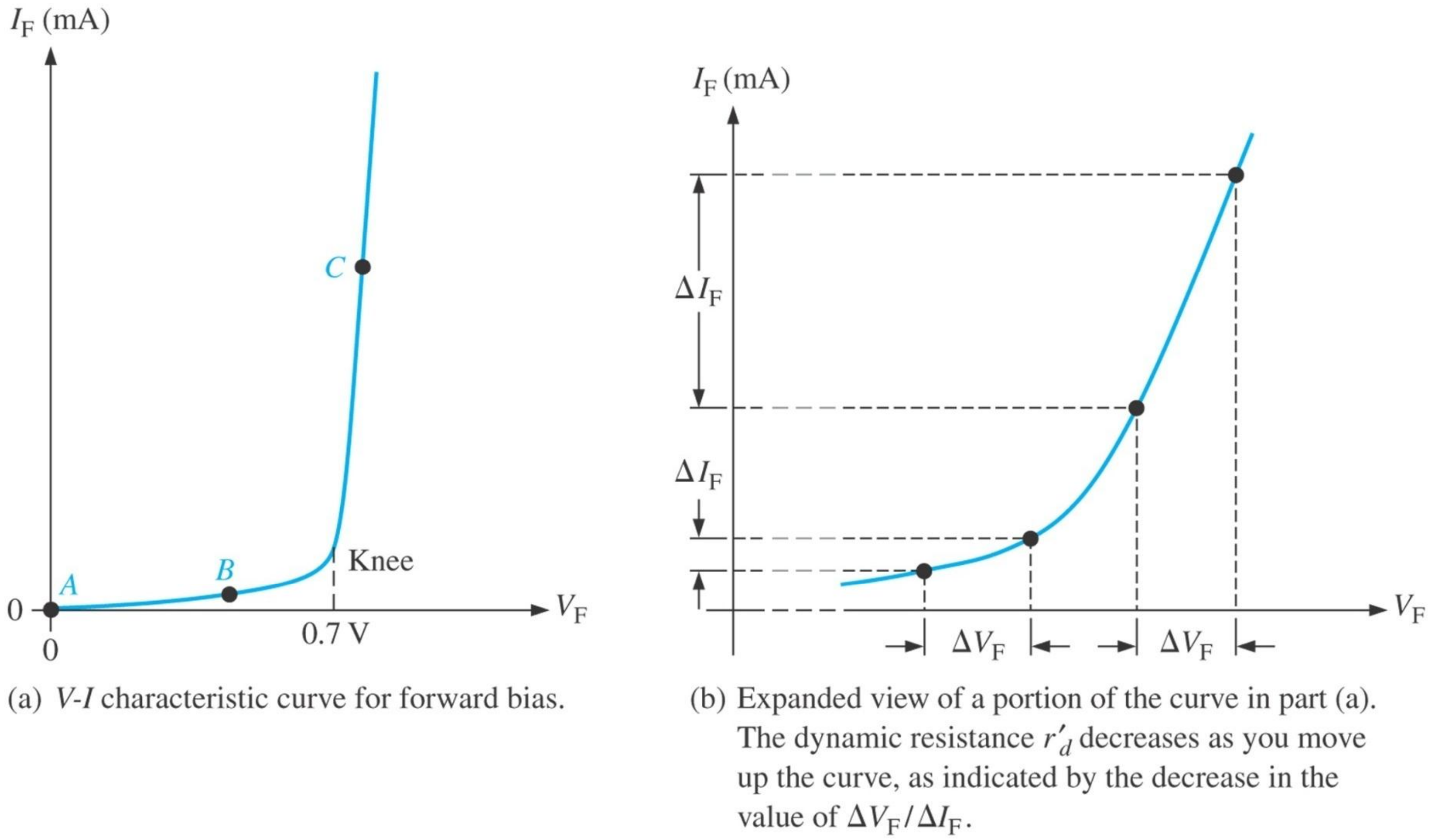


(a) Small forward-bias voltage ($V_F < 0.7$ V), very small forward current.

(b) Forward voltage reaches and remains at approximately 0.7 V. Forward current continues to increase as the bias voltage is increased.

- **In figure a** the voltage applied is less than the barrier potential so the diode for all practical purposes is still in a non-conducting state. Current is very small.
- **In figure b** With the applied voltage exceeding the barrier potential the now fully forward-biased diode conducts. Note that the only practical loss is the .7 Volts dropped across the diode.

Figure 1–27 Relationship of voltage and current in a forward-biased diode.



(a) V-I characteristic curve for forward bias.

(b) Expanded view of a portion of the curve in part (a). The dynamic resistance r'_d decreases as you move up the curve, as indicated by the decrease in the value of $\Delta V_F / \Delta I_F$.

VI CHARACTERISTIC FOR REVERSE BIAS

- **Graphing the V-I curve**

Figure 1–28 V-I characteristic curve for a reverse-biased diode.

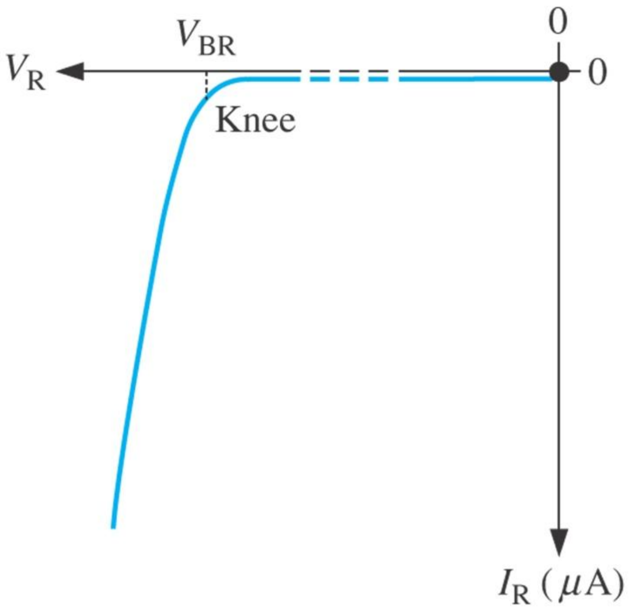
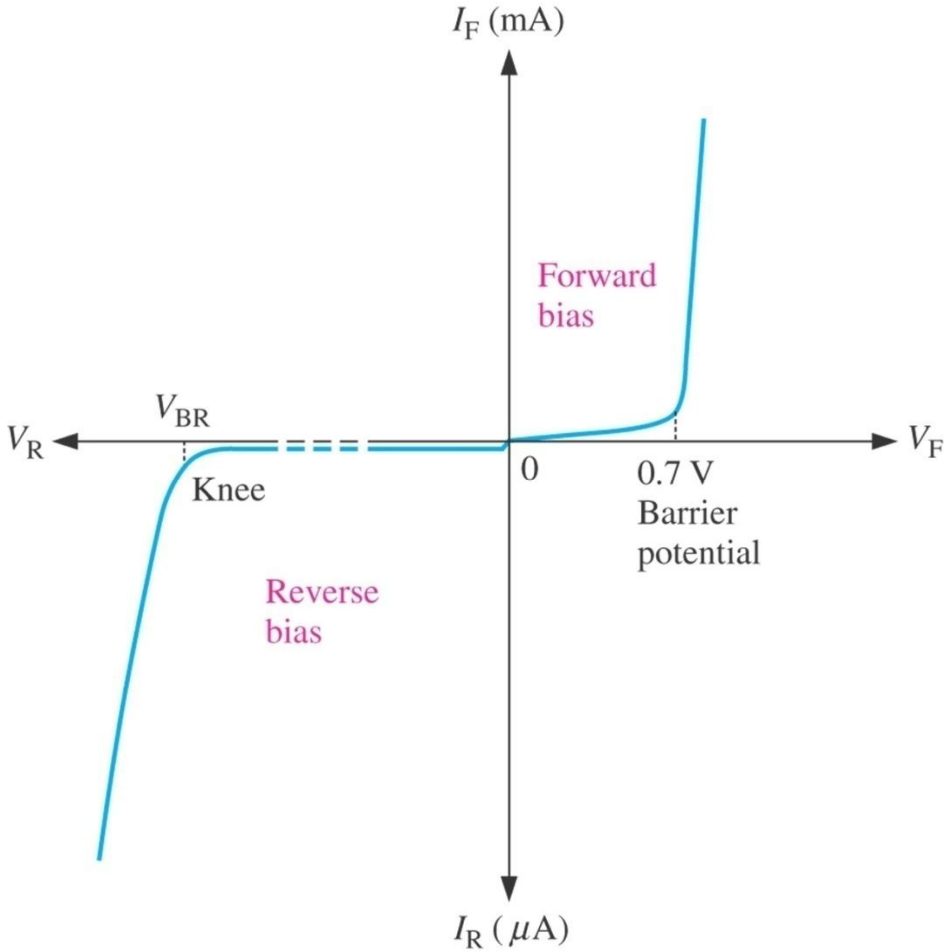


Figure 1–29 The complete V-I characteristic curve for a diode.



TEMPERATURE EFFECTS

- For a forward-biased diode, as temperature is increased, the forward current increases for a given value of forward voltage. For a reverse biased diode. As temperature is increased, the reverse current increases.

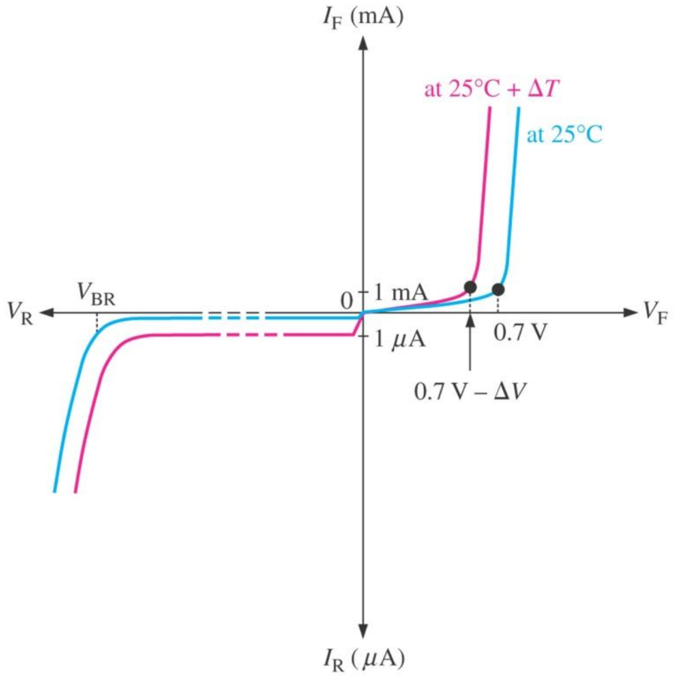
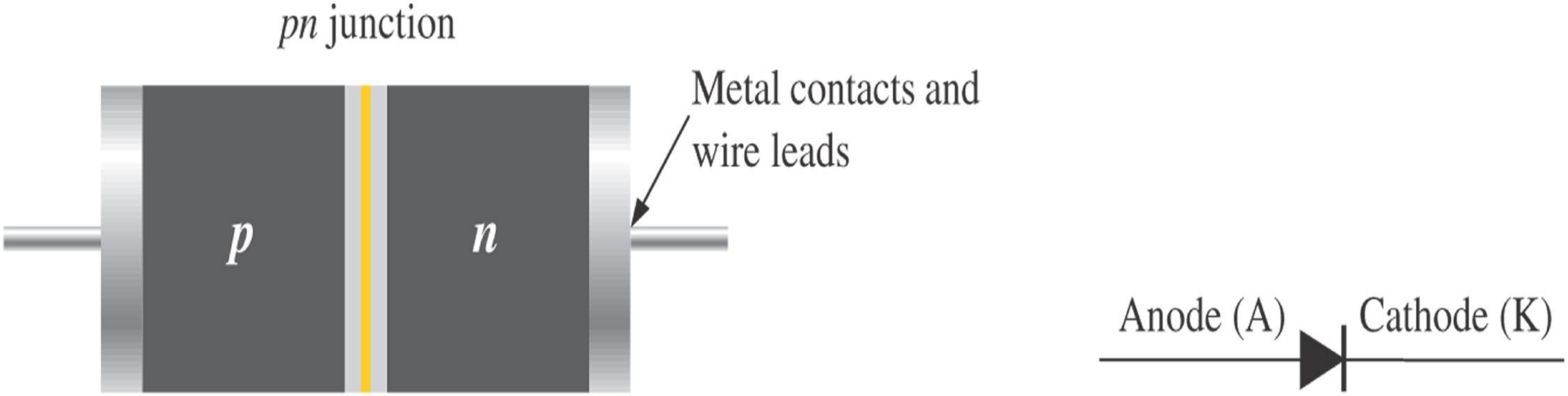


Figure 1–30 Temperature effect on the diode V-I characteristic. The 1 mA and 1 mA marks on the vertical axis are given as a basis for a relative comparison of the current scales.

DIODE MODELS

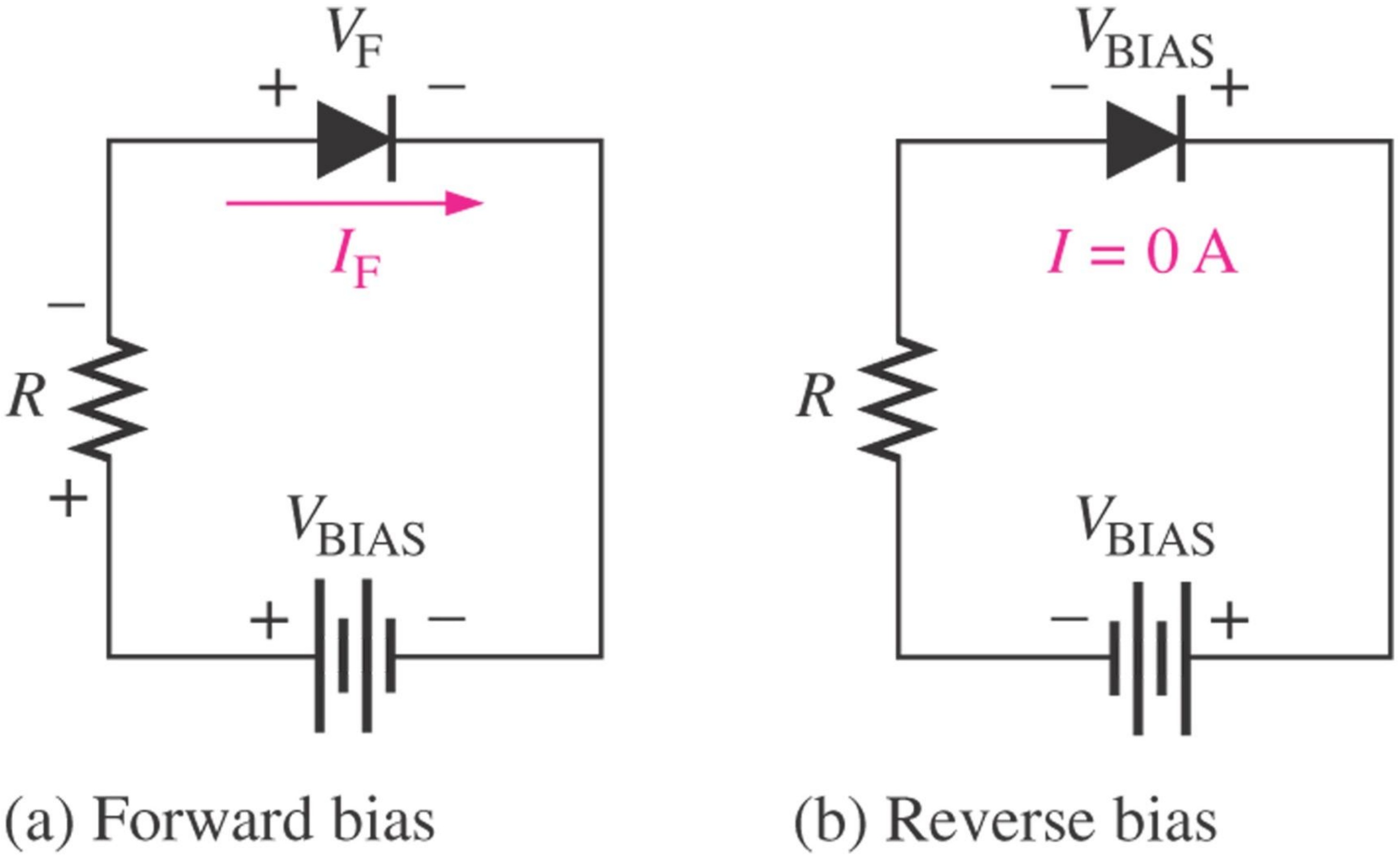
Figure 1–31 Diode structure and schematic symbol.



(a) Basic diode structure

(b) Schematic symbol

Figure 1–32 Forward-bias and reverse-bias connections showing the diode symbol.

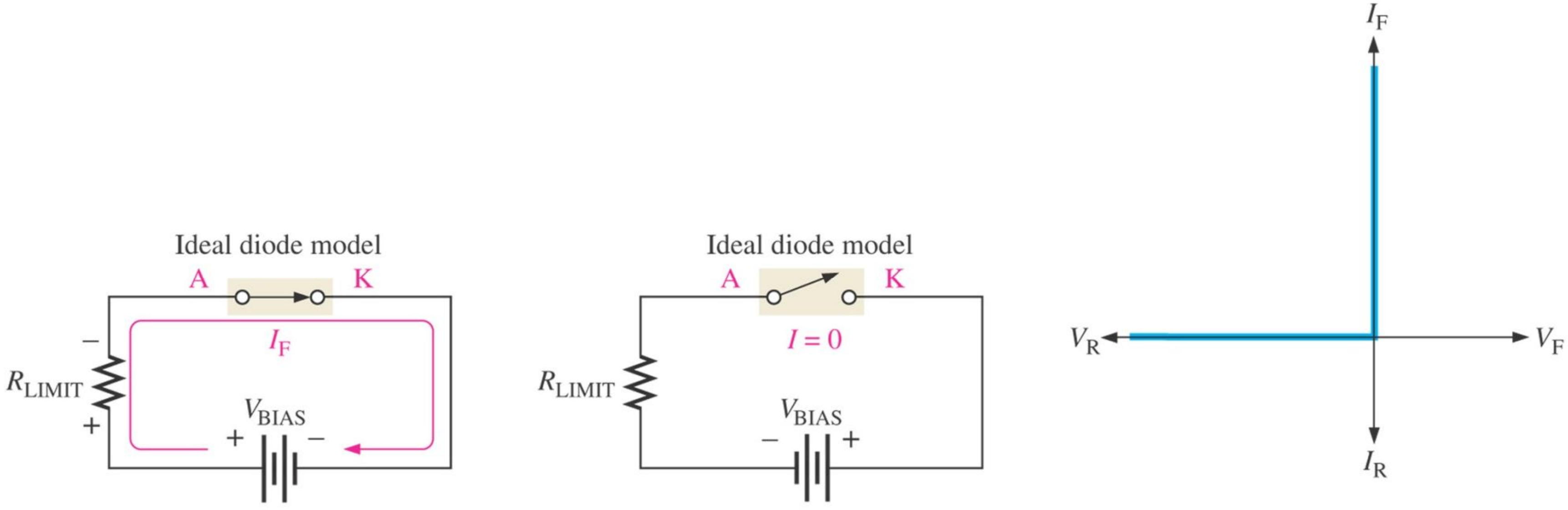


(a) Forward bias (b) Reverse bias

THE IDEAL DIODE MODEL

In this characteristic curve we do not consider the voltage drop or the resistive properties. Current flow proportionally increases with voltage.

Figure 1–33 The ideal model of a diode.

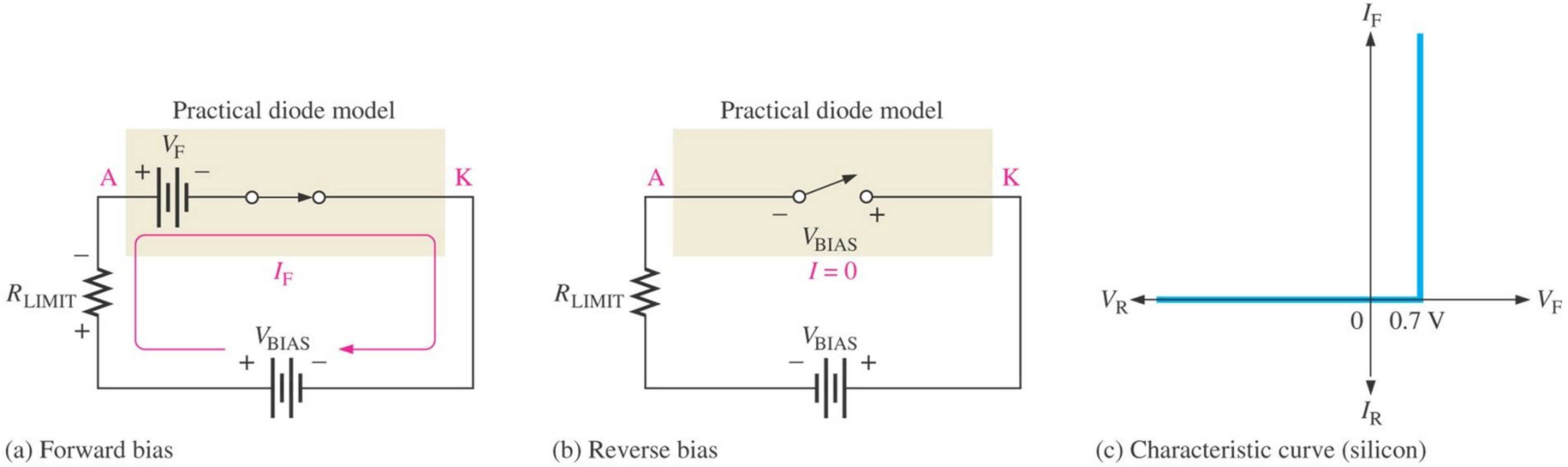


(a) Forward bias (b) Reverse bias (c) Ideal characteristic curve (blue)

PRACTICAL DIODE CHARACTERISTIC CURVE

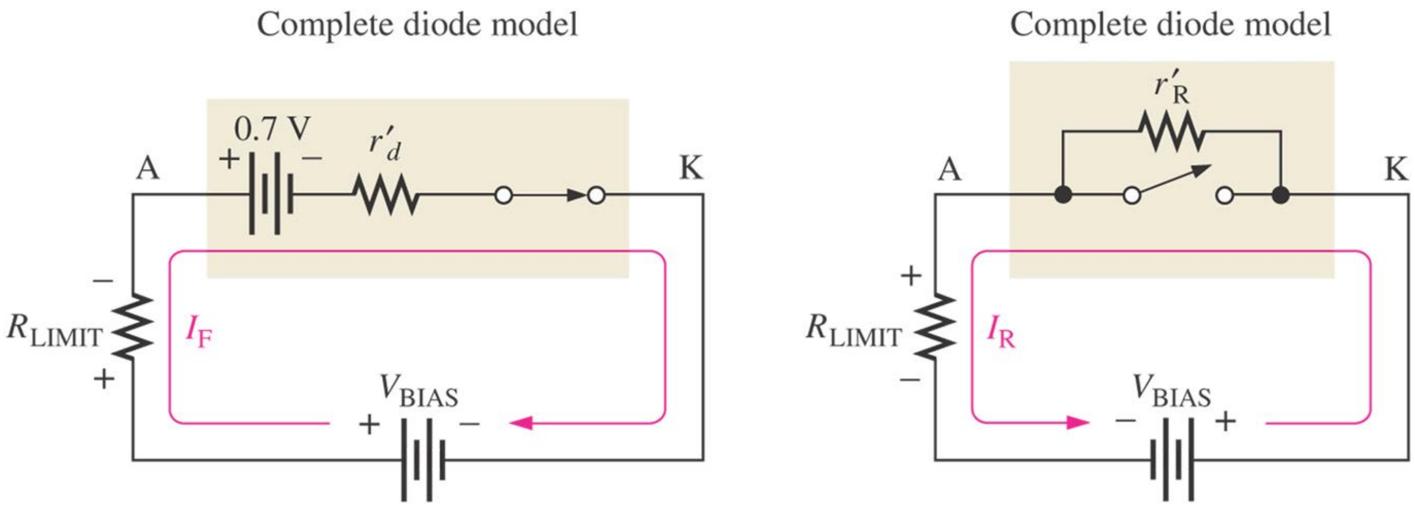
In most cases we consider only the forward bias voltage drop of a diode. Once this voltage is overcome the current increases proportionally with voltage. This drop is particularly important to consider in low voltage applications.

Figure 1–34 The practical model of a diode.



(a) Forward bias (b) Reverse bias (c) Characteristic curve (silicon)

Figure 1–35 The complete model of a diode.

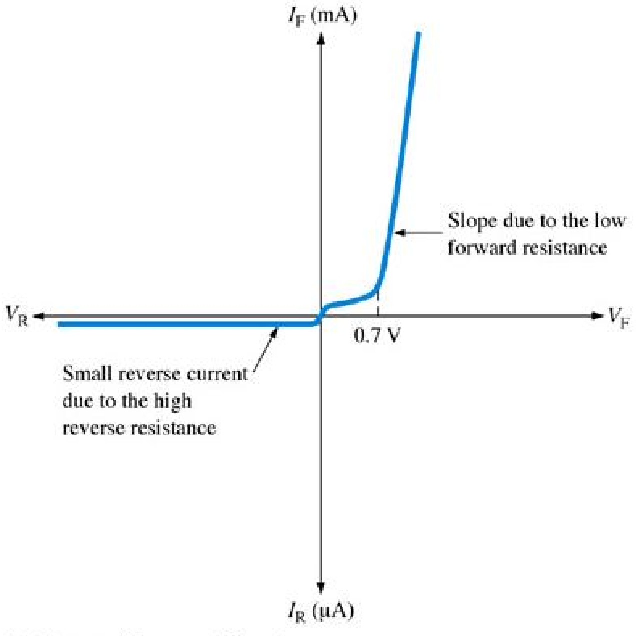


(a) Forward bias

(b) Reverse bias

COMPLEX CHARACTERISTIC CURVE OF A DIODE

The voltage drop is not the only loss of a diode. In some cases we must take into account other factors such as the resistive effects as well as reverse breakdown.



(c) Characteristic curve (silicon)

Ex : Find the current of forward bias silicon diode when E = 10 V and R = 1 kΩ.

$I_D = (E - V_F)/R = (10 - 0.7)/1\ k\Omega. = 9.3\ mA.$

Ex : Find the current and voltage of reverse bias silicon diod when E = 10 V, V_{BR} =90 V and R = 1 kΩ.

Since E < V_{BR}, reverse-bias diode behave like a open circuit, hence the only current flow is the reverse saturation current Is, which is very small, a few nA for a silicon and a few µA for a germanium diode.

$I_D = I_s = 0$ and $V_D = E = -10$ V.

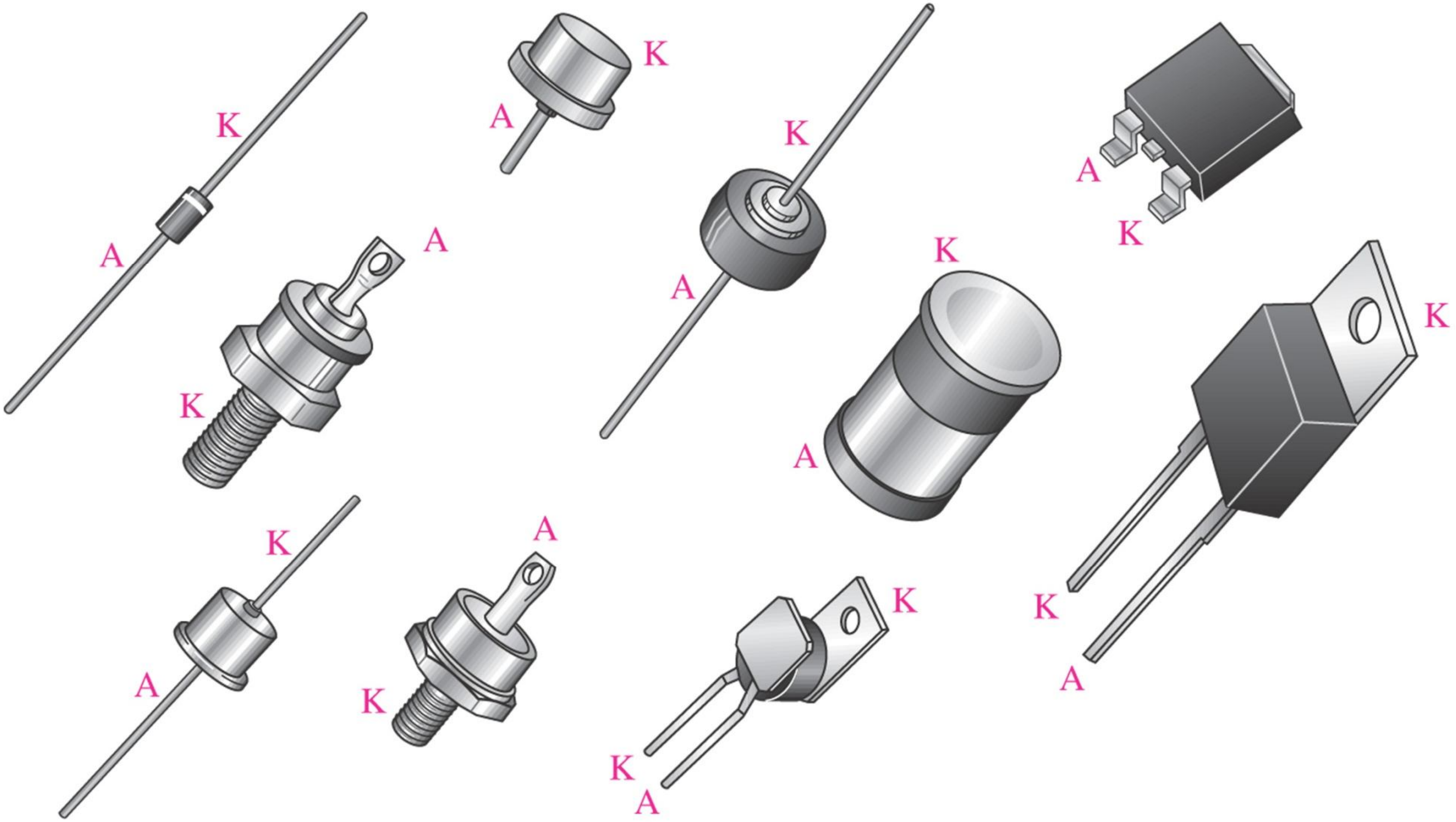
Ex : Find the current and voltage of reverse bias silicon diod when E = 100 V, V_{BR} =90 V and R = 1 kΩ.

Since E > V_{BR}, reverse breakdown occurs, V_{BR} drop across the diode and the reminder of the source voltage ($E - V_{BR}$) drop across the resistor R.

$I_D = (E - V_{BR})/R = (100 - 90)/1\ k\Omega = 10\ mA.$

TYPICAL DIODES

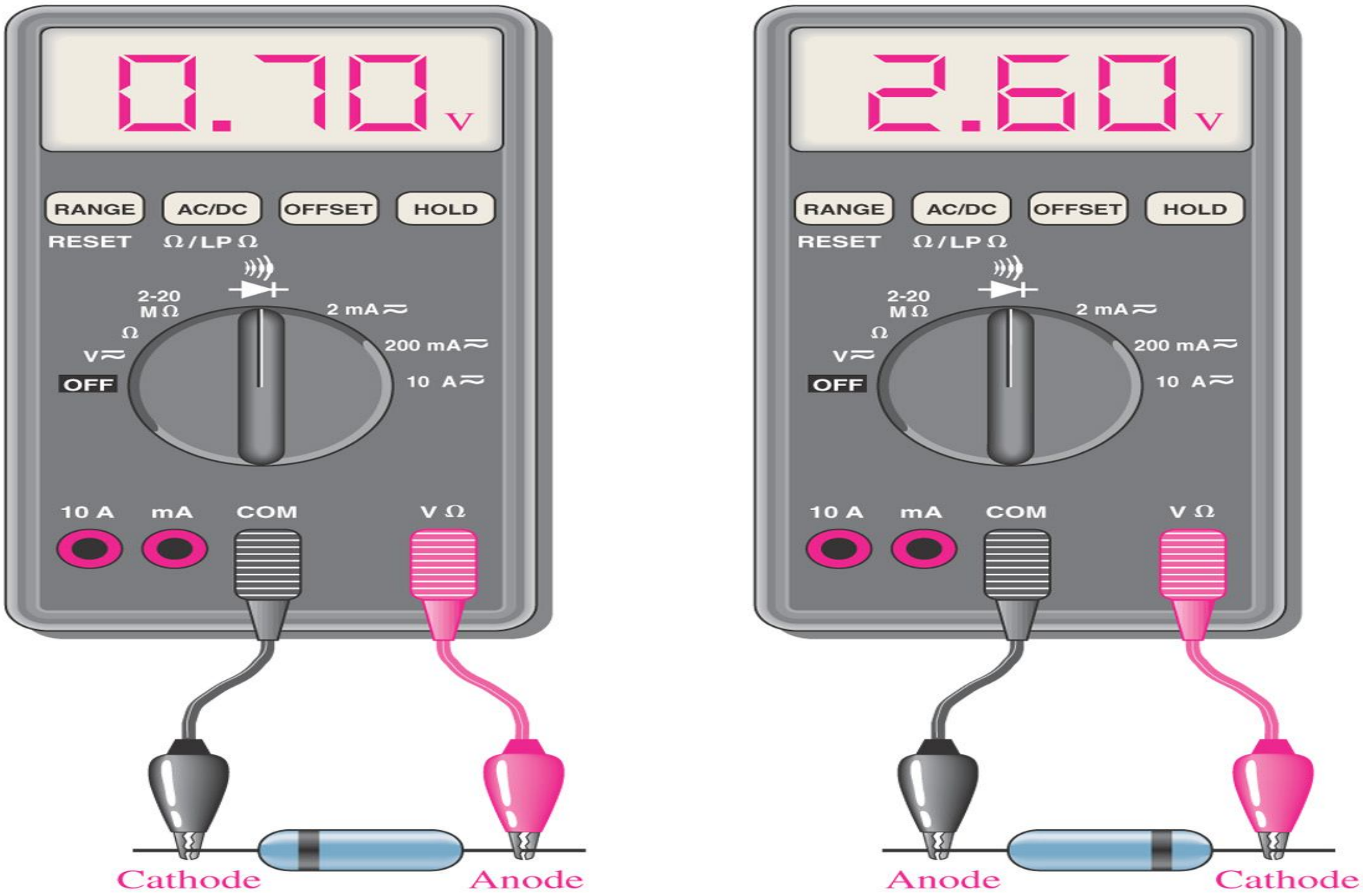
Figure 1–37 Typical diode packages with terminal identification.



TESTING A DIODE

- A multimeter can be used as a fast and simple way to check a diode. A good diode will show an extremely high resistance (ideally an open) with reverse bias and a very low resistance with forward bias.a defective open diode will show an extremely high resistance (or open) for both forward and reverse bias.
- With the diode check function a specific known voltage is applied from the meter across the diode. With the diode check function a good diode will show approximately .7 V or .3 V when forward biased.
- When checking in reverse bias the full applied testing voltage will be seen on the display. Note some meters show an infinite (blinking) display.

Figure 1–38 DMM diode test on a properly functioning diode.



(a) Forward-bias test

(b) Reverse-bias test

- An ohmmeter can be used to check the forward and reverse resistance of a diode if the ohmmeter has enough voltage to force the diode into conduction. Of course, in forward- biased connection, low resistance will be seen and in reverse-biased connection high resistance will be seen.

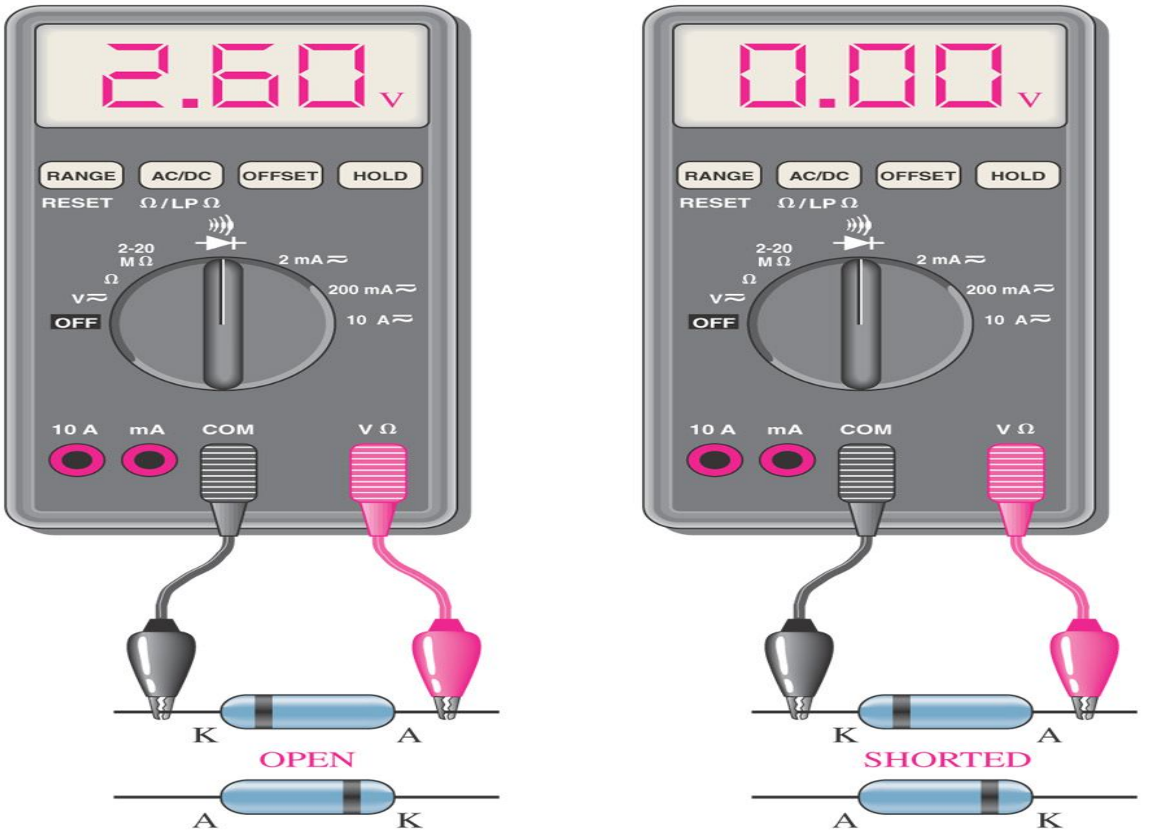
- **Open Diode**

- In the case of an *open diode* no current flows in either direction which is indicated by the full checking voltage with the diode check function or high resistance using an ohmmeter in both forward and reverse connections.

Shorted Diode

- In the case of a *shorted diode* maximum current flows indicated by a 0 V with the diode check function or low resistance with an ohmmeter in both forward and reverse connections.

Figure 1–39 Testing a defective diode.



(a) Forward- and reverse-bias tests for an open diode give the same indication. Some meters will display "OL."

(b) Forward- and reverse-bias tests for a shorted diode give the same 0 V reading. If the diode is resistive, the reading is less than 2.6 V.

SUMMARY

- Diodes, transistors, and integrated circuits are all made of semiconductor material.
- P-materials are doped with trivalent impurities
- N-materials are doped with pentavalent impurities.
- P and N type materials are joined together to form a PN junction.
- A diode is nothing more than a PN junction.
- At the junction a depletion region is formed. This creates barrier that requires approximately .3 V for a Germanium and .7 V for Silicon for conduction to take place.

SUMMARY

- There are three ways of analyzing a diode. These are ideal, practical, and complex. Typically we use a practical diode model.
- When reversed-biased, a diode can only withstand so much applied voltage. The voltage at which avalanche current occurs is called reverse breakdown voltage.
- A diode conducts when forward-biased and does not conduct when reverse biased.