Fundamentals of Electronic Technology

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Signal

- A signal is a physical quantity that reflects information, such as temperature, pressure, flow rate, sound, etc.

- Information needs to be represented and transmitted through changes in certain physical quantities such as sound, light, and electricity.

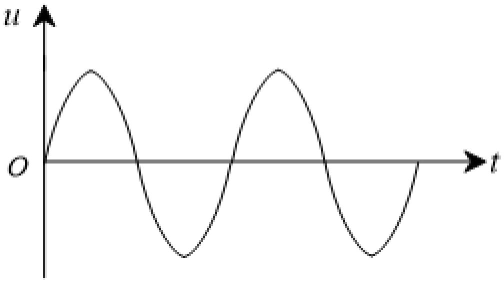
- Electric signal

- Due to the fact that non electric physical quantities can be converted into electric signals, and electric signals are easy to transmit and control, they have become the most widely used signals.
- Electric signals are often represented as voltage u (t) or current i (t) that varies over time

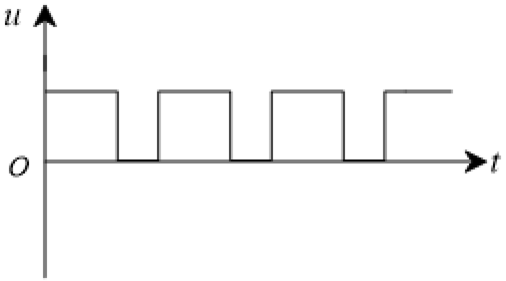
Analog Signal and Digital Signal

- Analog Signal: It has continuity in both time and amplitude, that is, there is a definite function value *u* or *i* at any time, and the amplitude of *u* or *i* is a continuous value

- Digital Signal: It has discreteness in both time and numerical values, with numerical values being integer multiples of the minimum value.

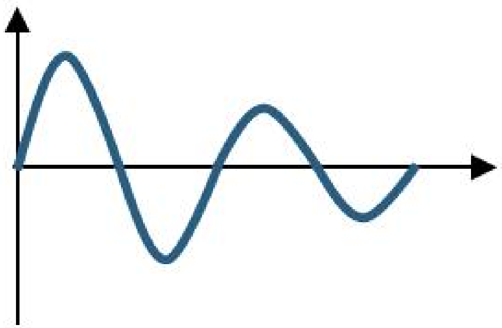


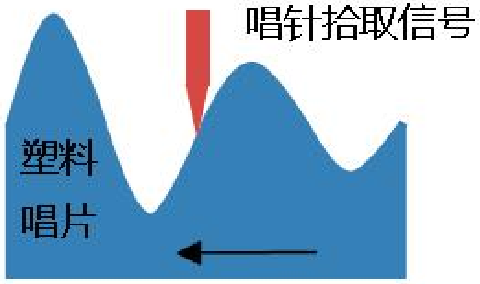
Analog Signal



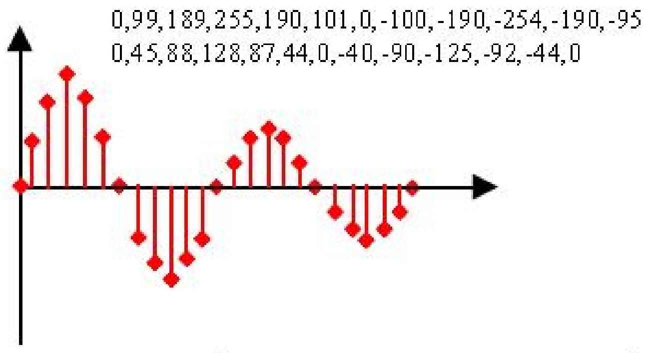
Digital Signal

Analog Signal and Digital Signal





Record: Analog way

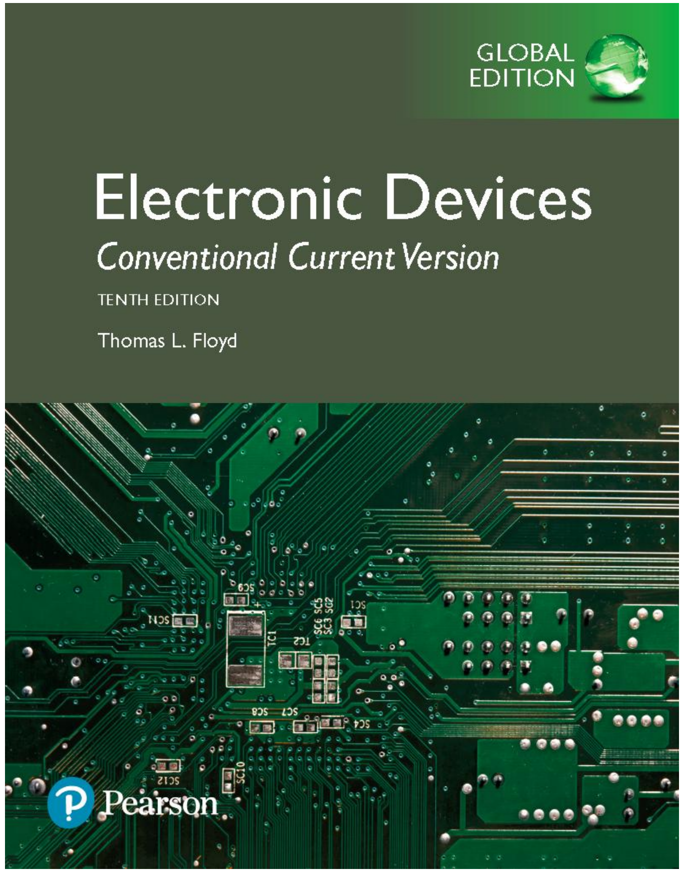


Digital file: Digital way

Module Introduction

- 24 Classes
- 40% CA including homework and attendance
- 60% Final exam

- Textbook: Electronic Devices , FLOYD, 10th EDITION, Pearson



CHAPTER 1 Introduction to Semiconductors

1.1 The Atom

- An **atom** is the smallest particle of an element that retains the characteristics of that element.
- According to the classical Bohr model, atoms have a planetary type of structure that consists of a central nucleus surrounded by orbiting electrons.
- The nucleus consists of positively charged particles called protons and uncharged particles called neutrons. The basic particles of negative charge are called electrons
- Each type of atom has a certain number of electrons and protons that distinguishes it from the atoms of all other elements.

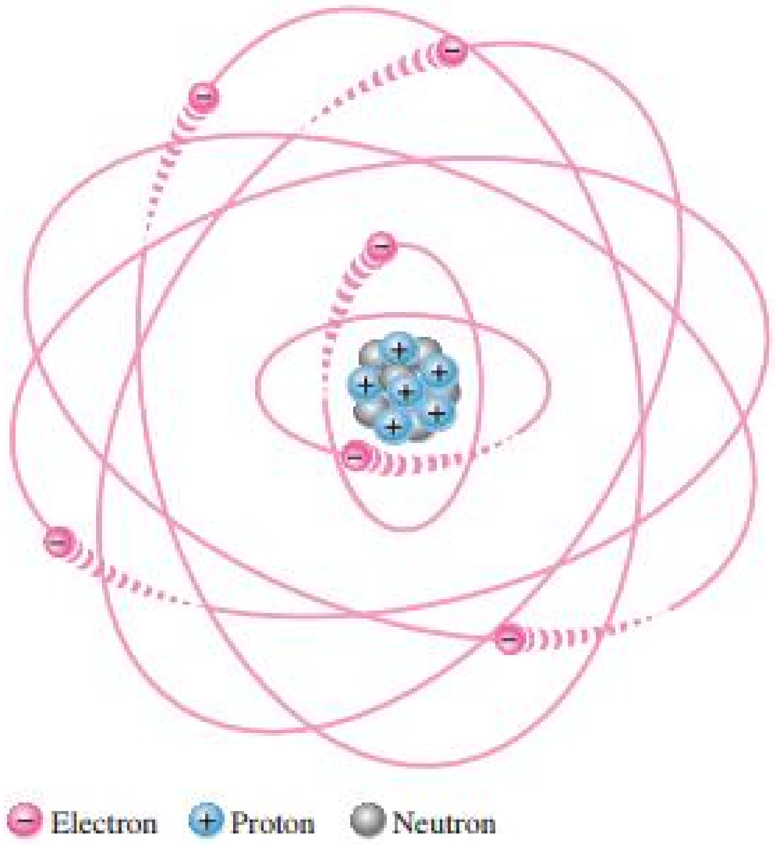


FIGURE 1-1 The Bohr model of an atom

Valence Electrons

- Each discrete distance (orbit) from the nucleus corresponds to a certain energy level.
- In an atom, the orbits are grouped into energy levels known as shells.
- Electrons that are in orbits farther from the nucleus have higher energy and are less tightly bound to the atom than those closer to the nucleus.
- This outermost shell is known as the valence shell, and electrons in this shell are called valence electrons.

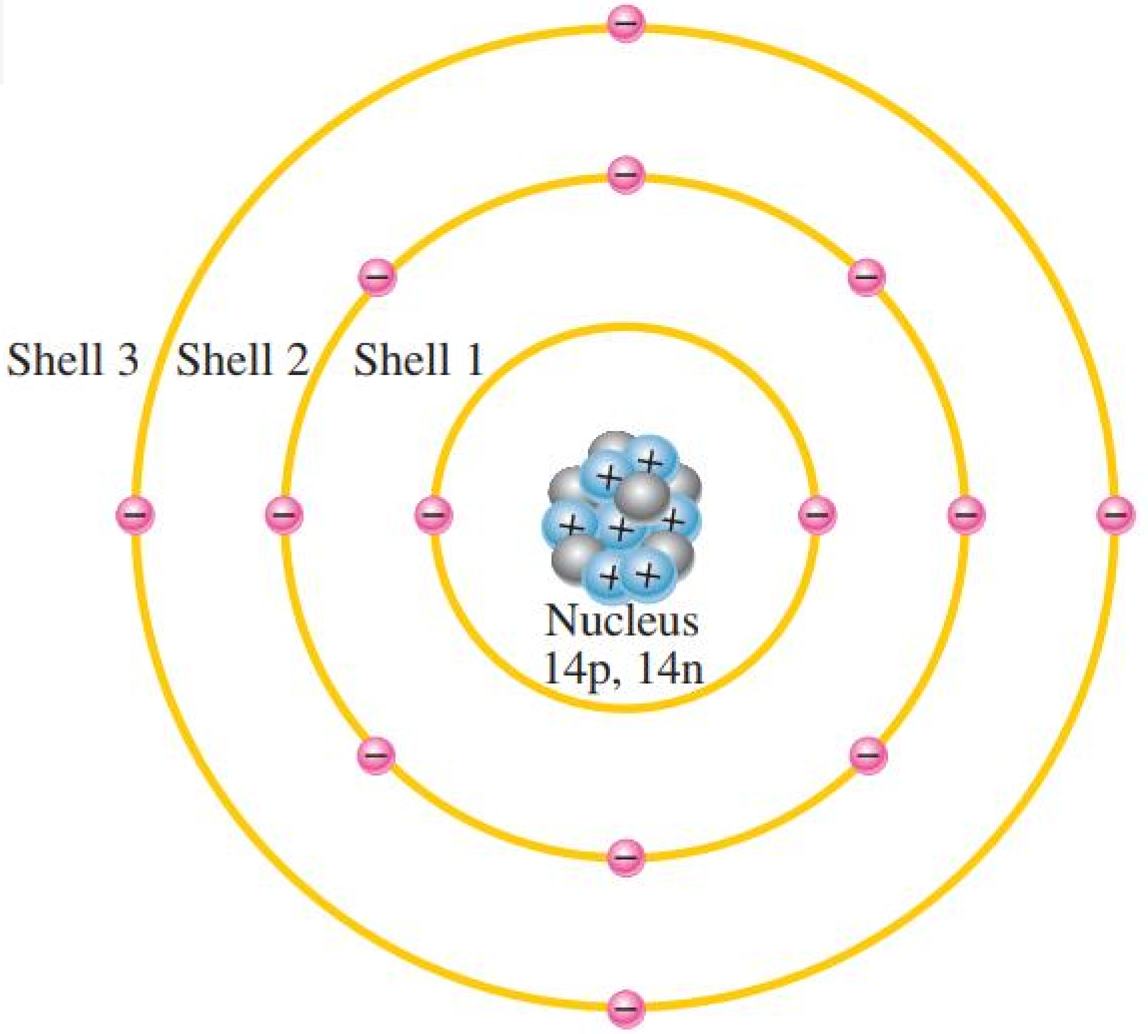


FIGURE 1-2 The Bohr model of the silicon atom

1.2 MATERIALS USED IN ELECTRONIC DEVICES

- In terms of their electrical properties, materials can be classified into three groups: conductors, semiconductors, and insulators.

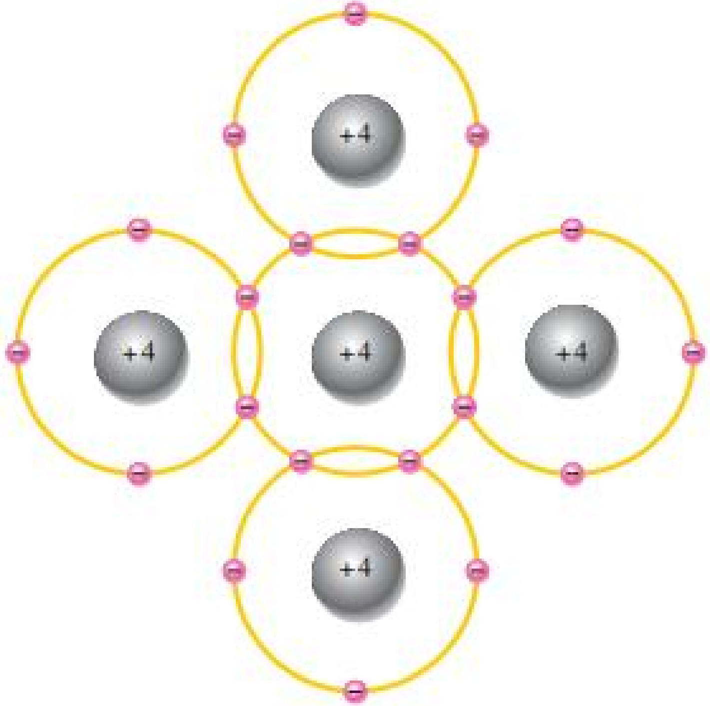
  - An insulator is a material that does not conduct electrical current under normal conditions. Valence electrons are tightly bound to the atoms; therefore, there are very few free electrons in an insulator. Examples of insulators are rubber, plastics, glass, mica, and quartz.

  - A conductor is a material that easily conducts electrical current. Most metals are good conductors, such as copper (Cu), silver (Ag), gold (Au), and aluminum (Al). In a conductive material the free electrons are available to carry current.

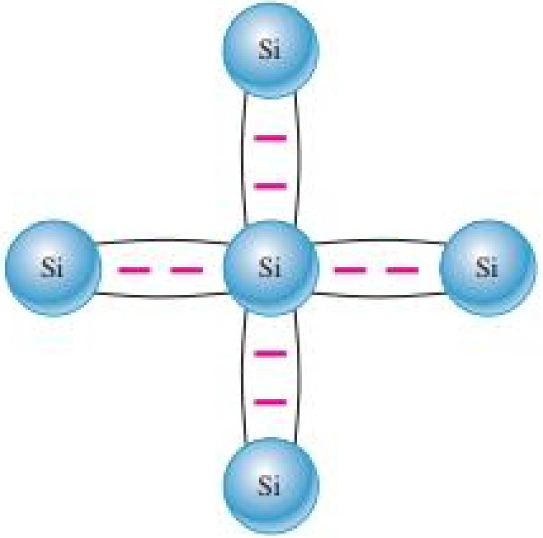
  - A semiconductor is a material that is between conductors and insulators in its ability to conduct electrical current. The single-element semiconductors are characterized by atoms with four valence electrons. Silicon is the most commonly used semiconductor.

Covalent Bonds

- Figure 1–3 shows how each silicon atom positions itself with four adjacent silicon atoms to form a silicon crystal.
- A silicon (Si) atom with its four valence electrons shares an electron with each of its four neighbors. This effectively creates eight shared valence electrons for each atom and produces a state of chemical stability.
- This sharing of valence electrons produces a strong covalent bond that hold the atoms together.



(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 1-3 Illustration of covalent bonds in silicon.

Covalent Bonds

- An intrinsic crystal is one that has no impurities.
- Covalent bonding in an intrinsic silicon crystal is shown in Figure 1–4.

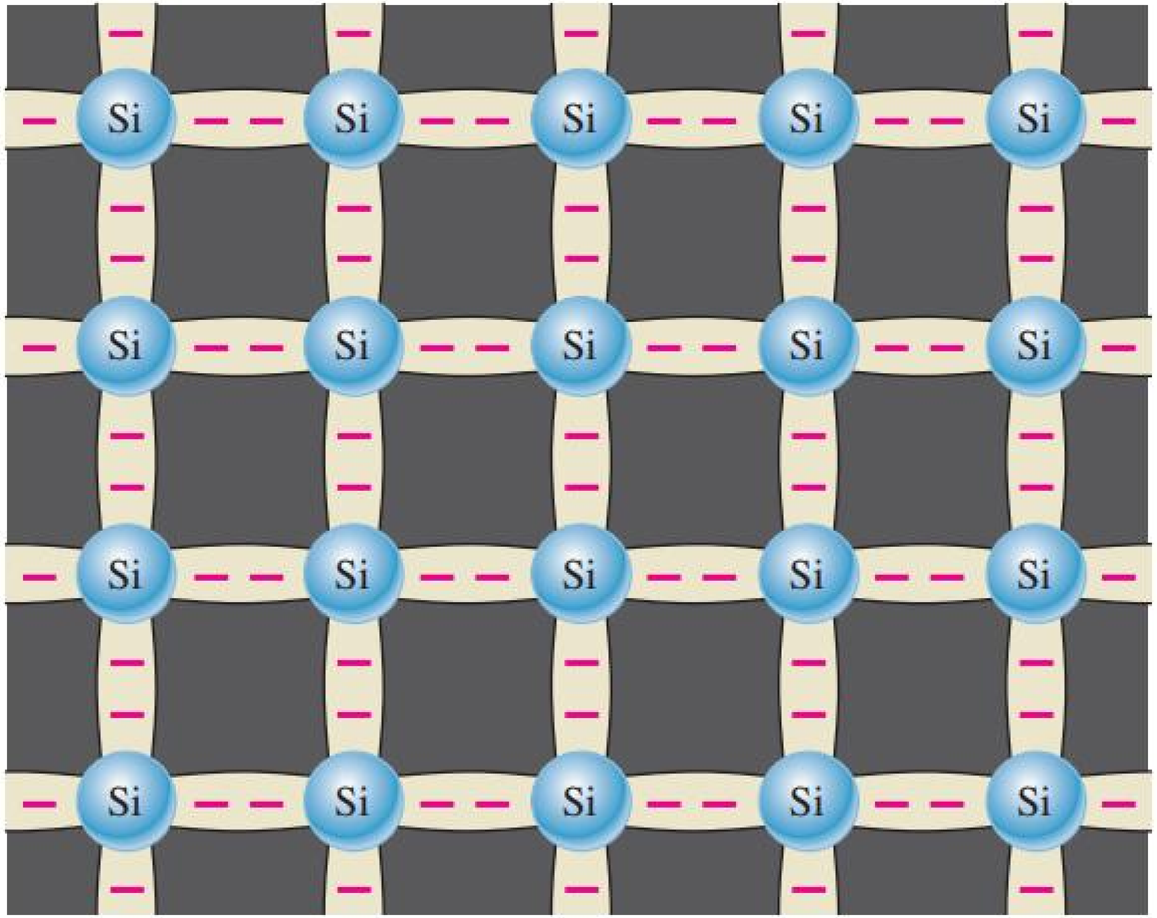


FIGURE 1-4 Covalent bonds in a silicon crystal.

1.3 CURRENT IN SEMICONDUCTORS

- An intrinsic (pure) silicon crystal at room temperature has sufficient heat (thermal) energy for some valence electrons to become free electrons.
- When an electron becomes free electron, a vacancy is left in the valence band within the crystal. This vacancy is called a hole.
- For every free electron, there is one hole left in the valence band, creating what is called an electron-hole pair.
- Recombination occurs when a free electron meet a hole during drifting randomly through the material.

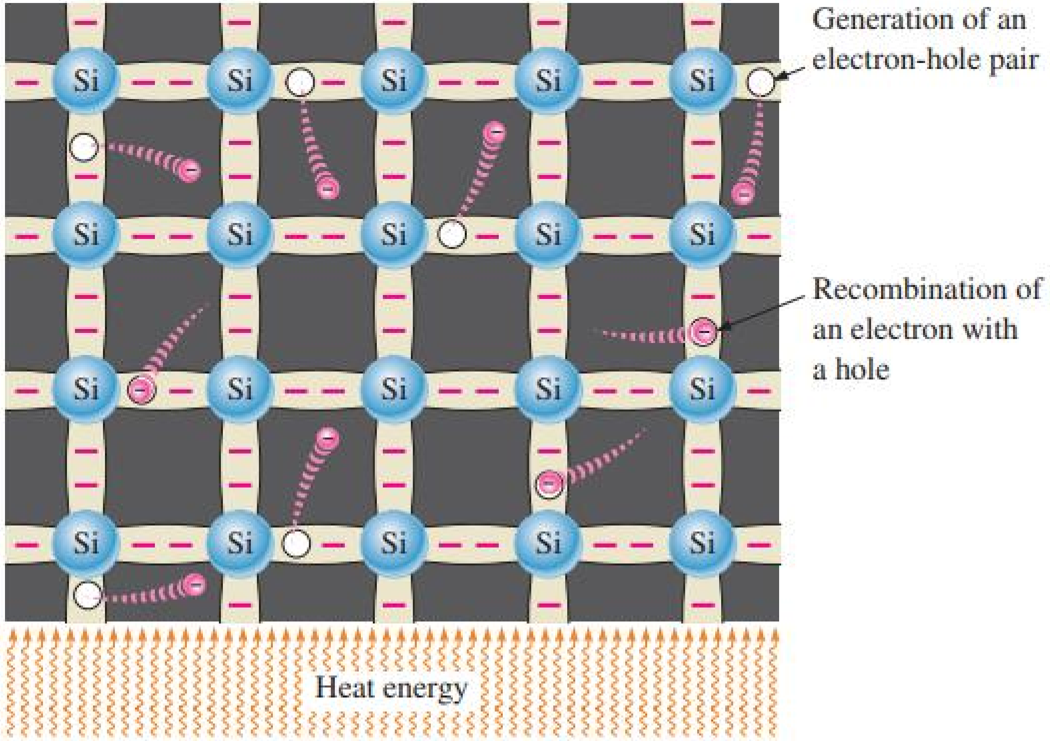


FIGURE 1-5 Electron-hole pairs in a silicon crystal.

Electron and Hole Current

- When a voltage is applied across a piece of intrinsic silicon, as shown in Figure 1–6, the thermally generated free electrons, which are free to move randomly in the crystal structure, are now easily attracted toward the positive end.
- This movement of free electrons is one type of current in a semiconductive material and is called electron current.

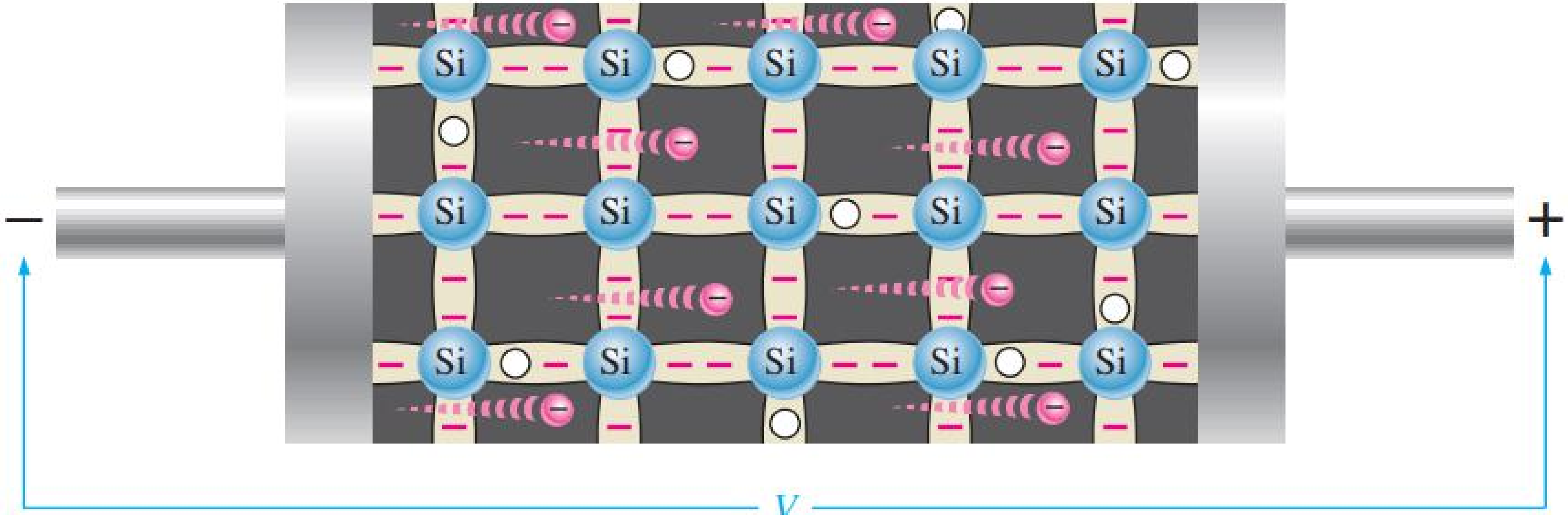


FIGURE 1-6 Electron current in intrinsic silicon is produced by the movement of thermally generated free electrons.

Electron and Hole Current

- A valence electron can move into a nearby hole, thus leaving another hole where it came from.
- Effectively the hole has moved from one place to another in the crystal structure, as illustrated in Figure 1–7.
- Although current in the valence band is produced by valence electrons, it is called hole current to distinguish it from electron current in the conduction band.

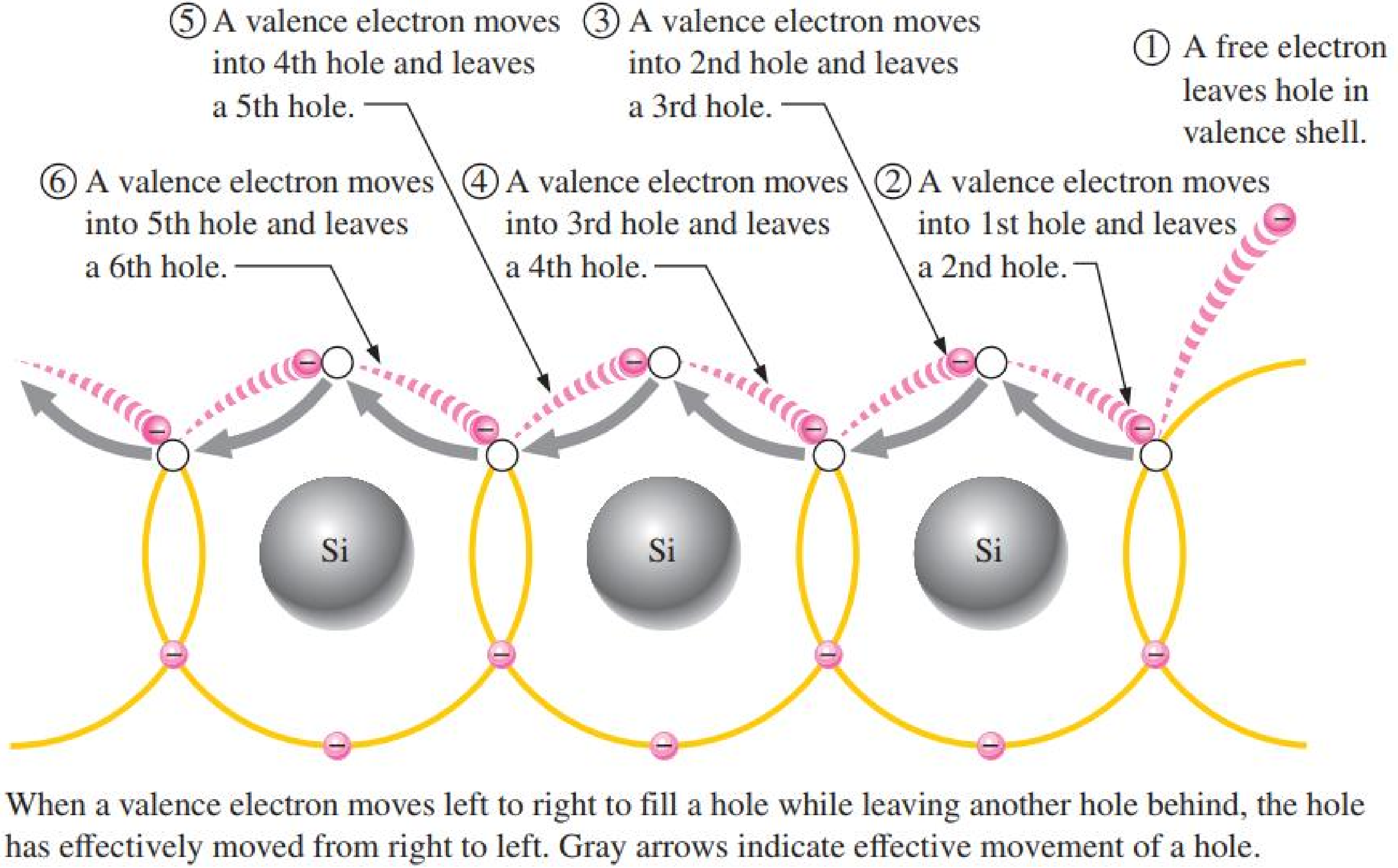


FIGURE 1-7 Hole current in intrinsic silicon.

1.4 *N*-TYPE AND *P*-TYPE SEMICONDUCTORS

- Since semiconductors are generally poor conductors, their conductivity 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 Semiconductor

- To increase the number of electrons in intrinsic silicon, pentavalent (5 valence electrons) impurity atoms are added. These are atoms with five valence electrons such as arsenic (As), phosphorus (P), bismuth (Bi), and antimony (Sb).
- Each pentavalent atom (antimony, in this case) forms covalent bonds with four adjacent silicon atoms, leaving one extra electron.
- This extra electron becomes a free (conduction) electron because it is not involved in bonding.
- Because the pentavalent atom gives up an electron, it is often called a donor atom.

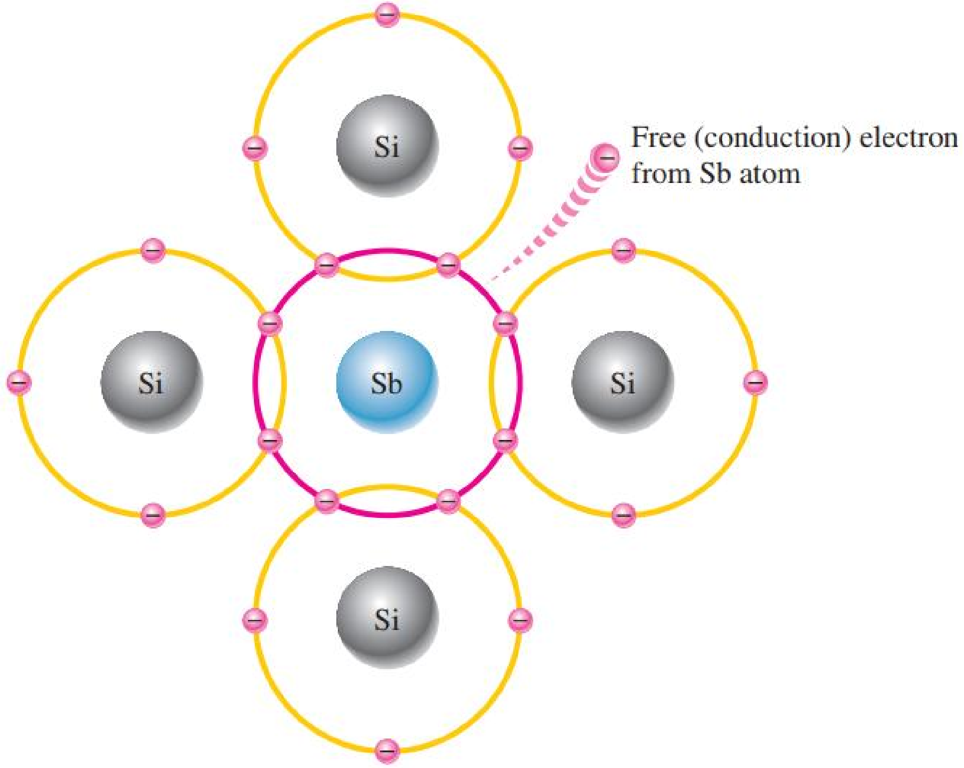


FIGURE 1-8 Pentavalent impurity atom in a silicon crystal structure. An antimony (Sb) impurity atom is shown in the center. The extra electron from the Sb atom becomes a free electron. .

Majority and Minority Carriers

- Since most of the current carriers are electrons, silicon doped with pentavalent atoms is an n-type semiconductor (the n stands for the negative charge on an electron).
- The electrons are called the majority carriers in n-type material.
- Although the majority of current carriers in n-type material are electrons, there are also a few holes that are created when electron-hole pairs are thermally generated.
- These holes are not produced by the addition of the pentavalent impurity atoms. Holes in an n-type material are called minority carriers.

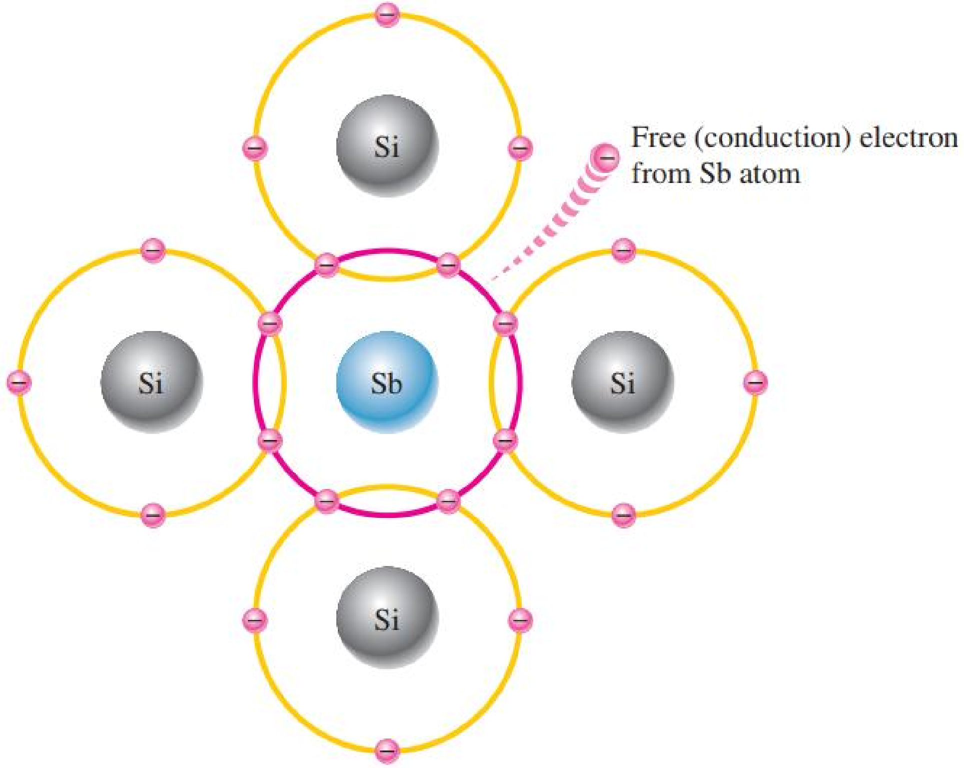
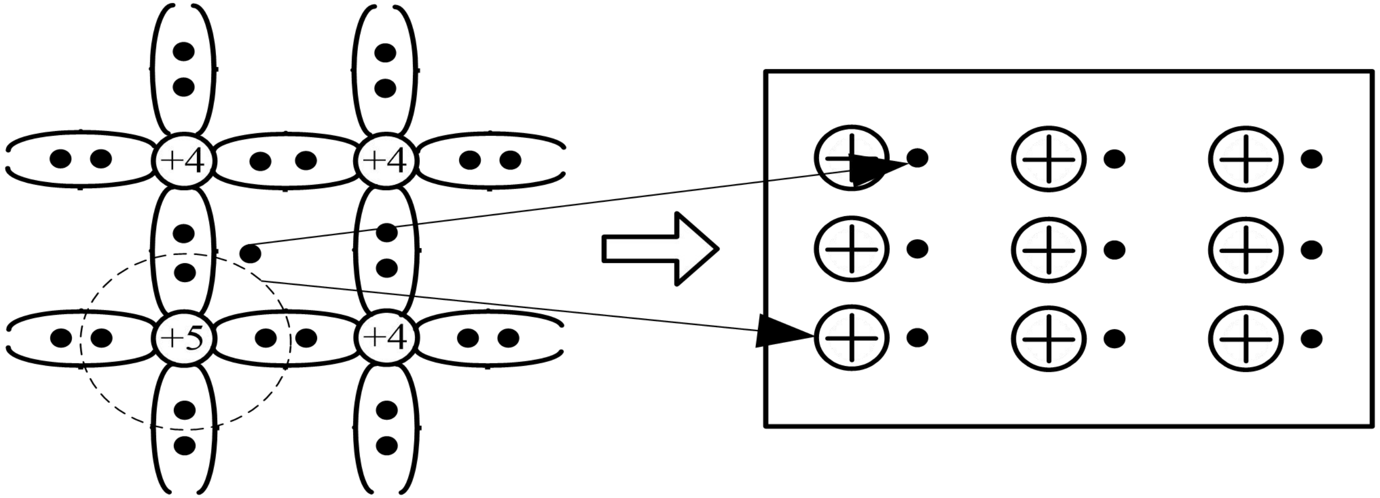


FIGURE 1-8 Pentavalent impurity atom in a silicon crystal structure. An antimony (Sb) impurity atom is shown in the center. The extra electron from the Sb atom becomes a free electron. .

Why addition of impurities （Doping）

- N-Type Semiconductor carrier concentration
- Silicon Atom concentration: $4.96\times10^{22}\text{cm}^{-3}$
- Before Doping: Free electrons concentration at room temperature $1.5\times10^{10}\text{cm}^{-3}$
- After Doping $4.96\times10^{16}\text{cm}^{-3}$ Antimony： Free electrons concentration $4.96\times10^{16}\text{cm}^{-3}$



Free electrons and unmovable positive Ion

FIGURE 1-9 Schematic Diagram of N-Type Semiconductor

P-Type Semiconductor

- To increase the number of holes in intrinsic silicon, trivalent impurity atoms are added. These are atoms with three valence electrons such as boron (B), indium (In), and gallium (Ga).

- Each trivalent atom (boron, in this case) forms covalent bonds with four adjacent silicon atoms. All three of the boron atom's valence electrons are used in the covalent bonds; and, since four electrons are required, a hole results when each trivalent atom is added.

- Because the trivalent atom can take an electron, it is often referred to as an acceptor atom.

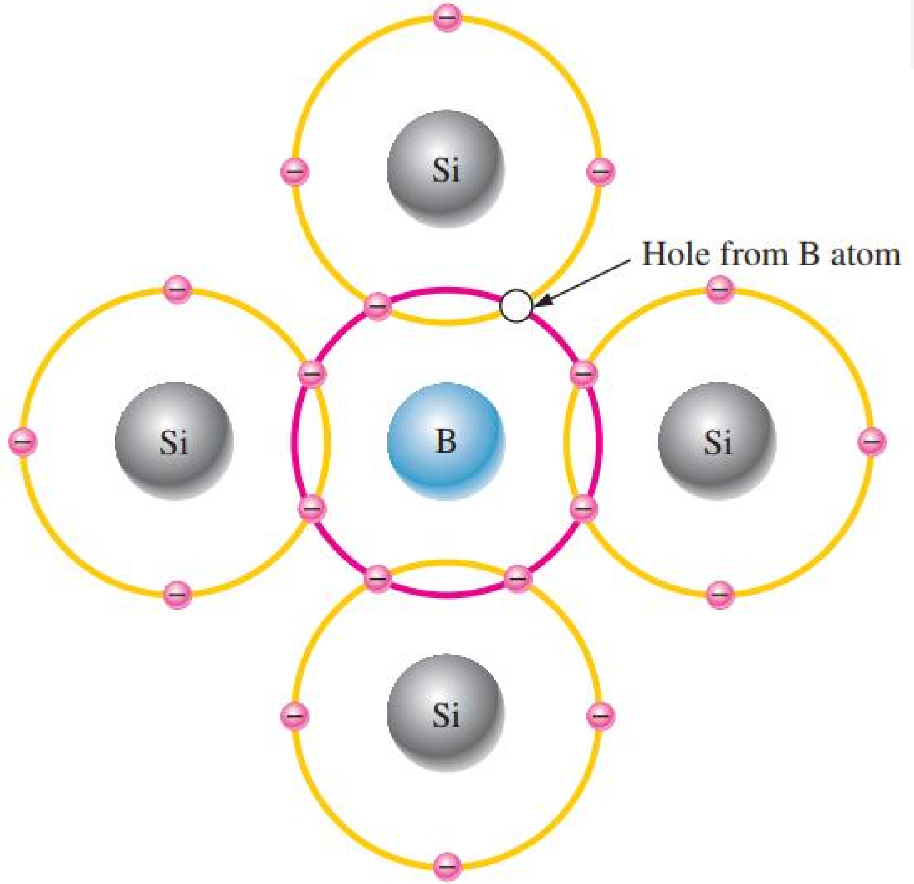


FIGURE 1-10 Trivalent impurity atom in a silicon crystal structure. A boron (B) impurity atom is shown in the center.

P-Type Semiconductor

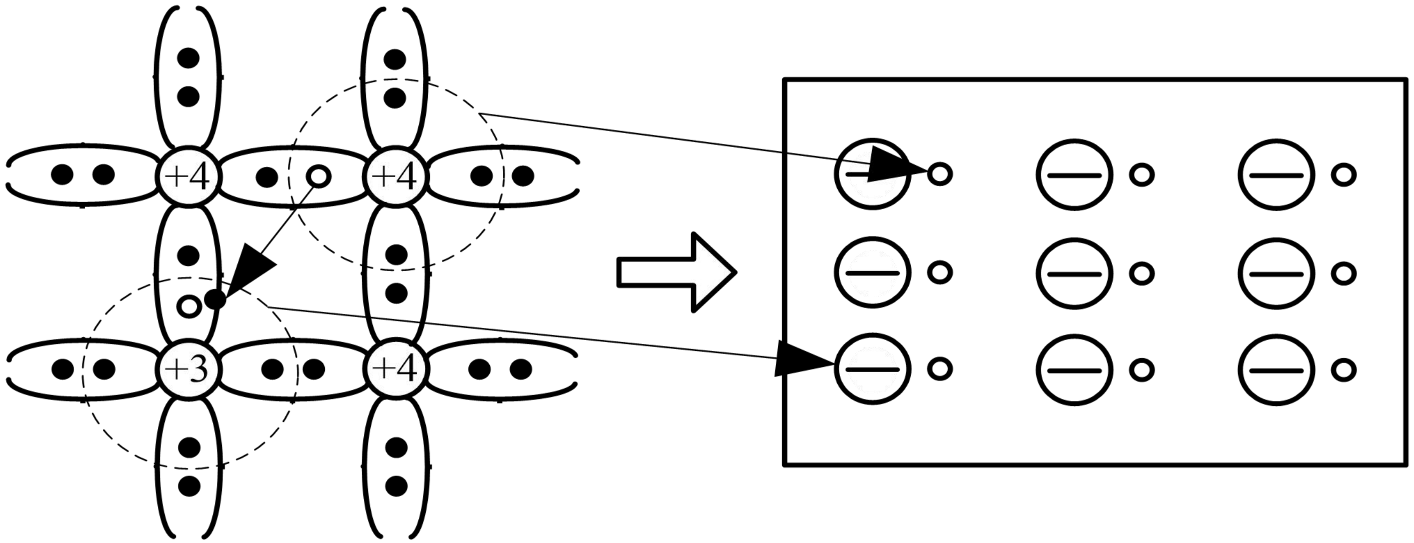


FIGURE 1-11 Schematic Diagram of P-Type Semiconductor

Majority and Minority Carriers

- Since most of the current carriers are holes, silicon (or germanium) doped with trivalent atoms is called a p-type semiconductor.
- 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-hole pairs are thermally generated.
- These free electrons are not produced by the addition of the trivalent impurity atoms. Conduction-band electrons in p-type material are the minority carriers.

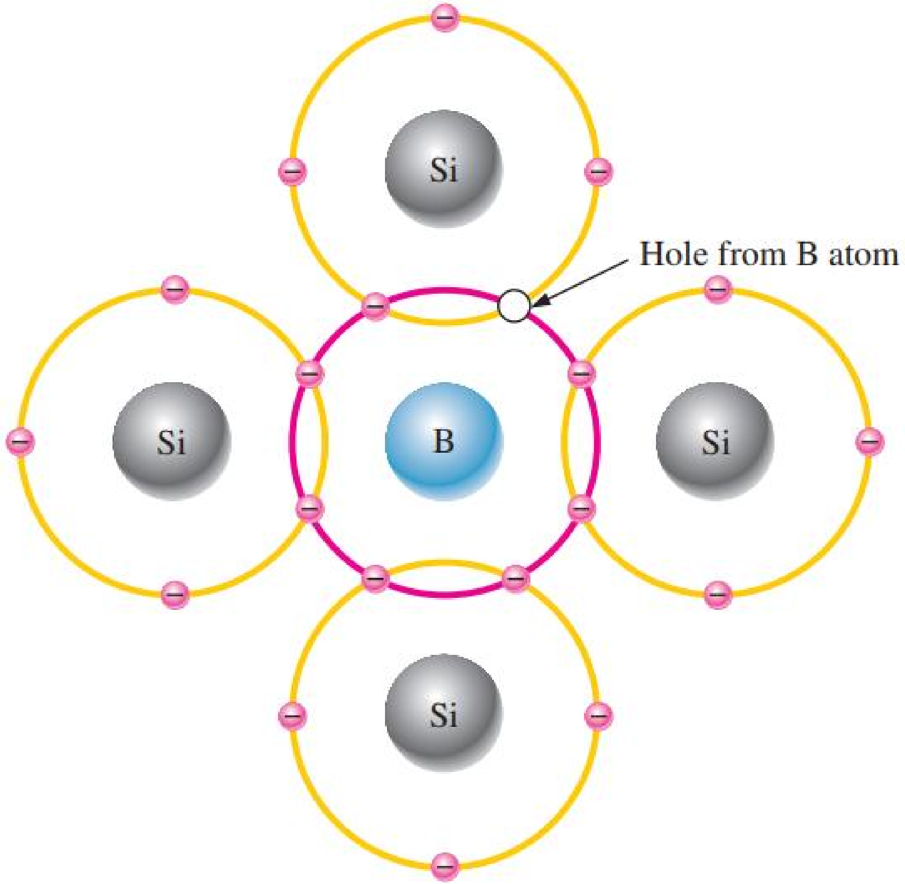


FIGURE 1-10 Pentavalent impurity atom in a silicon crystal structure. An antimony (Sb) impurity atom is shown in the center. The extra electron from the Sb atom becomes a free electron. .

1.5 THE PN JUNCTION

- If a piece of intrinsic silicon is doped so that part is n-type and the other part is p-type, a pn junction forms at the boundary between the two regions.
- The p region has many holes (majority carriers) and only a few thermally generated free electrons (minority carriers). The n region has many free electrons (majority carriers) and only a few thermally generated holes (minority carriers).

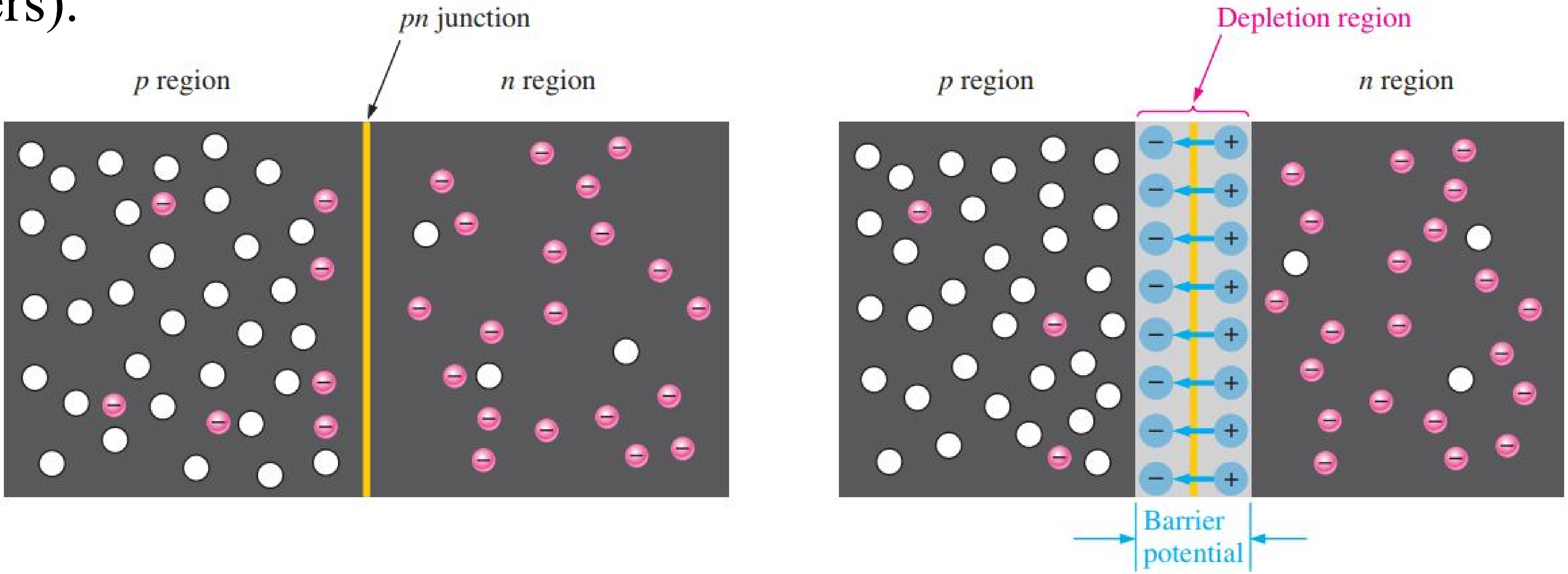


FIGURE 1-12 Formation of the depletion region. The width of the depletion region is exaggerated for illustration purposes.

Formation of the Depletion Region

- The free electrons near the junction in the n region begin to diffuse across the junction into the p region where they combine with holes near the junction.
- Before the pn junction is formed, recall that there are as many electrons as protons in the n-type material, making the material neutral in terms of net charge. The same is true for the p-type material.

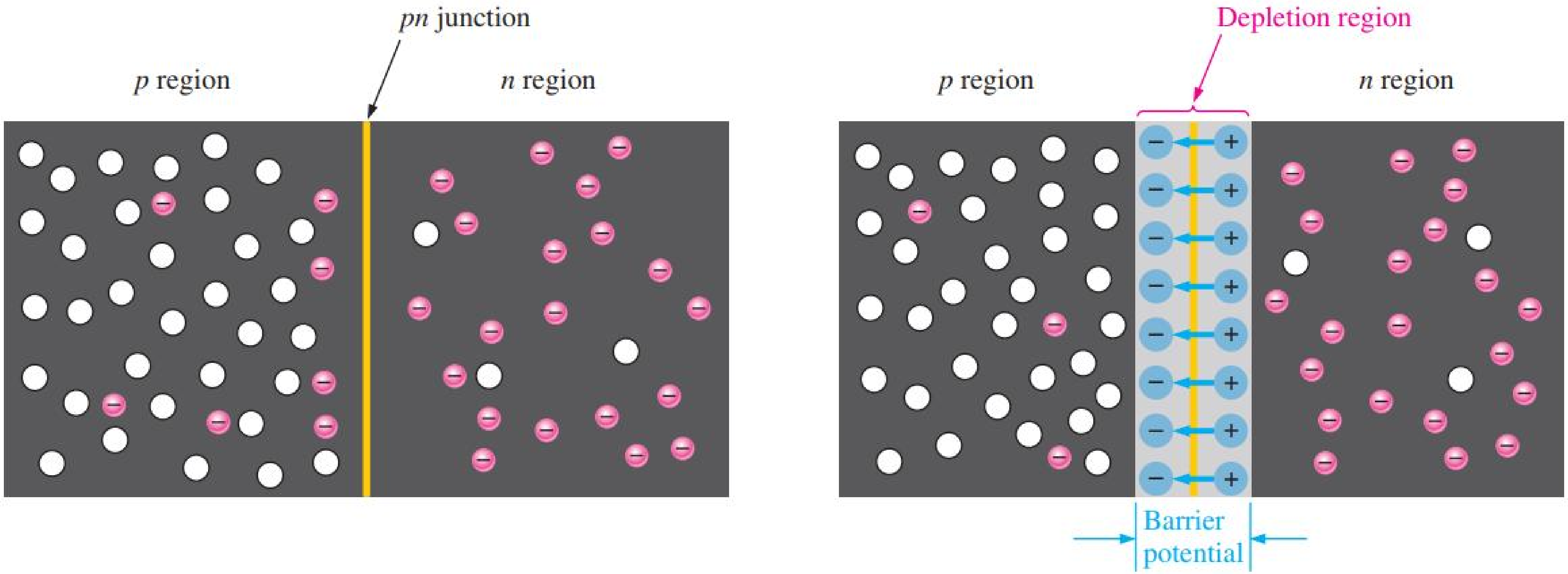


FIGURE 1-12 Formation of the depletion region. The width of the depletion region is exaggerated for illustration purposes.

- When the pn junction is formed, the n region loses free electrons as they diffuse across the junction. This creates a layer of positive charges (pentavalent ions) near the junction.
- As the electrons move across the junction, the p region loses holes as the electrons and holes combine. This creates a layer of negative charges (trivalent ions) near the junction.
- These two layers of positive and negative charges form the depletion region.

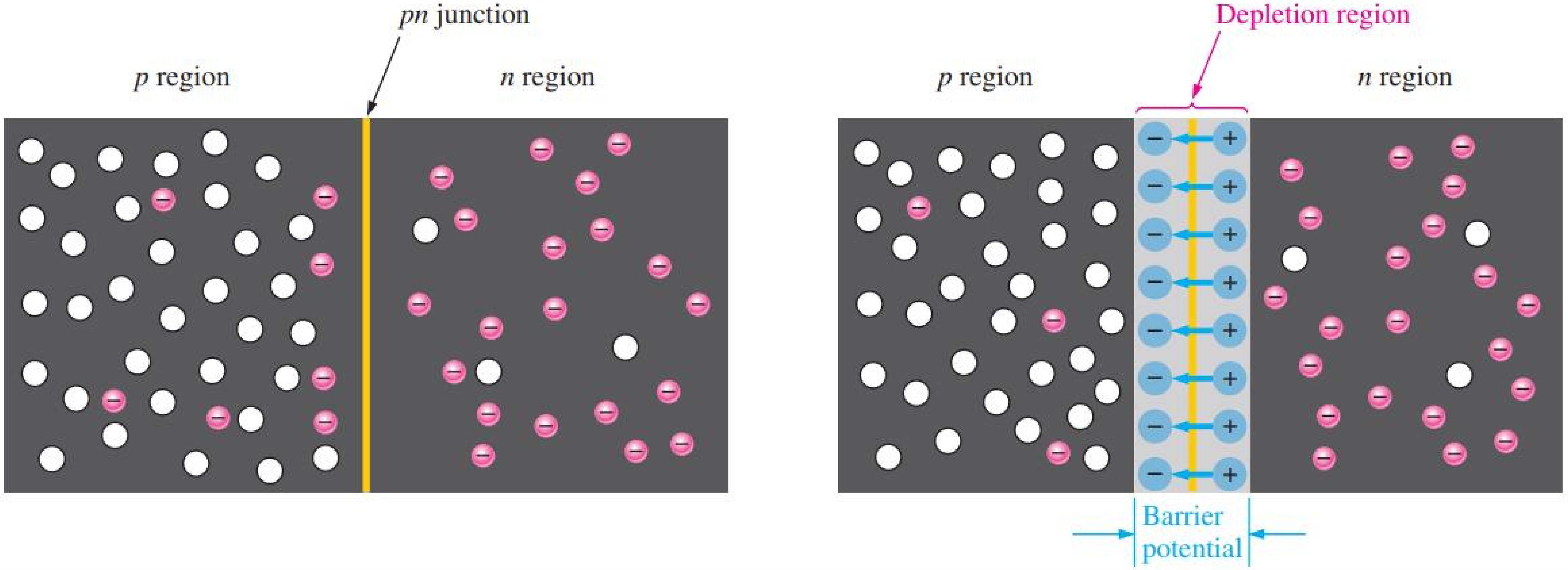


FIGURE 1-12 Formation of the depletion region. The width of the depletion region is exaggerated for illustration purposes.

- After the initial surge of free electrons across the pn junction, the depletion region has expanded to a point where equilibrium is established and there is no further diffusion of electrons across the junction.
- In the depletion region there are many positive charges and many negative charges on opposite sides of the pn junction. The forces between the opposite charges form an electric field.

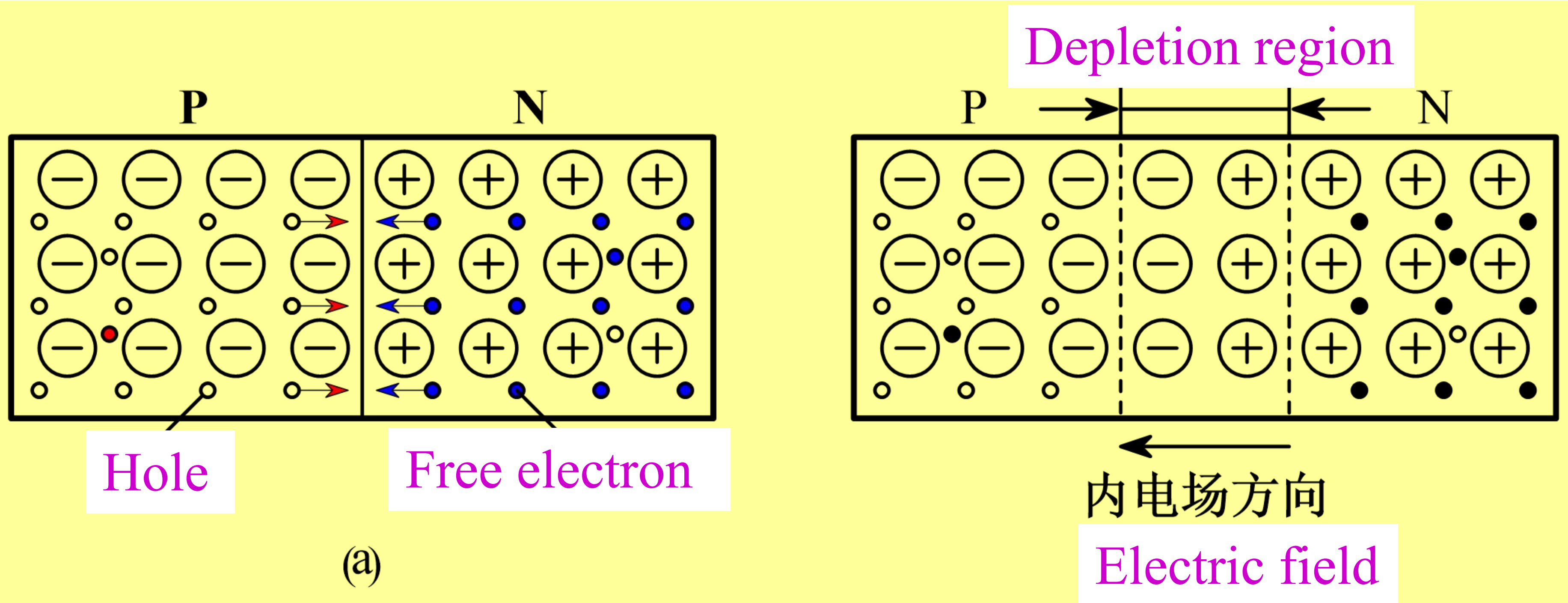
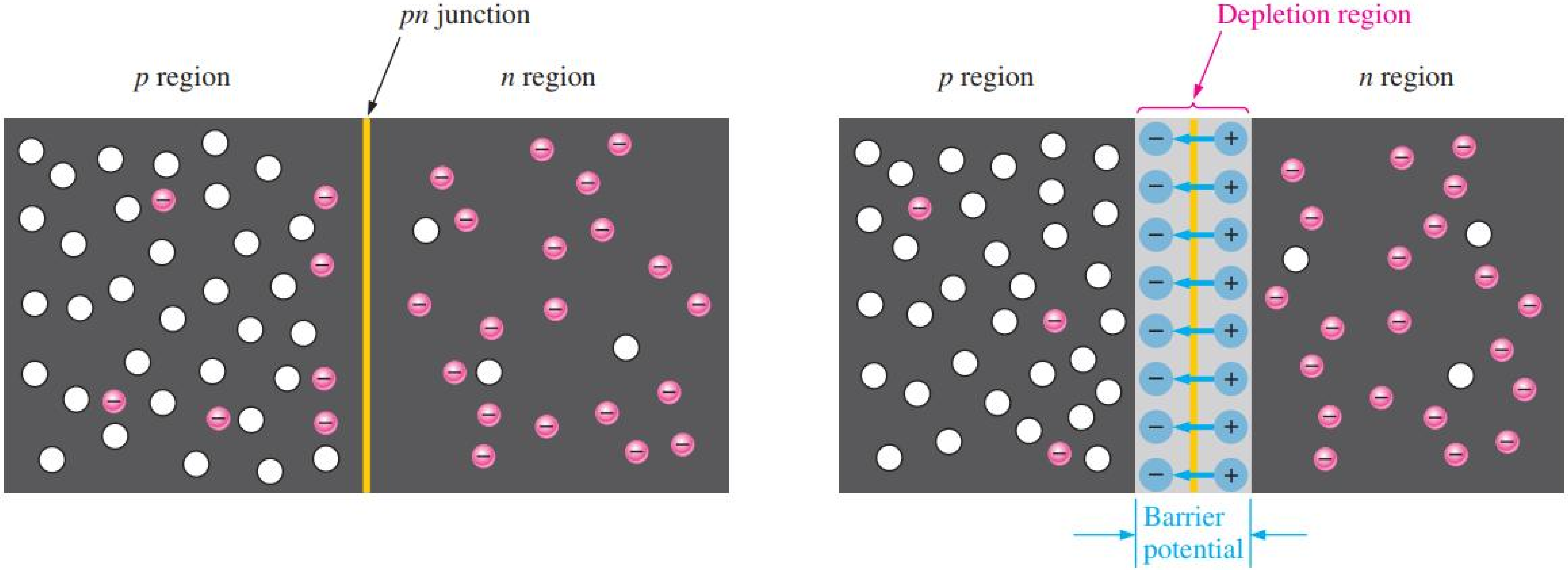


FIGURE 1-13 Formation of the depletion region.

- 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 the barrier potential and is expressed in volts..
- The typical barrier potential is approximately 0.7 V for silicon and 0.3 V for germanium at 25°C.



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