# Semiconductor Devices
# Fall 2014


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# This Lecture

- Reading
  - 1.1-9 and 1.11 Electrons and holes in semiconductors
  - 2.1-2.2 Motion and recombination of *n* & *p*
- Concepts:
  - Energy band model
  - Distribution functions and effective density of states
  - Intrinsic carriers and ionized dopant impurities
  - Charge neutrality
  - Drift current and mobility (applied field)

- Carbon ”C” is an element with valence IV in the same group as Si och Ge. What is correct?

A) C is a SC
B) C is an insulator
C) C is a SC with zero bandgap
D) C is an organic semiconductor

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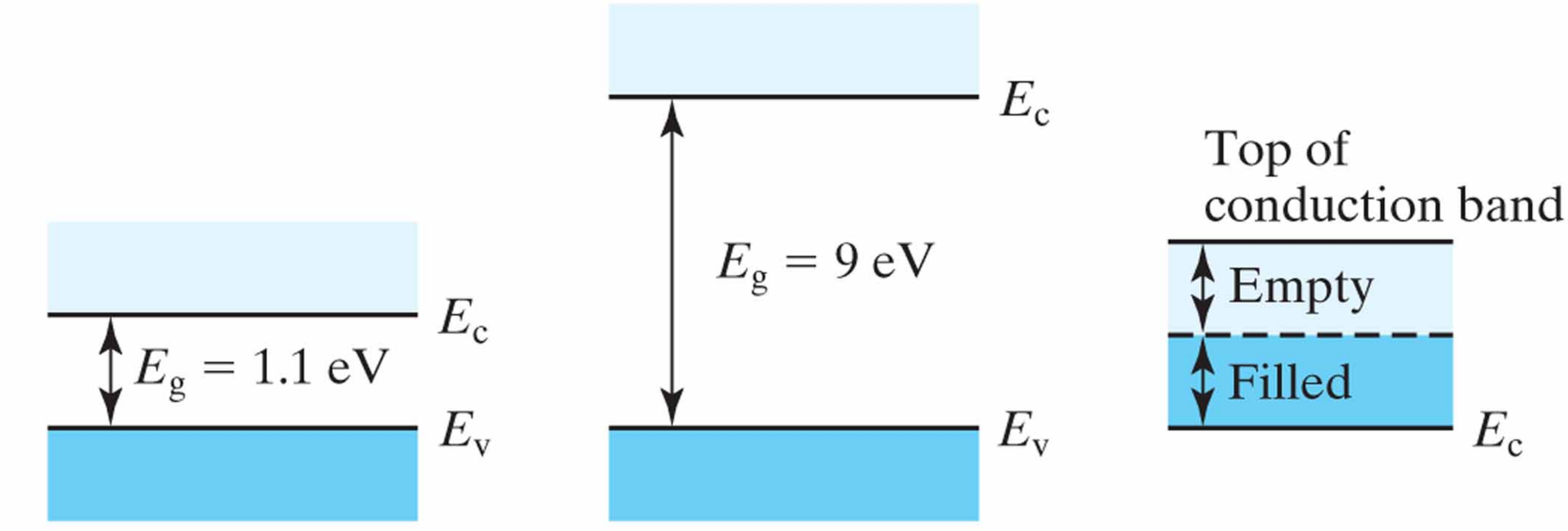
**TABLE 1–1 • Band-gap energies of selected semiconductors.**

| Semiconductor | InSb | Ge | Si | GaAs | GaP | ZnSe | Diamond |
|---|---|---|---|---|---|---|---|
| $E_g$ (eV) | 0.18 | 0.67 | 1.12 | 1.42 | 2.25 | 2.7 | 6.0 |




(a) Si, semiconductor (b) $SiO_2$, insulator (c) Conductor

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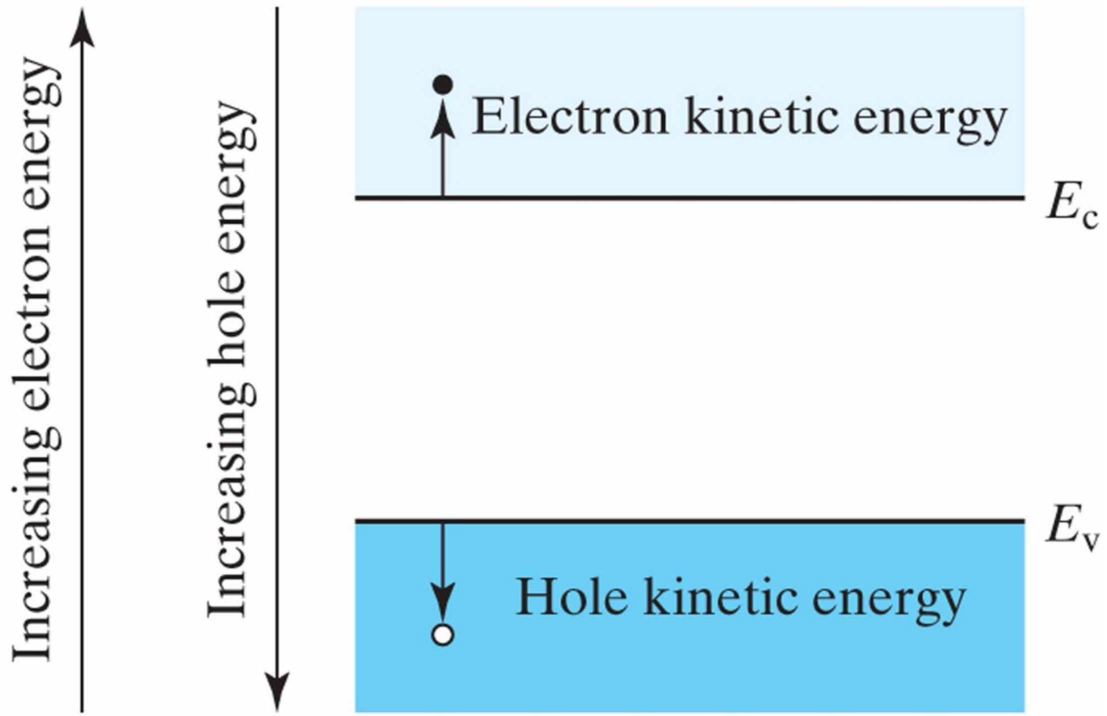
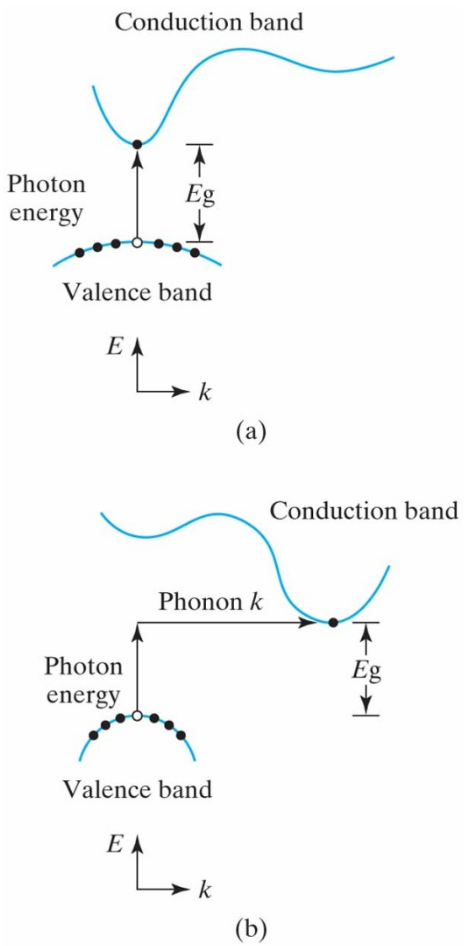


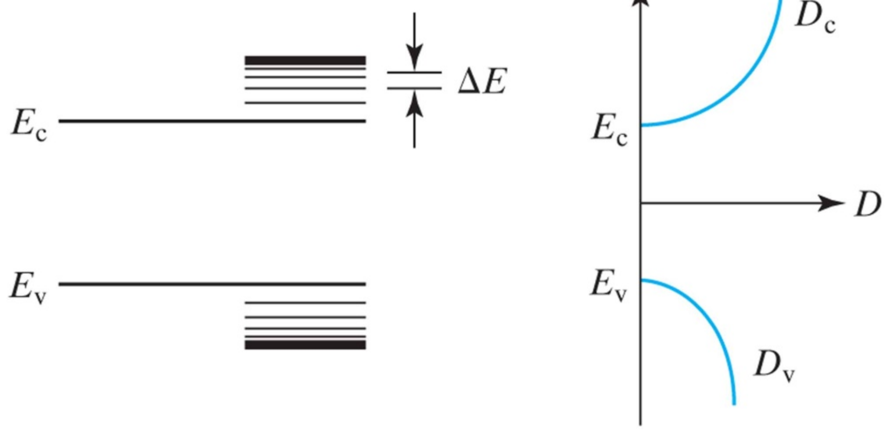

**TABLE 1–3 • Electron and hole effective masses, $m_n$ and $m_p$, normalized to the free electron mass.**

| | Si | Ge | GaAs | InAs | AlAs |
|---|---|---|---|---|---|
| $m_n/m_0$ | 0.26 | 0.12 | 0.068 | 0.023 | 2.0 |
| $m_p/m_0$ | 0.39 | 0.30 | 0.50 | 0.30 | 0.3 |

# **Figure 4.27** The *E–k* diagrams of (a) direct-gap semiconductor and (b) indirect-gap semiconductor.

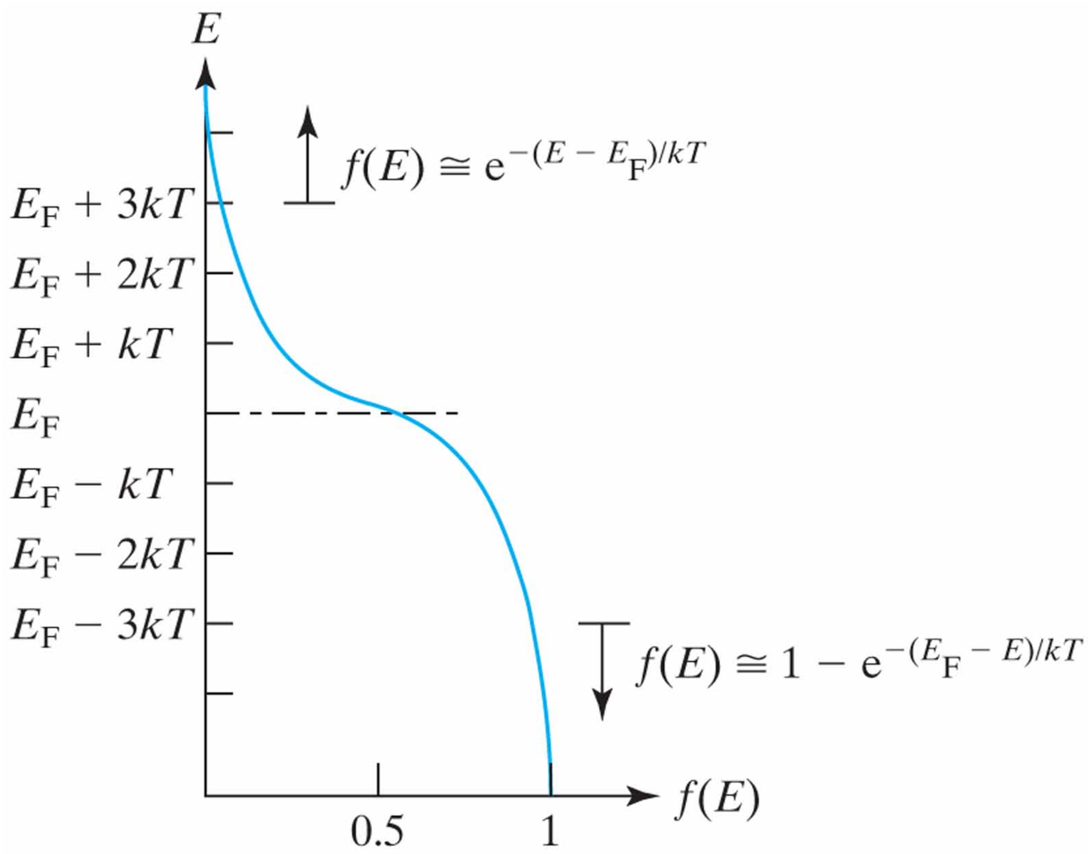



- The curvature of the bands show that electrons and holes have different effective mass
- There is a minimum on the k-axis which gives bandgap Eg, direct or indirect



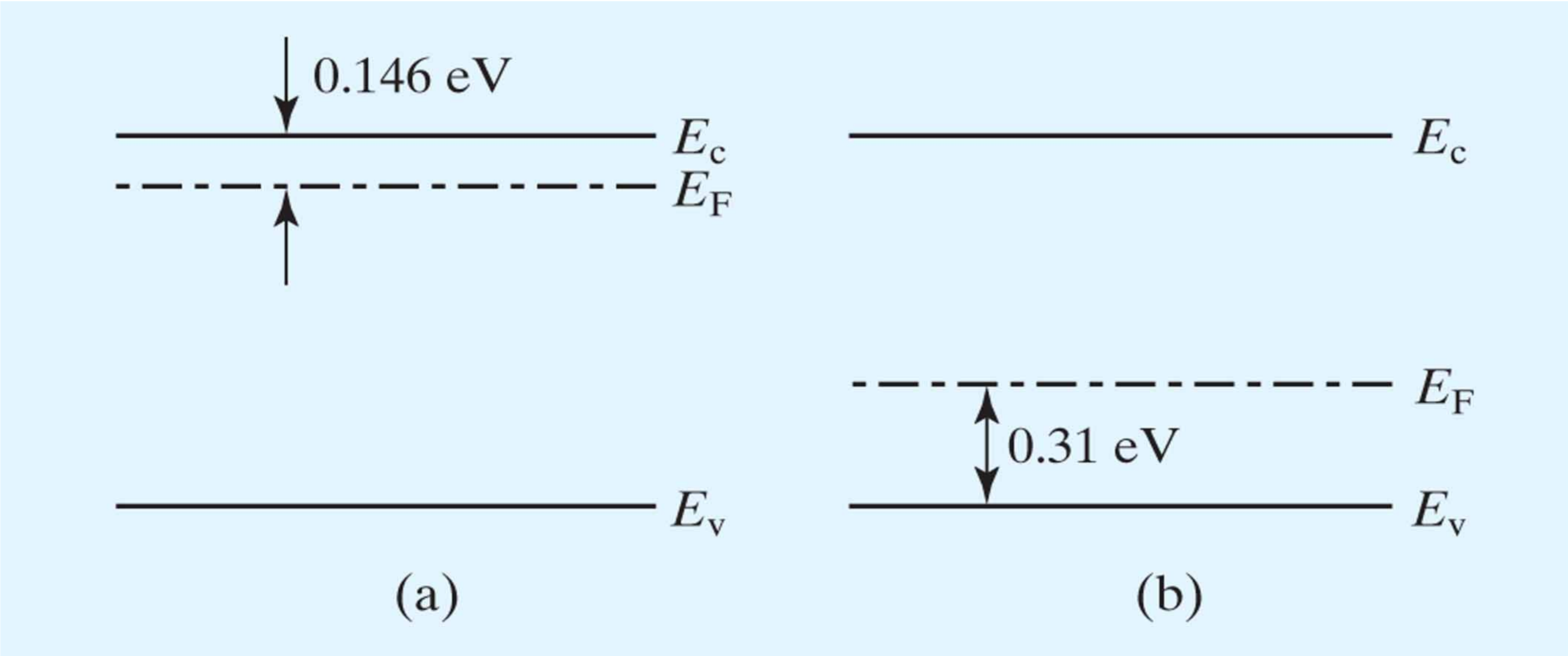
$\Delta E$
$E_c$
$E_v$
$E$
$D_c$
$D$
$D_v$


(a) (b)

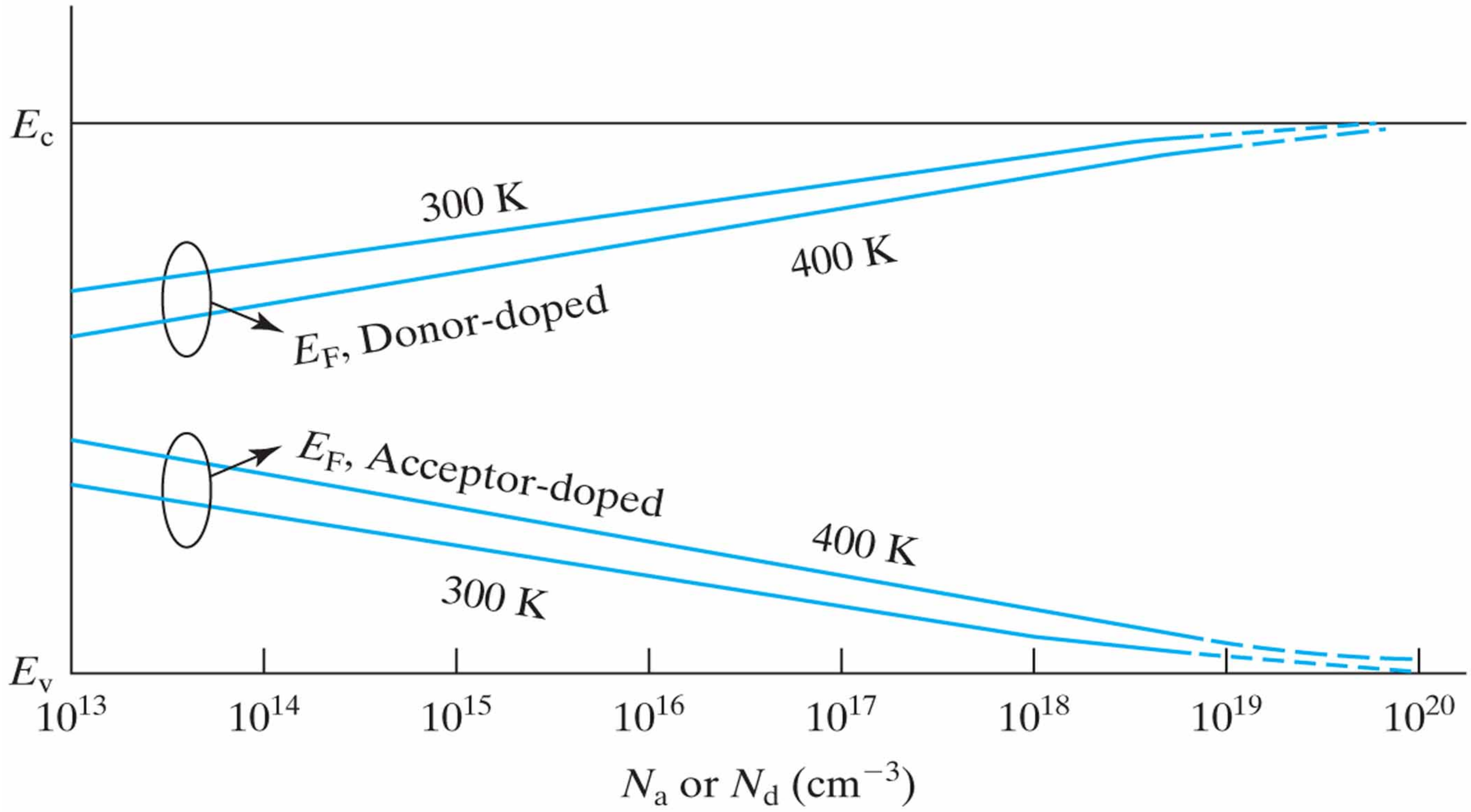


$E$
$f(E) \cong e^{-(E - E_F)/kT}$
$E_F + 3kT$
$E_F + 2kT$
$E_F + kT$
$E_F$
$E_F - kT$
$E_F - 2kT$
$E_F - 3kT$
$f(E) \cong 1 - e^{-(E_F - E)/kT}$
0.5
1
$f(E)$

# **Figure 1.22** Location of $E_F$ when $n$ = $10^{17}$cm$^{-3}$ (a), and $p$ = $10^{14}$cm$^{-3}$ (b).



# **Figure 1.21** Location of Fermi level vs. dopant concentration in Si at 300 and 400 K



# Donor/acceptor levels & temp dep.

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**Figure 1.12** Energy levels of donors and acceptors.

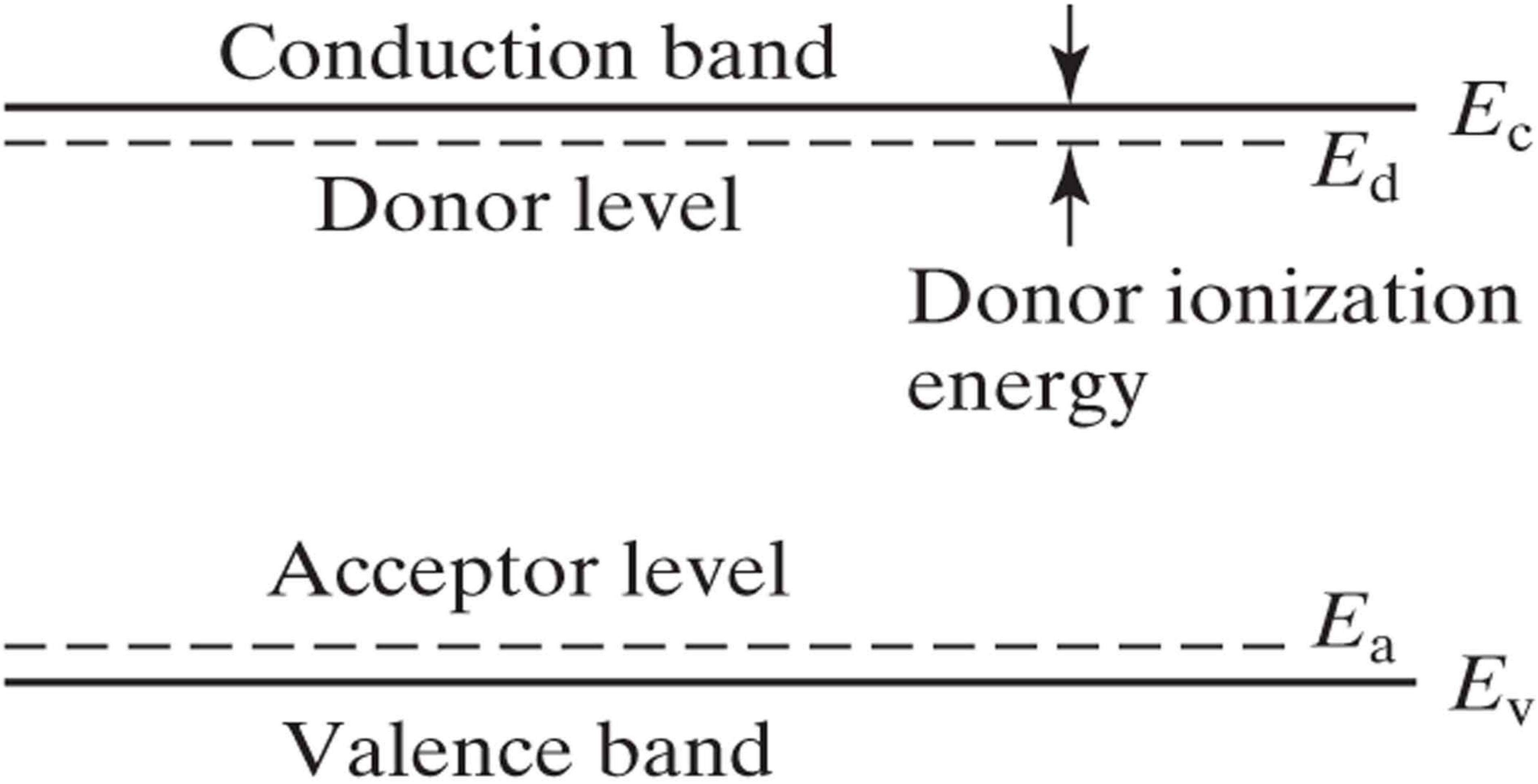


**Table 1.2** Ionization energy of selected donors and acceptors in silicon.

**TABLE 1–2 • Ionization energy of selected donors and acceptors in silicon.**

| | Donors | | | Acceptors | | |
|---|---|---|---|---|---|---|
| **Dopant** | Sb | P | As | B | Al | In |
| **Ionization energy, $E_c - E_d$ or $E_a - E_v$ (meV)** | 39 | 44 | 54 | 45 | 57 | 160 |

**Figure 1.23** Location of $E_F$ and $E_d$. Not to scale.

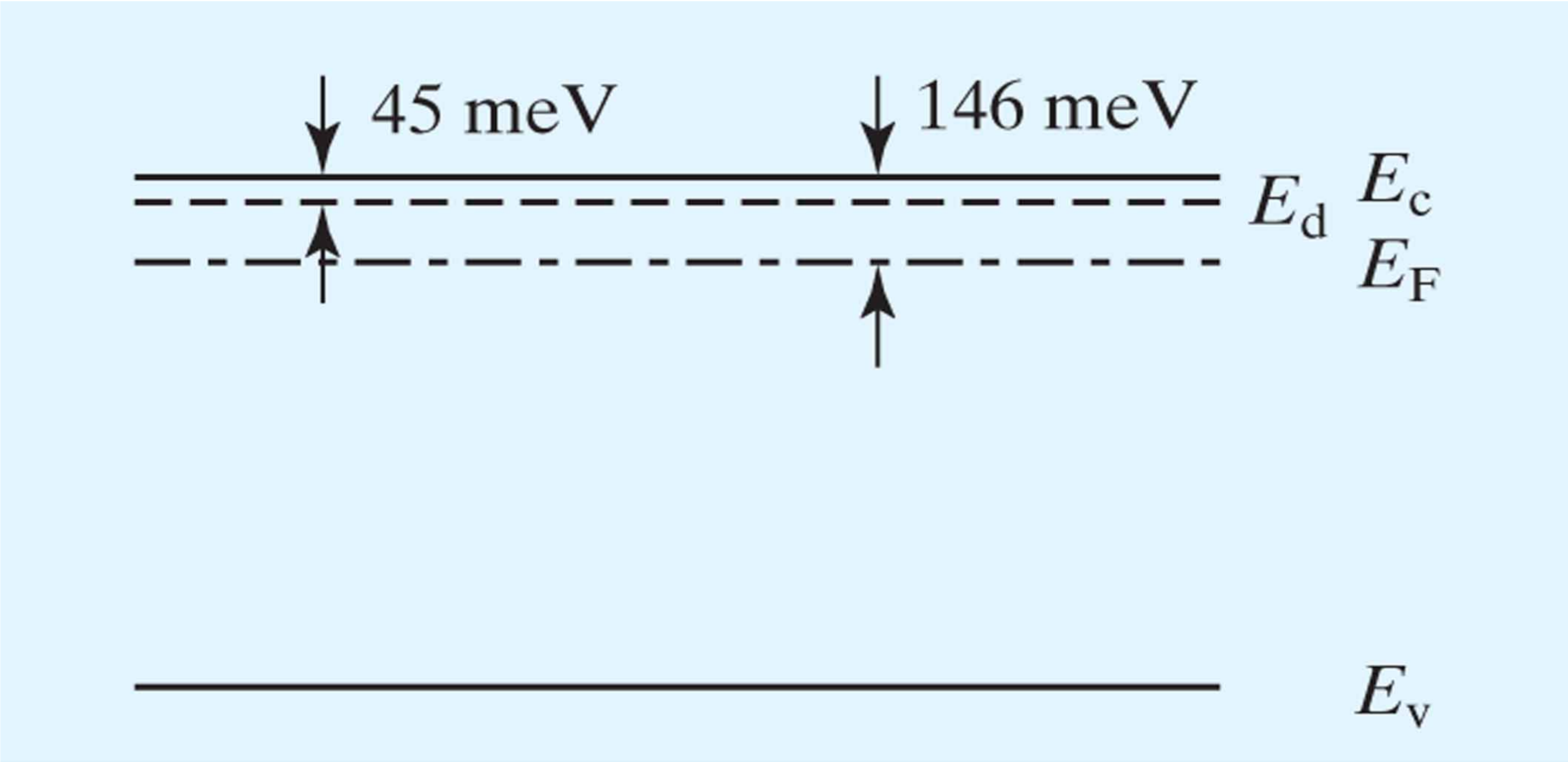
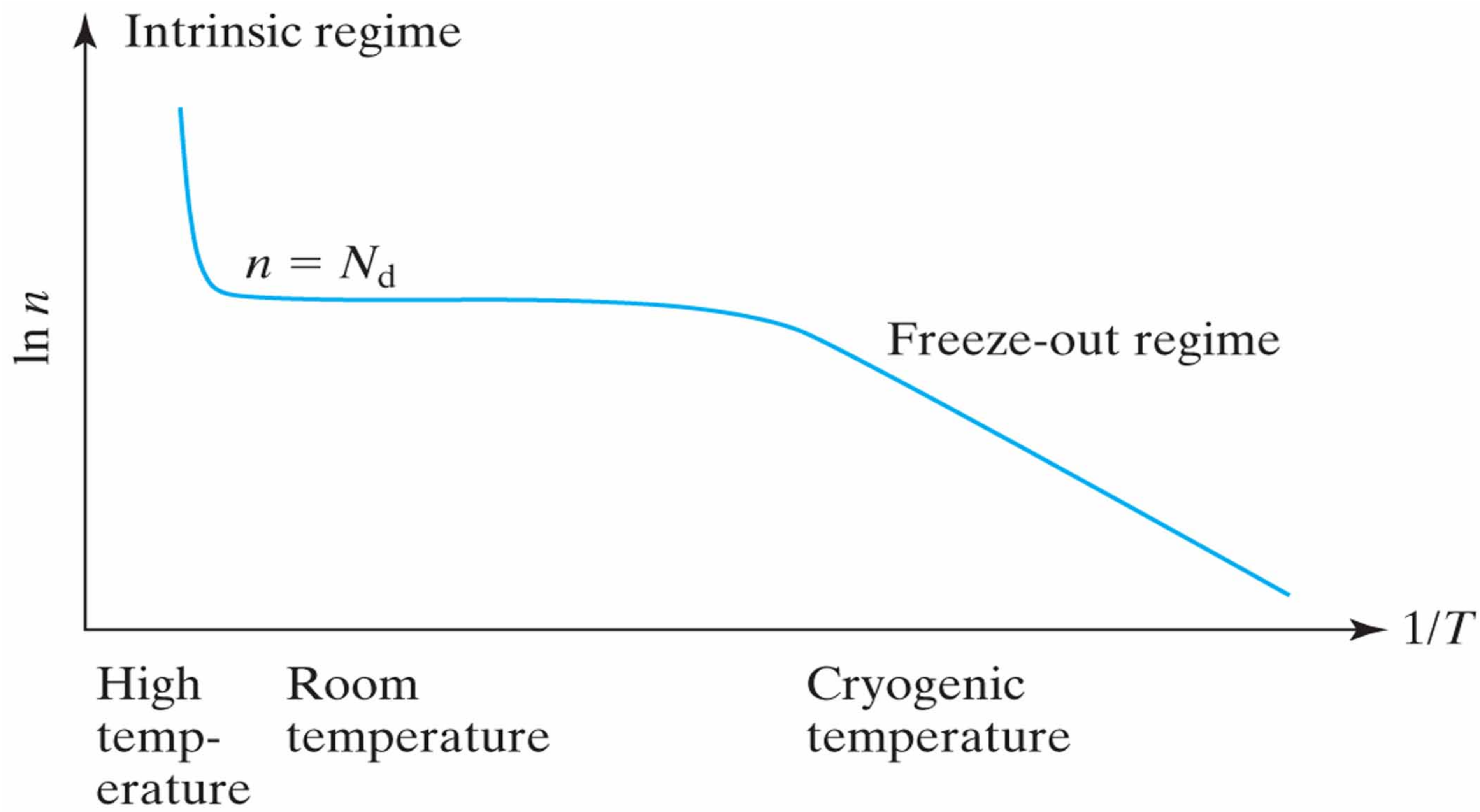


**Figure 1.25** Variation of carrier concentration in an N-type semiconductor over a wide range of temperature.



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# Chapter 2

- Motion and Recombination of Electrons and Holes

# Två typer of motion

**Figure 2.1** The thermal motion of an electron or a hole changes direction frequently by scattering off imperfections in the semiconductor crystal.

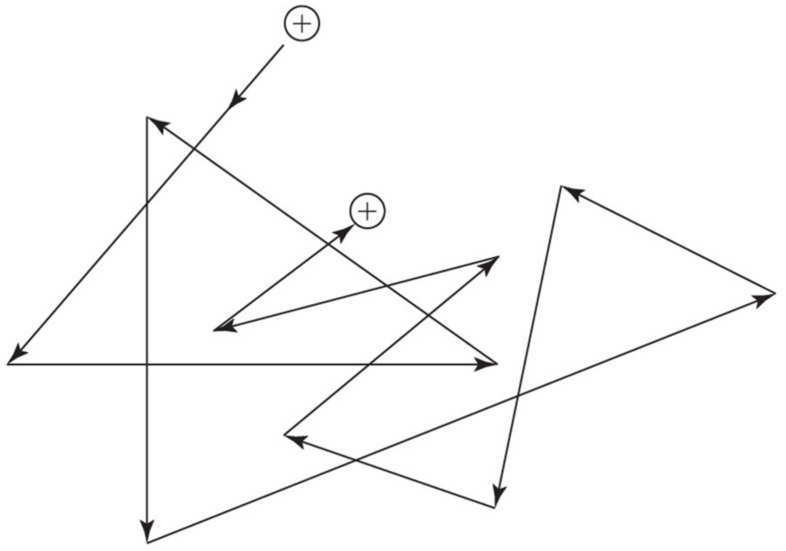

**Figure 2.3** An electric field creates a drift velocity that is superimposed on the thermal velocity.

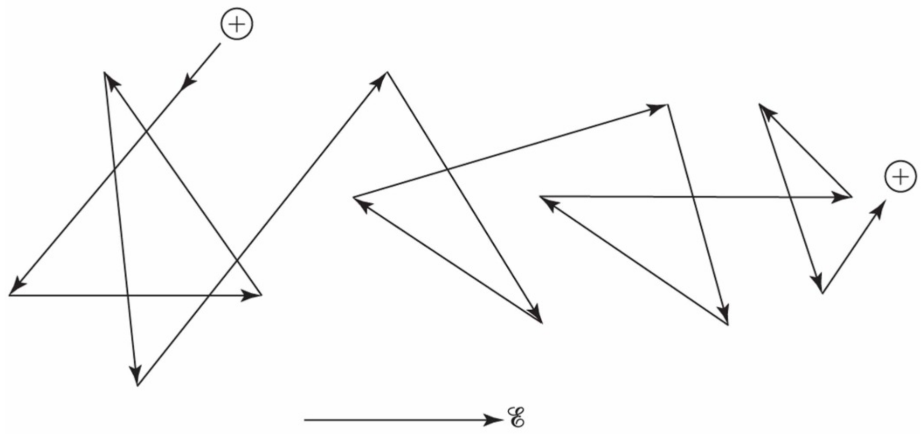

**Figure 2.4** An electron can be scattered by an acceptor ion (a) and a donor ion (b) in a strikingly similar manner, even though the ions carry opposite types of charge. The same is true for a hole (not shown).

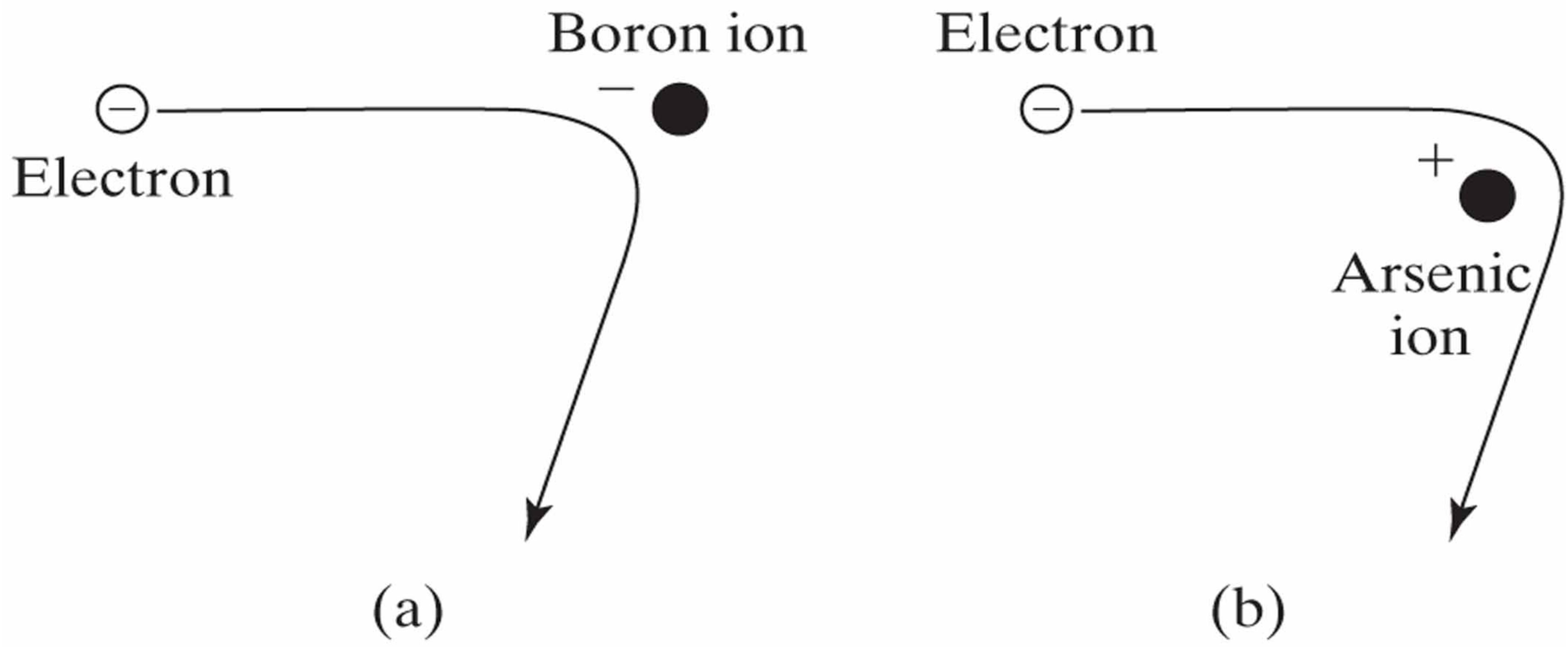

**Figure 2.5** The electron and hole mobilities of silicon at 300 K. At low dopant concentration, the electron mobility is dominated by phonon scattering; at high dopant concentration, it is dominated by impurity ion scattering. (After [3].)

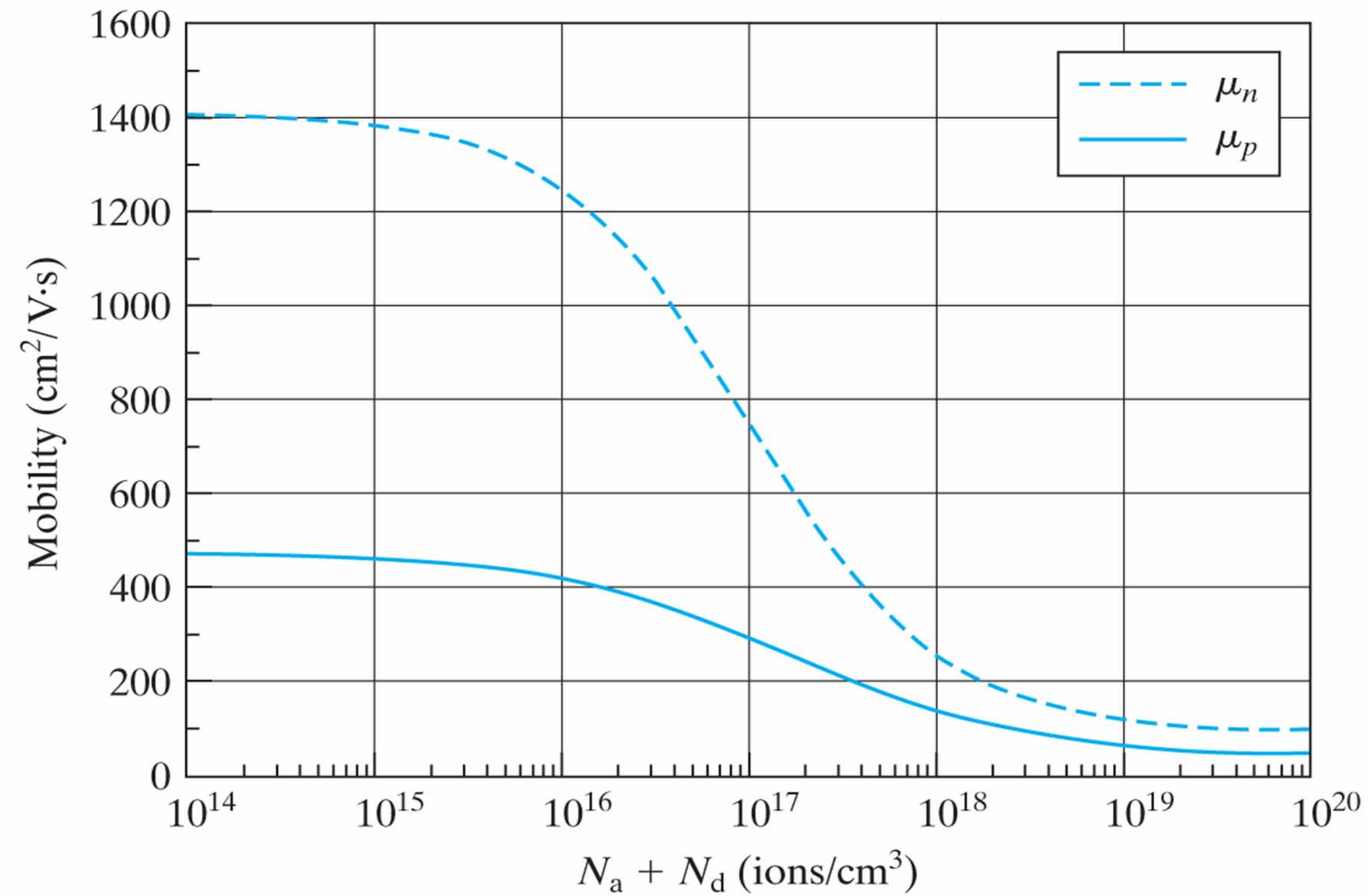

**Figure 2.6** Temperature dependence of the electron mobility in Si. (After [4], reprinted by permission of John Wiley & Sons, Inc.)

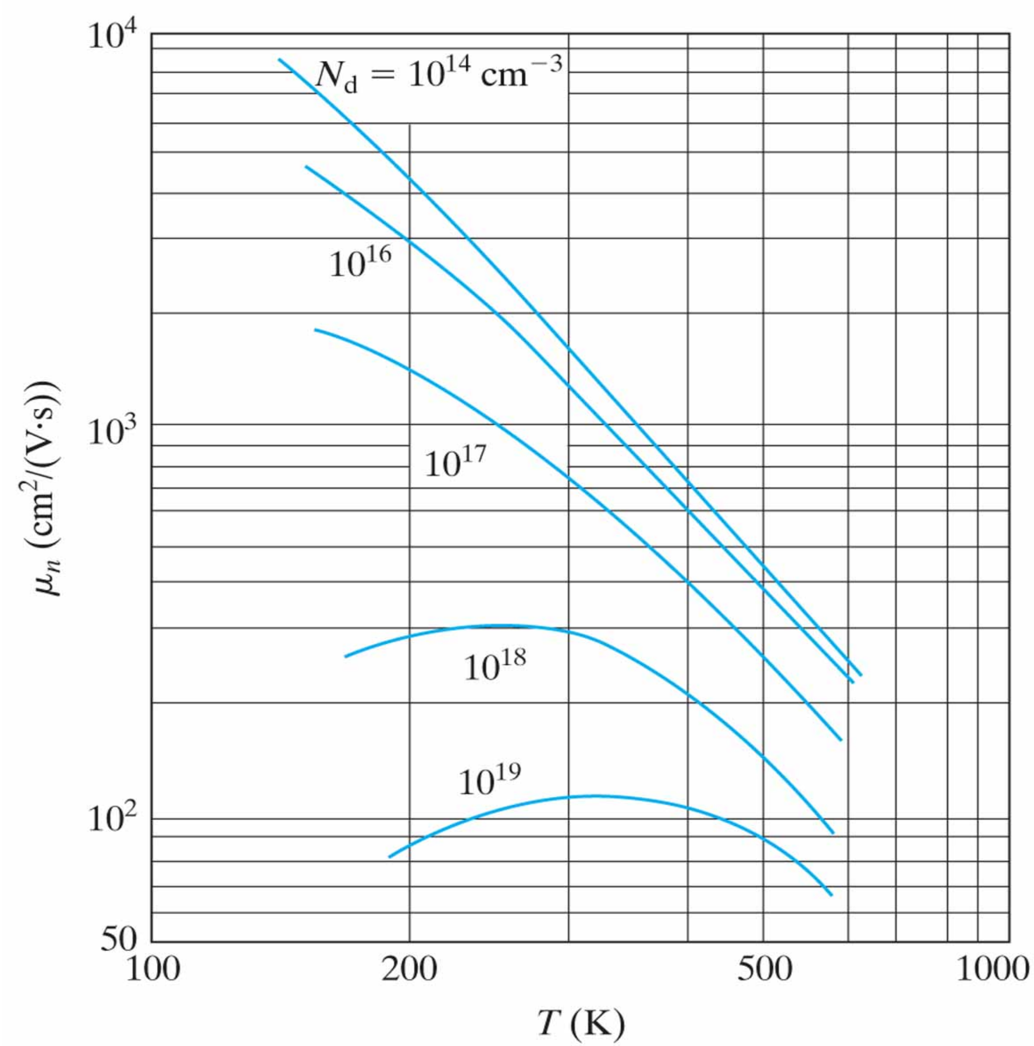

**Figure 2.7** A P-type semiconductor bar of unit area is used to demonstrate the concept of current density.

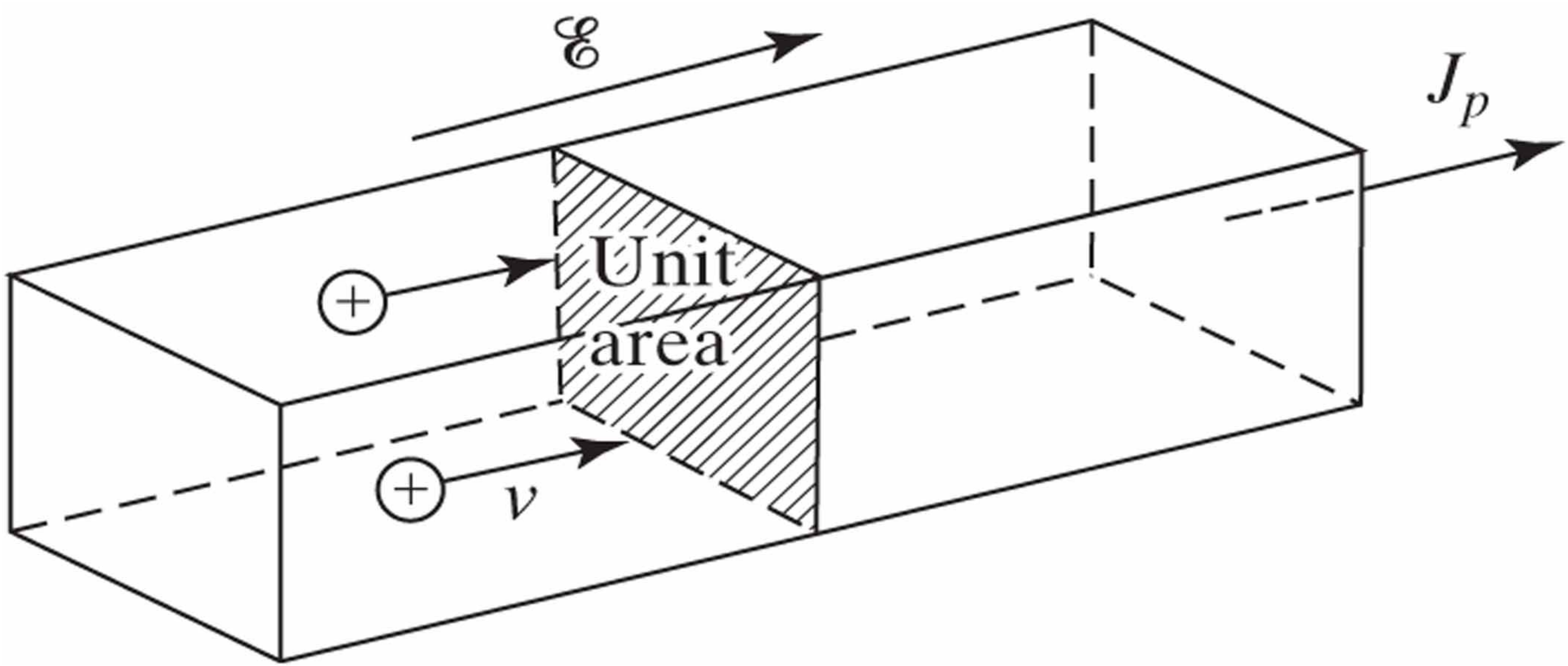

**Figure 2.8** Conversion between resistivity and dopant density of silicon at room temperature. (After [3].)

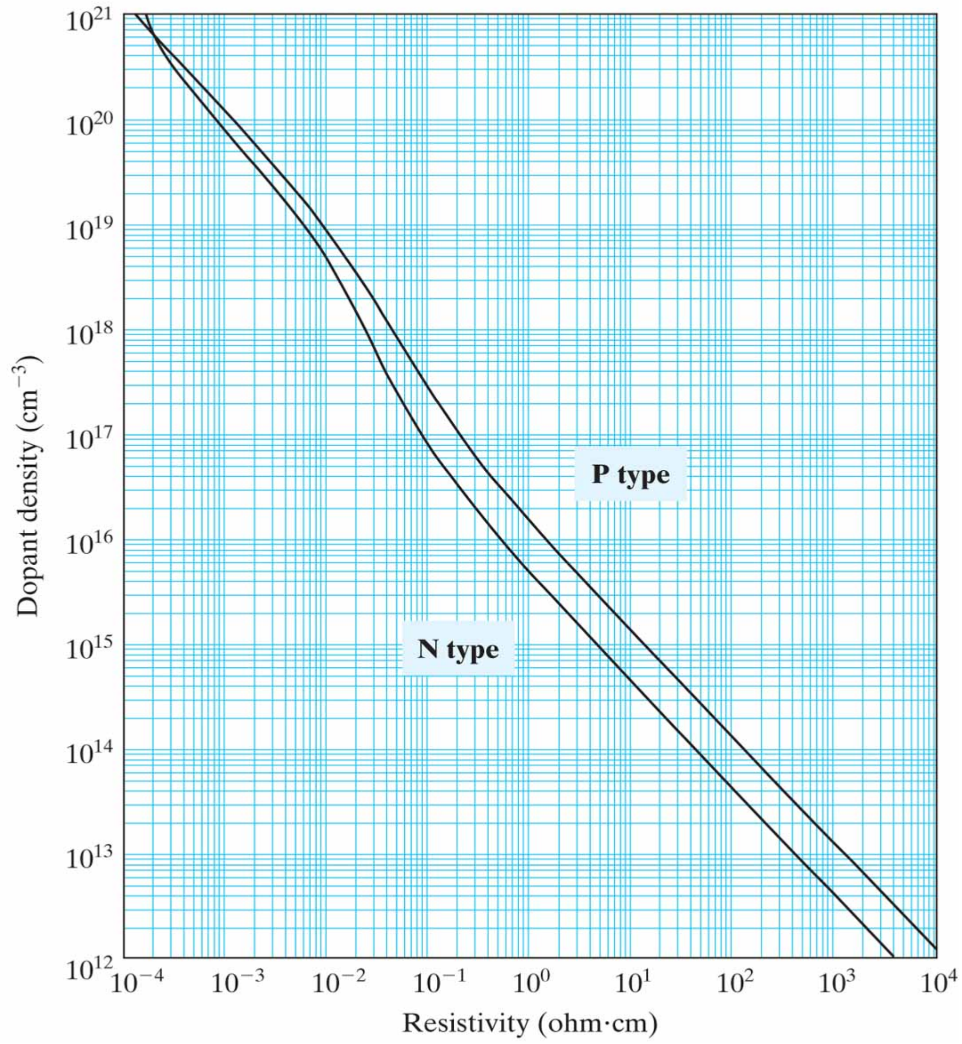

**Figure 2.9** Particles diffuse from high-concentration locations toward low-concentration locations.

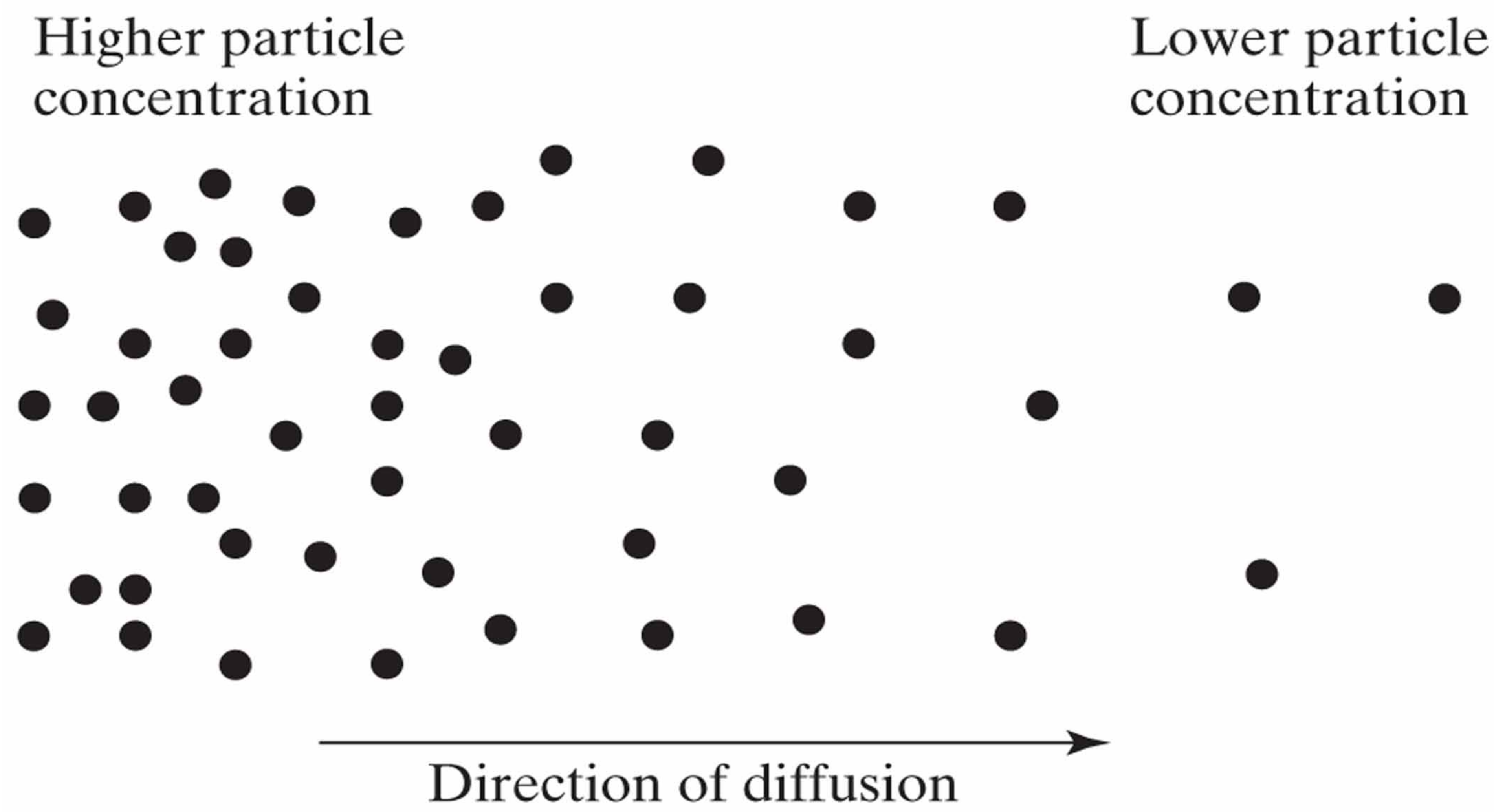

**Figure 2.10** A positive slope of carrier concentration produces a positive electron diffusion current (a), but a negative hole diffusion current (b).

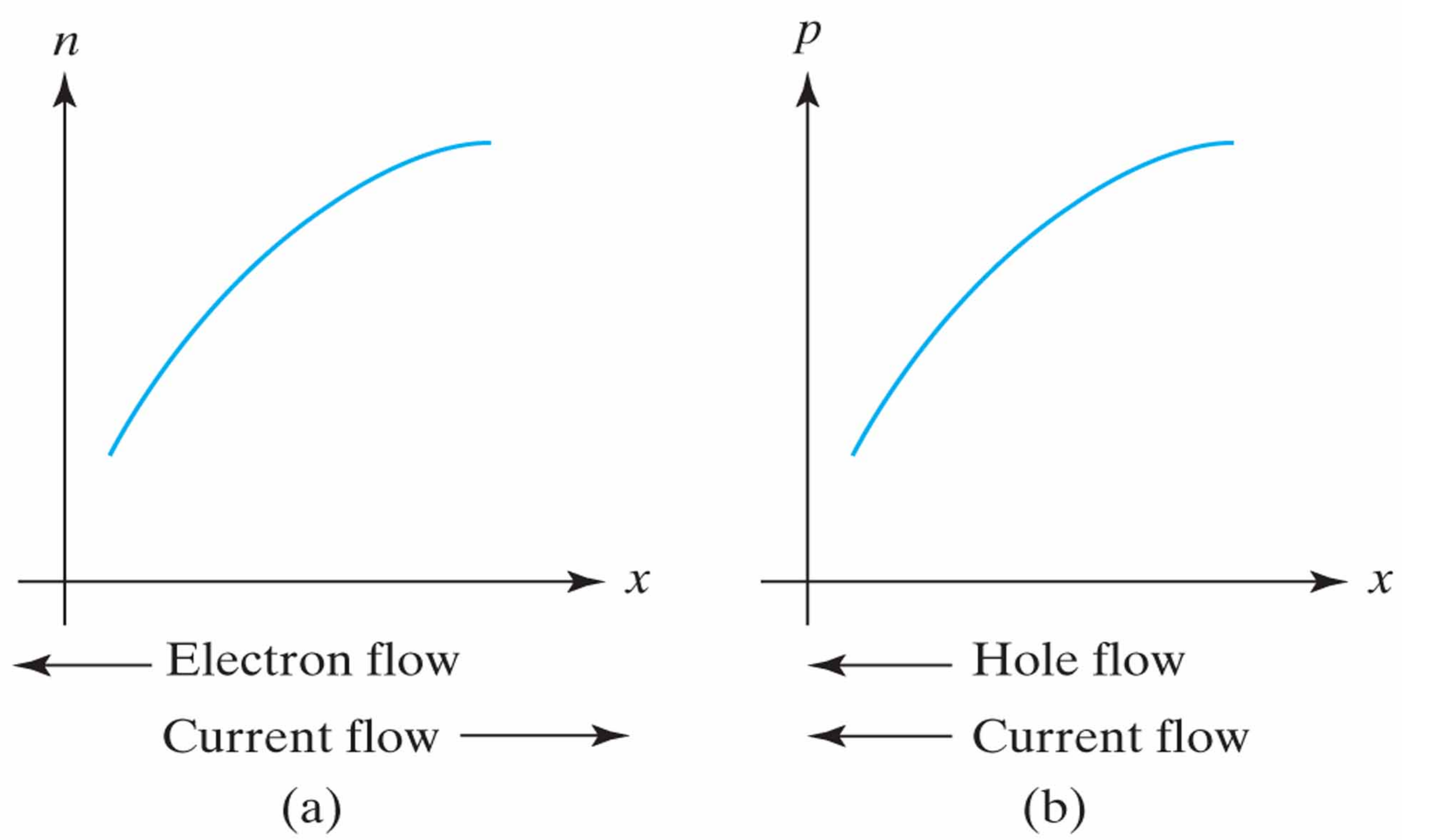

**Figure 2.11** Energy band diagram of a semiconductor under an applied voltage. 0.7 eV is an arbitrary value.

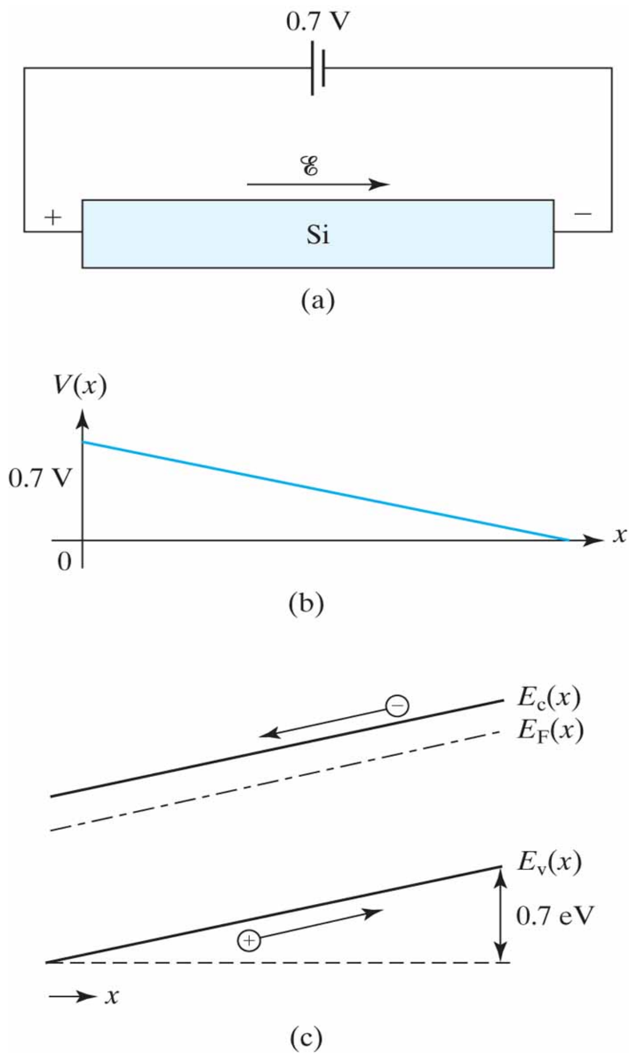

**Figure 2.12** A piece of N-type semiconductor in which the dopant density decreases toward the right.

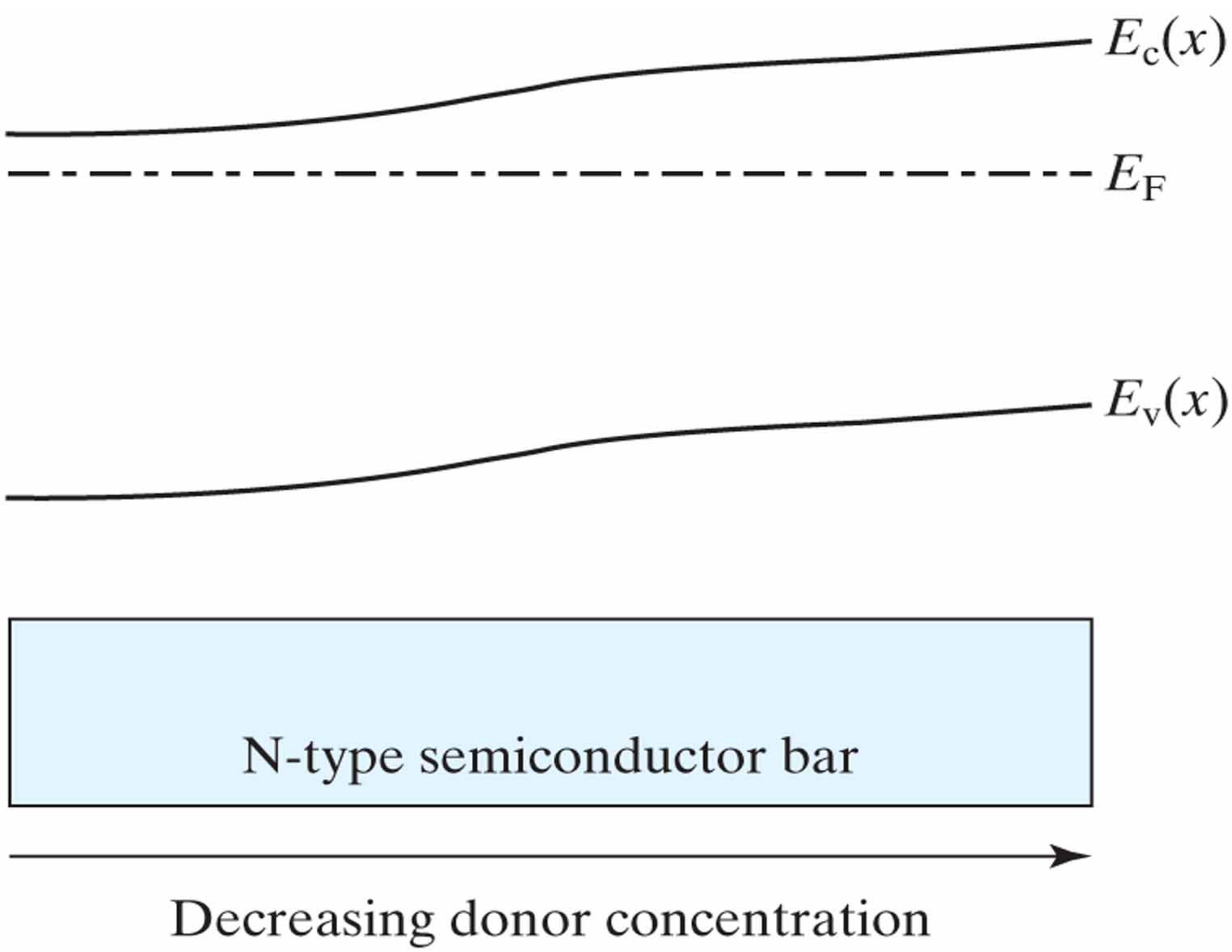

**Figure 2.13** An electron–hole pair recombines when an electron drops from the conduction band into the valence band. In silicon, direct recombination is unimportant and the lifetime is highly variable and determined by the density of recombination centers.

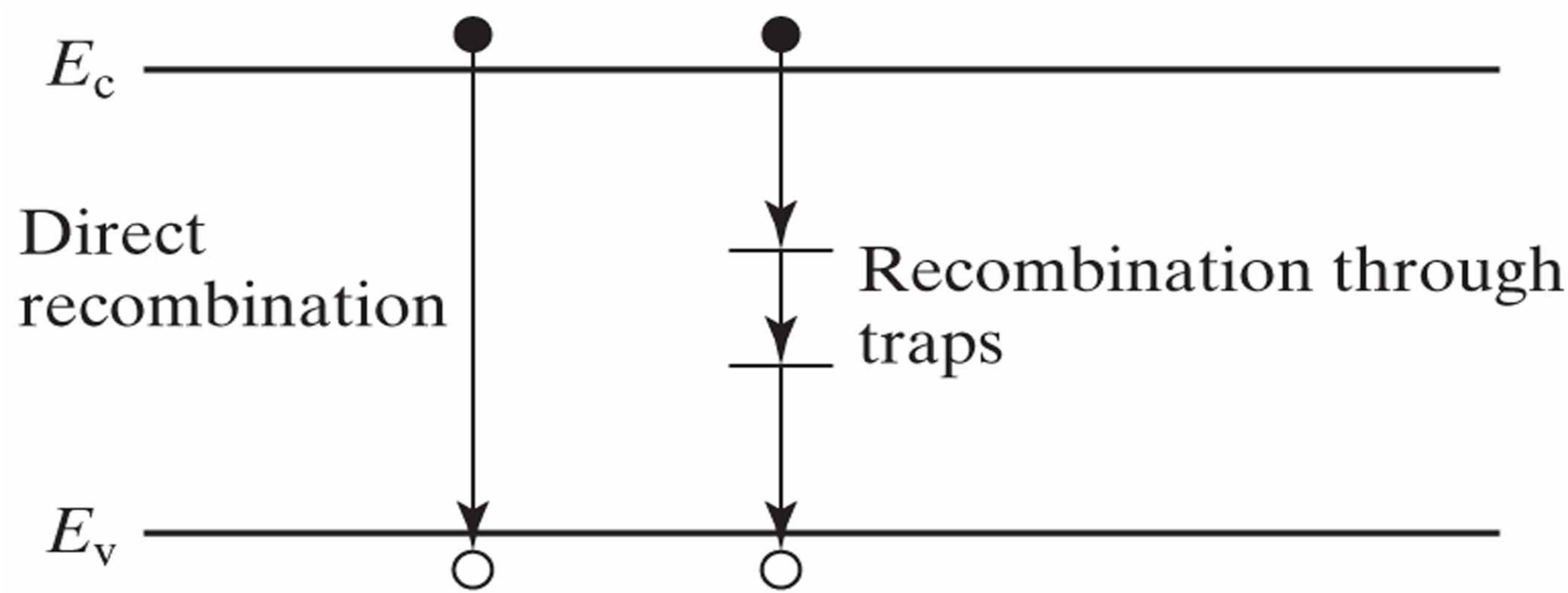

**Figure 2.14** Location of $E_F$, $E_{Fn}$, and $E_{Fp}$.

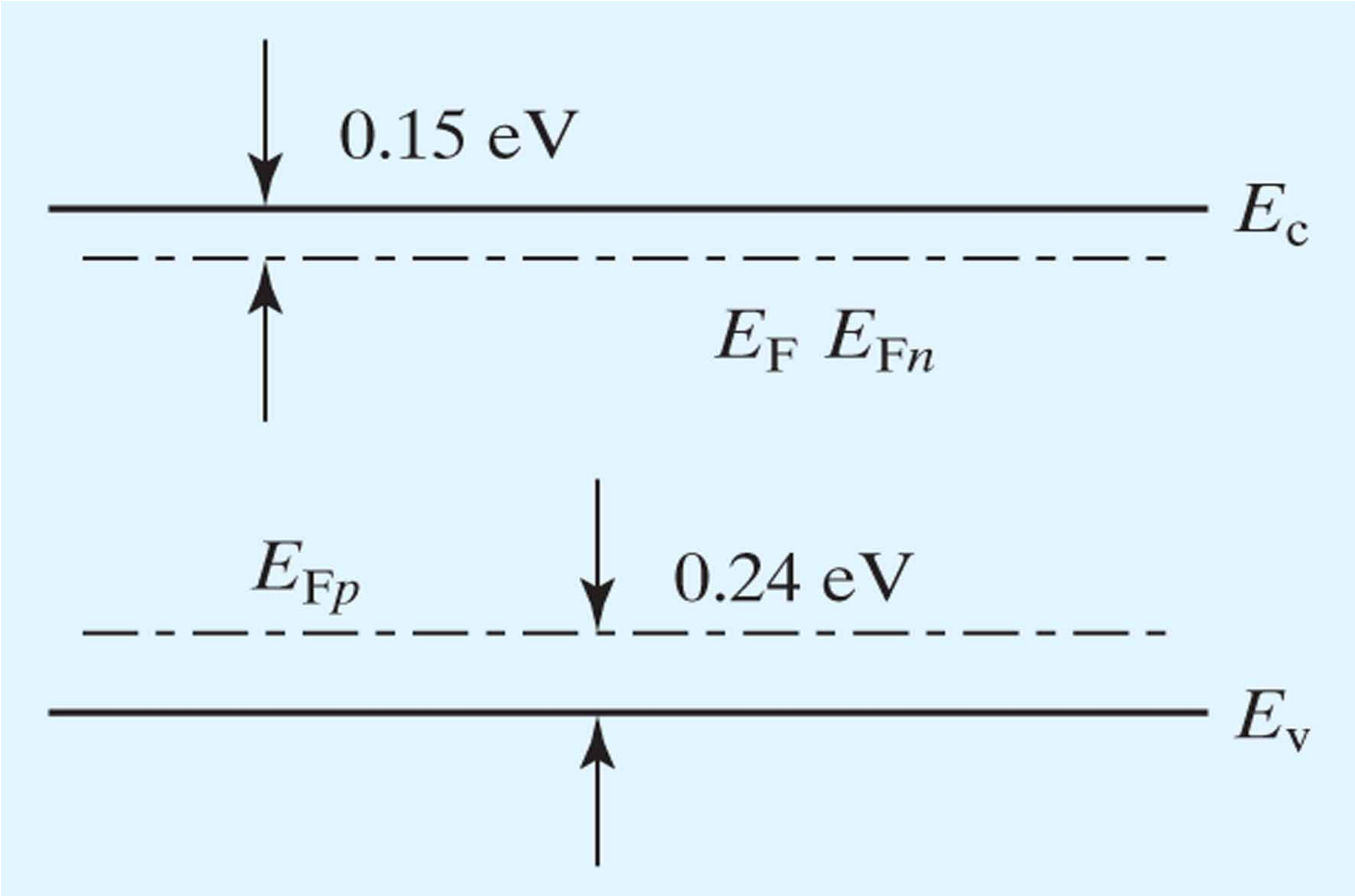

**Figure 2.15**

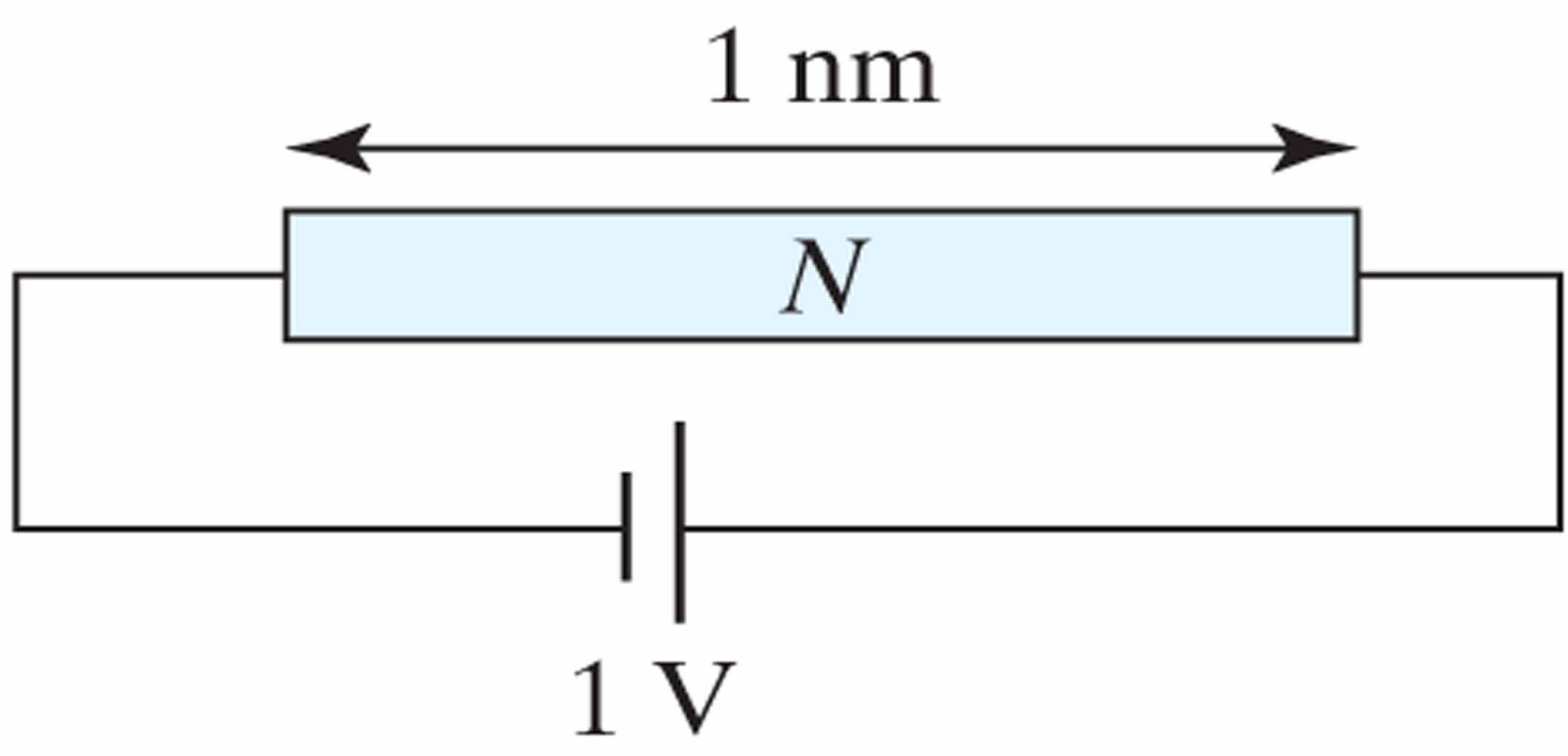

**Figure 2.16**