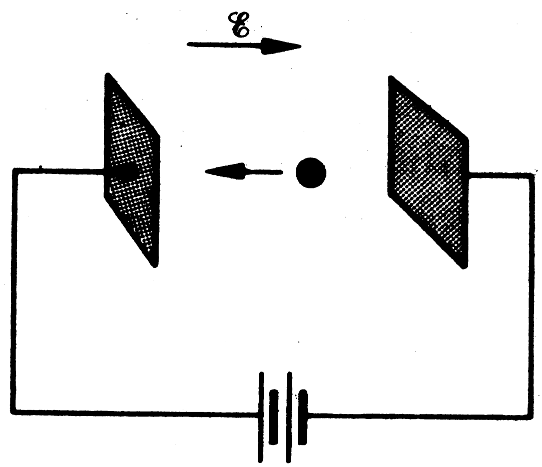
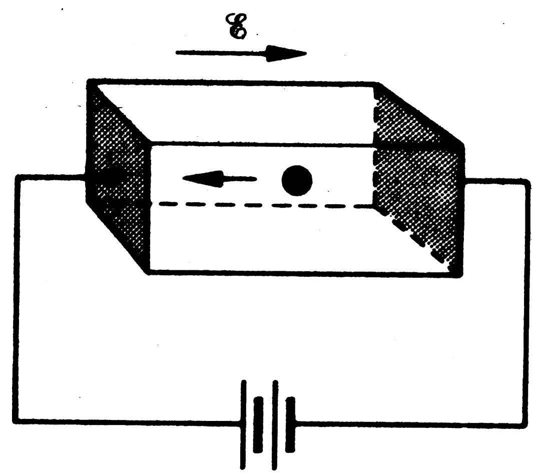
Chapter 2-2. Carrier properties

Mass like charge is a very basic property of electrons and holes. The mass of electrons in a semiconductor may be different than its mass in vacuum.

Effective mass concept



(a)



(b)

$$F = -q\mathcal{E} = m_0 \frac{\mathrm{d}v}{\mathrm{d}t}$$

$$F = -q\mathcal{E} = m_n^* \frac{\mathrm{d}v}{\mathrm{d}t}$$

Effective mass

- Electrons moving inside a semiconductor crystal will collide with semiconductor atoms, there by causing periodic deceleration of the carriers
- In addition to applied electric field, the electrons also experience complex field forces inside the crystals
- The effective mass can have different values along different directions
- The effective mass will be different depending on the property we are observing. So you can have conductivity effective mass, density of states effective mass, etc.

Table 2.1 Density of States Effective Masses at 300 K.

Material	m_n^*/m_0	m_p^*/m_0
Si	1.18	0.81
Ge	0.55	0.36
GaAs	0.066	0.52

Carrier numbers in intrinsic materials

Intrinsic semiconductor or pure semiconductor has equal numbers of electrons and holes at a particular temperature.

Number of electrons/cm^3 [n] = number of holes/cm^3 [p]
Why is $n = p$?

This is an intrinsic property of the semiconductor and is called intrinsic carrier concentration, n_i

At $T = 300$ K, n_i = 2×10^6 / cm^3 in GaAs
1×10^{10} / cm^3 in Si
2×10^{13} / cm^3 in Ge

How large is this compared to the number of Si atoms/cm^3?
What happens to n_i at higher temperature? At 0 K?

Extrinsic semiconductors

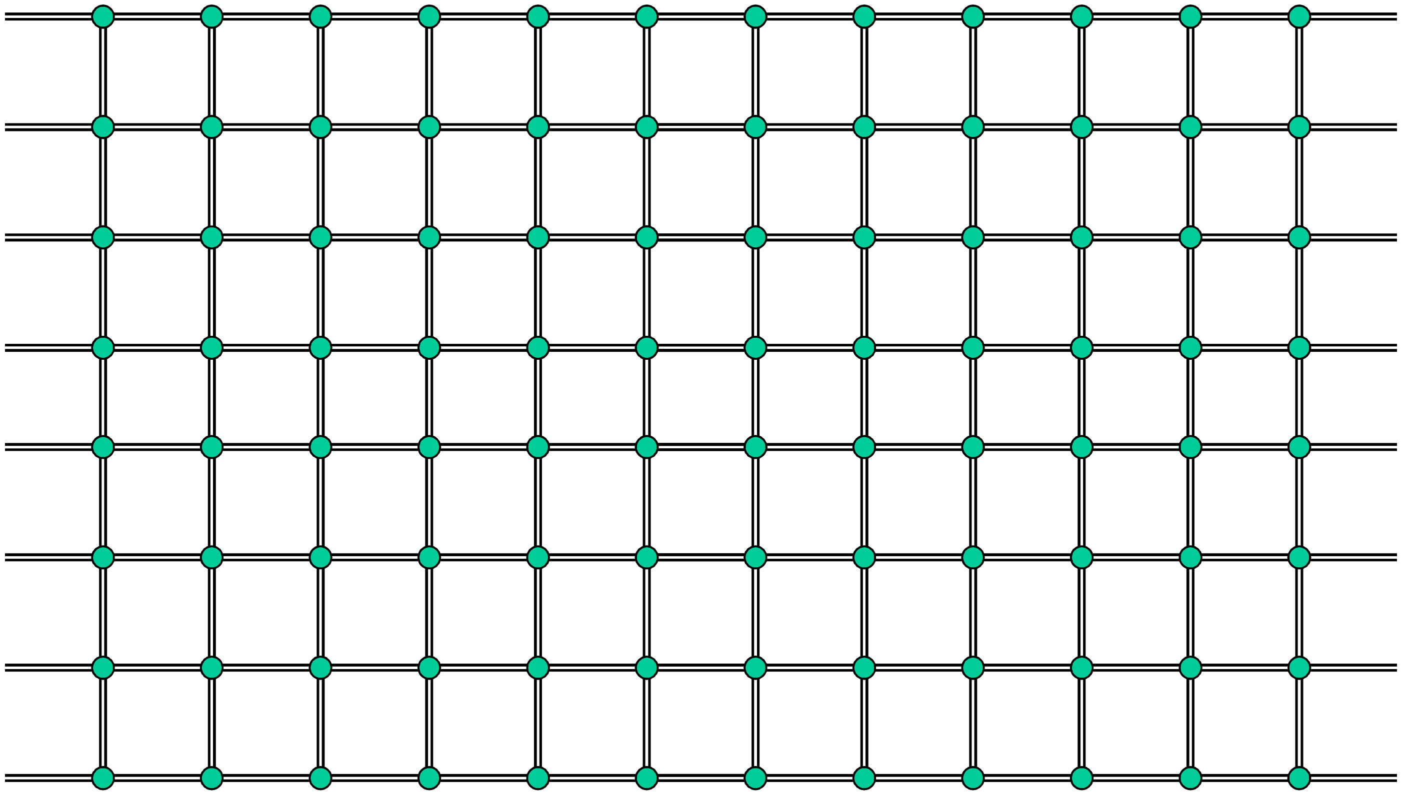
Table 2.2 Common Silicon Dopants. Arrows indicate the most widely employed dopants.

Donors (Electron-increasing dopants)		*Acceptors (Hole-increasing dopants)*	
P ← As ← Sb	Column V elements	B ← Ga In Al	Column III elements

Elements in column V of the periodic table have 5 electrons in their outer shell (one more than Si)! This can be easily released, thus increasing the net free electrons in the Si crystal.

Elements of column III of the periodic table have only 3 electrons in their outer shell (one less than Si)! To complete the bond, the atom can accept an electron by breaking a bond somewhere else, thus creating a broken bond, or a hole.

Two-dimensional representation of Si lattice



Visualization of (a) donors and (b) acceptors

Phosphorus (P) atom   Boron (B) atom

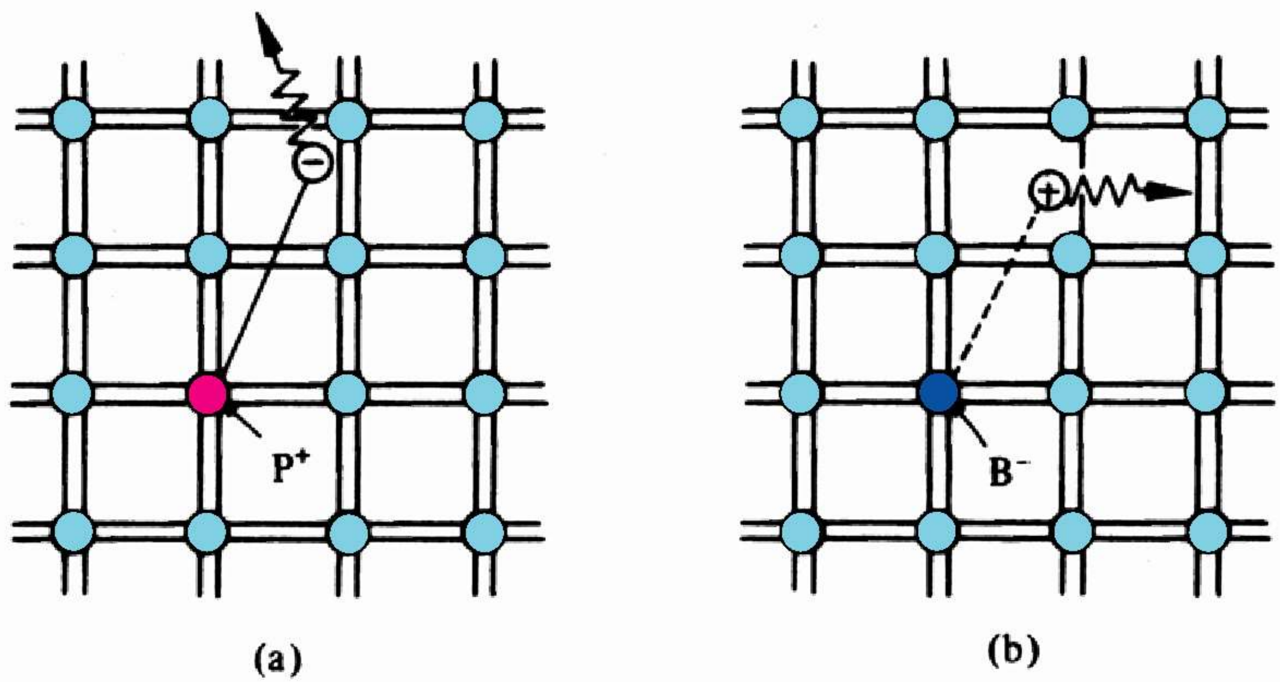


Figure 2.10

Pseudo-hydrogen atom model for donors

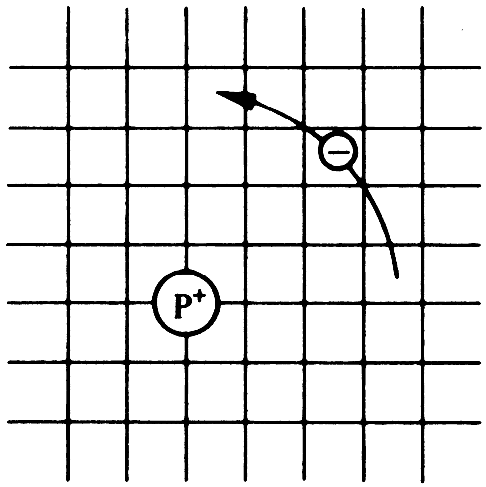


Figure 2.11

Instead of m_0, we have to use m_n^*.
Instead of ε_o, we have to use $K_s\,\varepsilon_o$.

K_s is the relative dielectric constant of Si ($K_{s,\,Si} = 11.8$).

$$E_H = -\frac{m_0\, q^4}{2\,(4\pi\,\varepsilon_0 \hbar)^2} = -13.6\text{ eV}$$

(see page 24 of text)

$$E_d = -\frac{m_n^*\, q^4}{2\,(4\pi\, K_s\, \varepsilon_0\, \hbar)^2} = -13.6\text{ eV}\;\frac{m_n^*}{m_0}\left(\frac{\varepsilon_0}{K_s\varepsilon_0}\right)^2 \approx -0.05\text{ eV}$$

This is an approximate value. More accurate values are given next.

Binding energies for dopants

Table 2.3 Dopant-Site Binding Energies.

Donors	$\lvert E_B \rvert$	*Acceptors*	$\lvert E_B \rvert$
Sb	0.039 eV	B	0.045 eV
P	0.045 eV	Al	0.067 eV
As	0.054 eV	Ga	0.072 eV
		In	0.16 eV

Questions:

How much energy is required to break a Si-Si bond?

How much energy is required to break the 5th electron from As in Si?

How much energy is required to break a Si-Si bond when that bond is adjacent to a B atom?

Does the freeing of an electron from a donor atom create an extra hole?

Energy-band model for donors

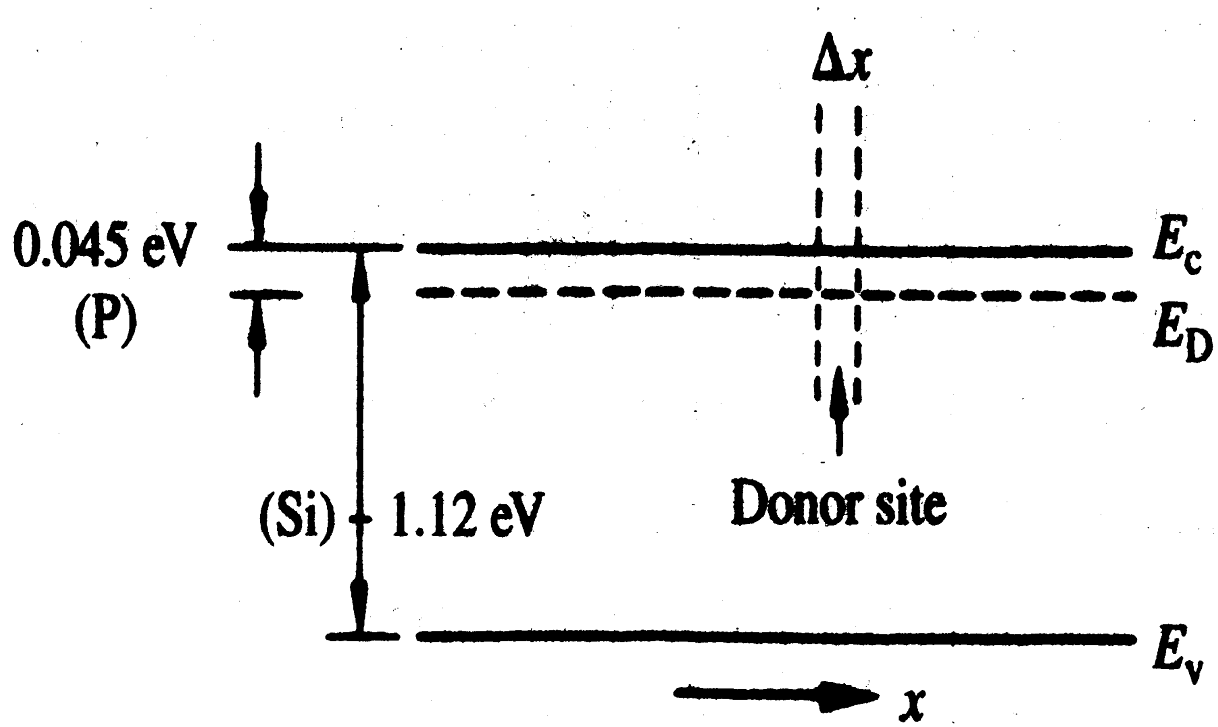


Figure 2.12

Temperature effects on donors and acceptors

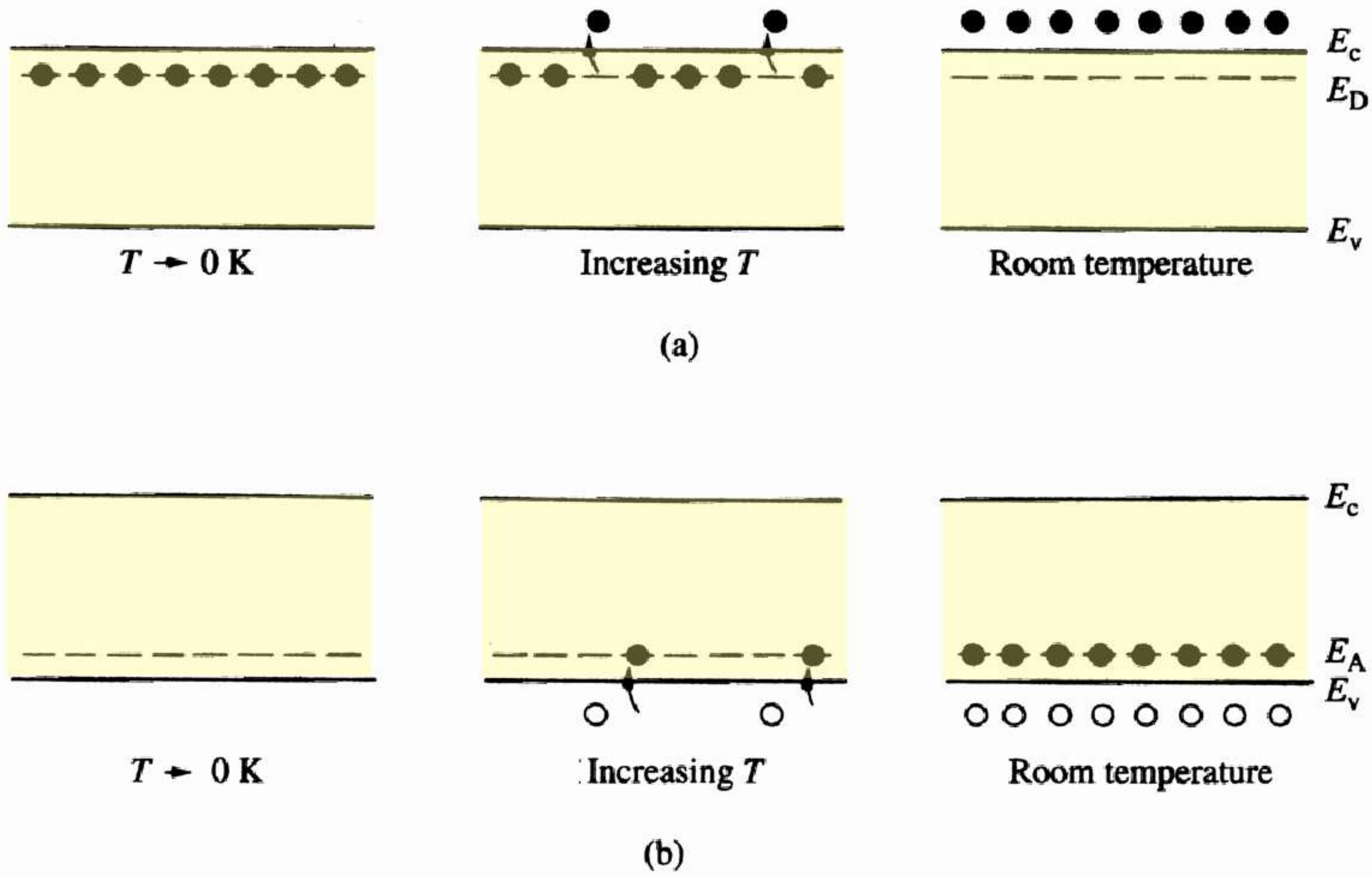


Figure 2.13

Some items to remember

- Ionization energy of electrons in hydrogen
- Bond and band models of semiconductors
- Intrinsic semiconductors and intrinsic carrier concentrations.
- Extrinsic semiconductors
- Dopants: Donors and acceptors
- n-type material
- p-type material
- Majority carriers
- Minority carriers
- Band models of donors and acceptors
- Band gap energies of Si, Ge and GaAs