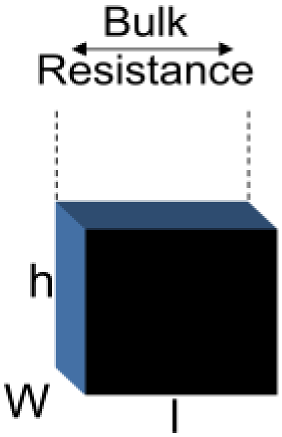
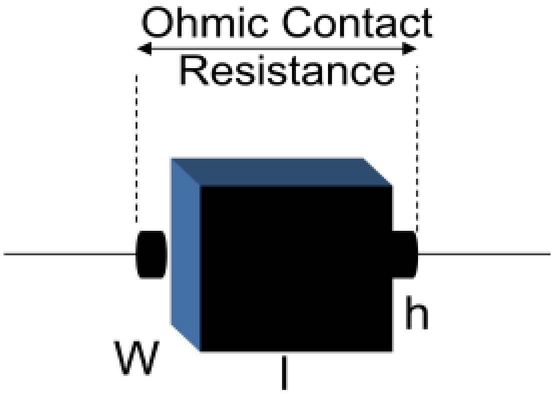
3- Intrinsic and Extrinsic Materials

3.1 Conductor

It is any material that will permit a generous flow of charge due to the application of a limited amount of external pressure. Resistance may be given as a function of the resistivity (ρ).

$$R = \frac{\rho l}{A}$$

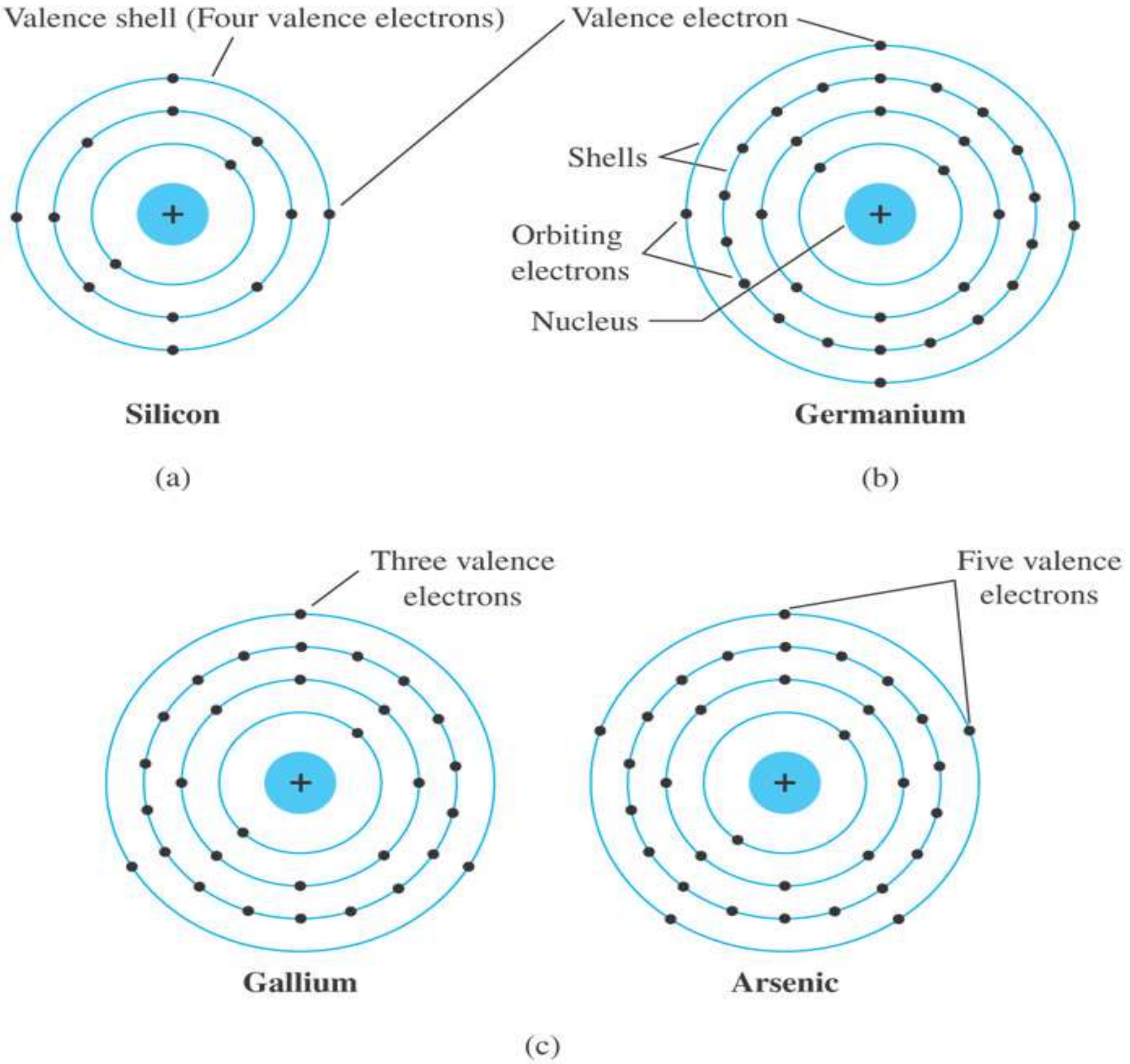




Typical Resistive values (At 300 K, room temperature)		
Conductor	**Semiconductor**	**Insulator**
$\rho=10^{-6}$ Ω.cm (copper)	$\rho=50$ Ω.cm (Ge)	$\rho=10^{12}$ Ω.cm (mica)
	$\rho=50 \times 10^{3}$ Ω.cm (Si)	

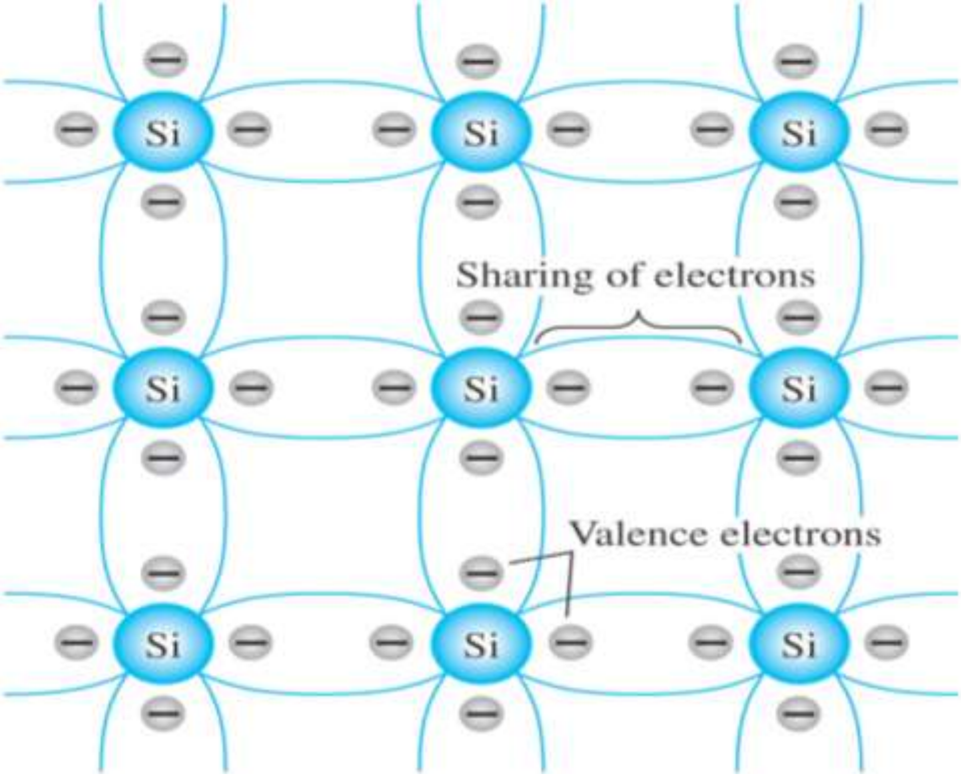
3.2 Silicon and Germanium

- Ge has 32 orbiting electrons.
- Si has 14 orbiting electrons.
- *Each one has 4 electrons at the outermost shell (valence)*



Atomic structure of (a) silicon; (b) germanium; and (c) gallium and arsenic.

Covalent bonding of the silicon atom.



Valence electrons can absorb sufficient kinetic energy from natural causes to break the covalent bond and be a FREE electron.

Natural Causes:

- Light Energy → Photons
- Thermal Energy

3.3 Intrinsic Material

It is a semiconductor which is well refined to reduce the Impurities to a very low level.

Q/In a perfectly pure semiconductor in thermal equilibrium at finite temperature, how many electrons and holes are there?

$$n_o = p_o$$

Also:

$$n_o p_o = n_i^2$$

Then:

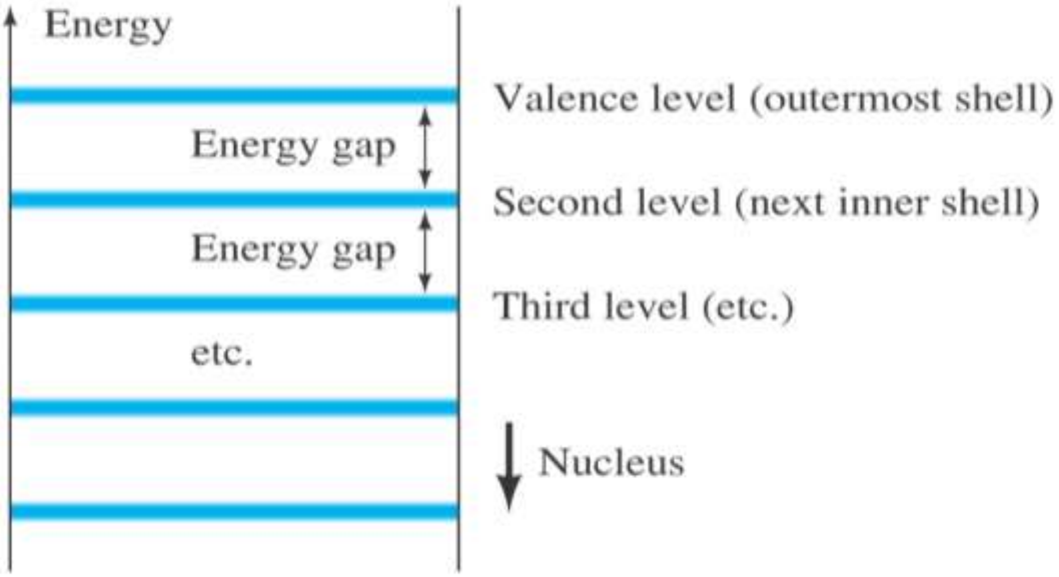
$$n_o = p_o = n_i$$

$$n_i \equiv \textit{intrinsic} \text{ carrier concentration } [cm^{-3}]$$

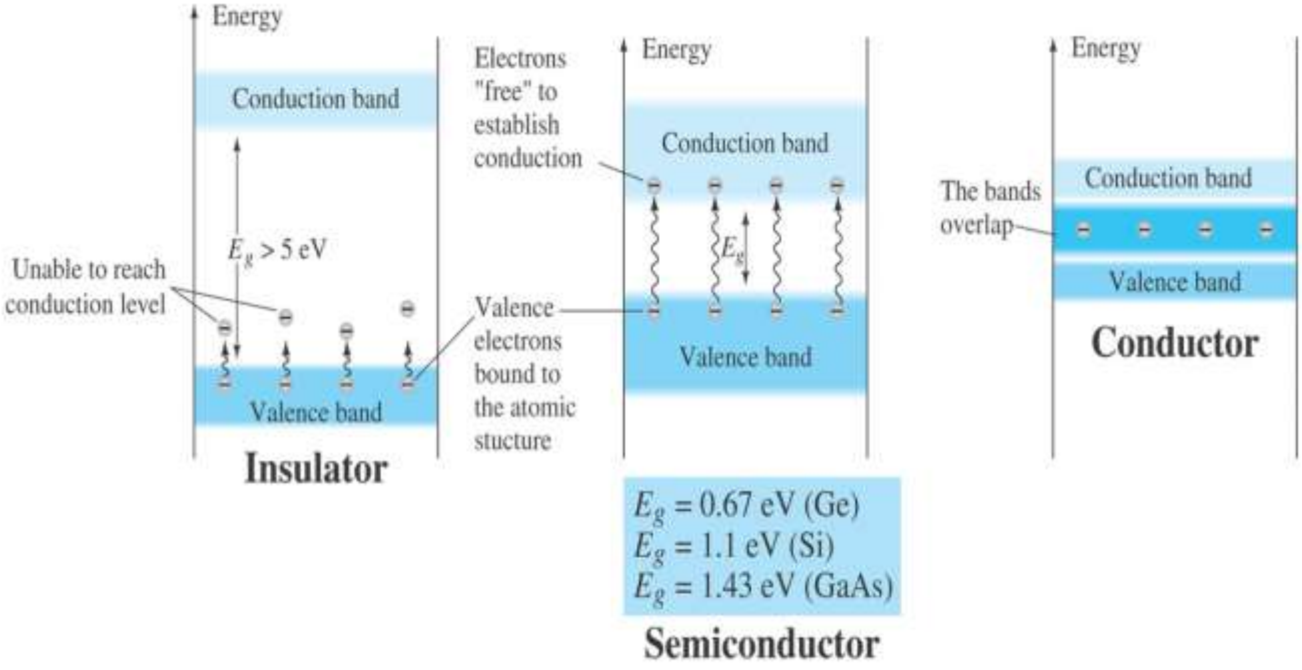
In Si at 300 K (”room temperature”): $n_i \simeq 1 \times 10^{10}\ cm^{-3}$

n_i very strong function of temperature: $T \uparrow \rightarrow n_i \uparrow$

3.4 Energy Levels



(a)Discrete levels in isolated atomic structures



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

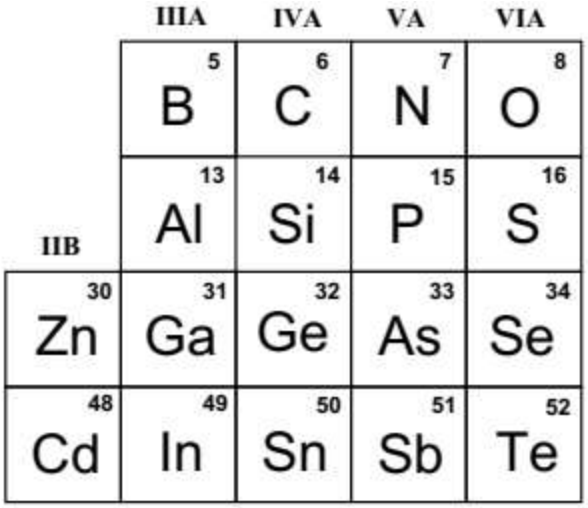
H.Work / Compare between ***Ge*** *and* ***Si*** *from all point of views*

3.5 Doping (Making Extrinsic Materials)

The electrical characteristics of silicon and germanium are improved by adding materials in a process called doping. There are just two types of doped semiconductor materials:

<u>*n*-type</u> materials make the silicon (or germanium) atoms more negative. It is doped by adding impurities elements that have FIVE valence electrons.

For Si, group V atoms with 5 valence electrons (such as As,P, Sb). At room temperature, each donor releases 1 electron that is available for conduction.



IIB	IIIA	IVA	VA	VIA
	5 B	6 C	7 N	8 O
	13 Al	14 Si	15 P	16 S
30 Zn	31 Ga	32 Ge	33 As	34 Se
48 Cd	49 In	50 Sn	51 Sb	52 Te

Define:

$$N_d \equiv \text{donor concentration } [cm^{-3}]$$

- If $N_d \ll n_i$, doping irrelevant
(*intrinsic* semiconductor) $\rightarrow n_o = p_o = n_i$

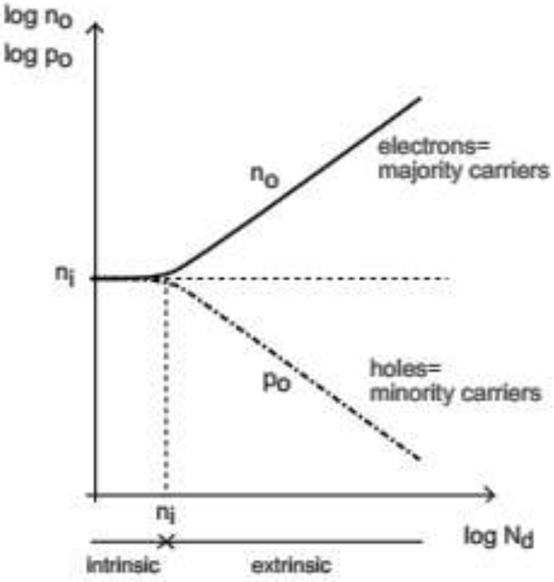
- If $N_d \gg n_i$, doping controls carrier concentrations
(*extrinsic* semiconductor) $\rightarrow$

$$n_o = N_d \qquad\qquad p_o = \frac{n_i^2}{N_d}$$

Note: $n_o \gg p_o$: *n-type semiconductor*

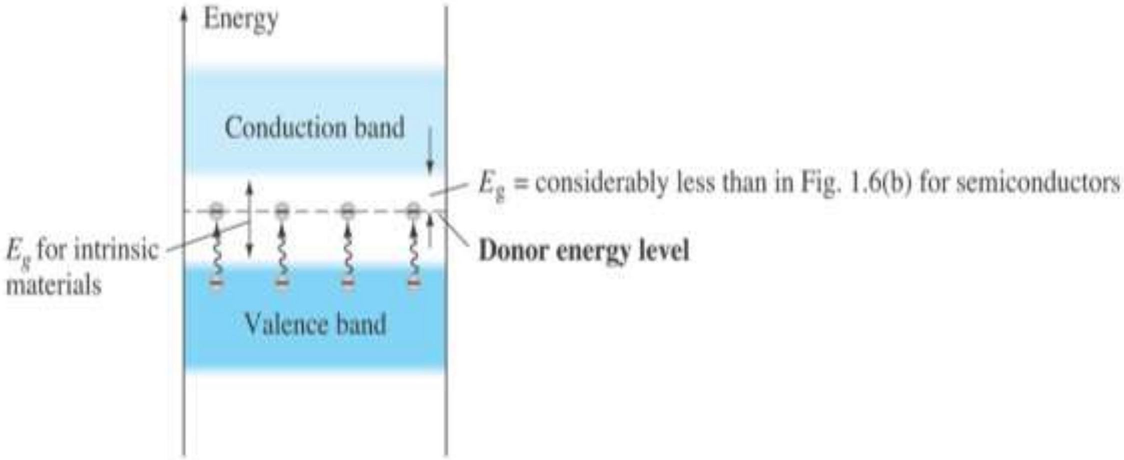
Example:
$N_d = 10^{17}\ cm^{-3} \rightarrow n_o = 10^{17}\ cm^{-3}$, $p_o = 10^3\ cm^{-3}$.

In general: $N_d \sim 10^{15} - 10^{20}\ cm^{-3}$

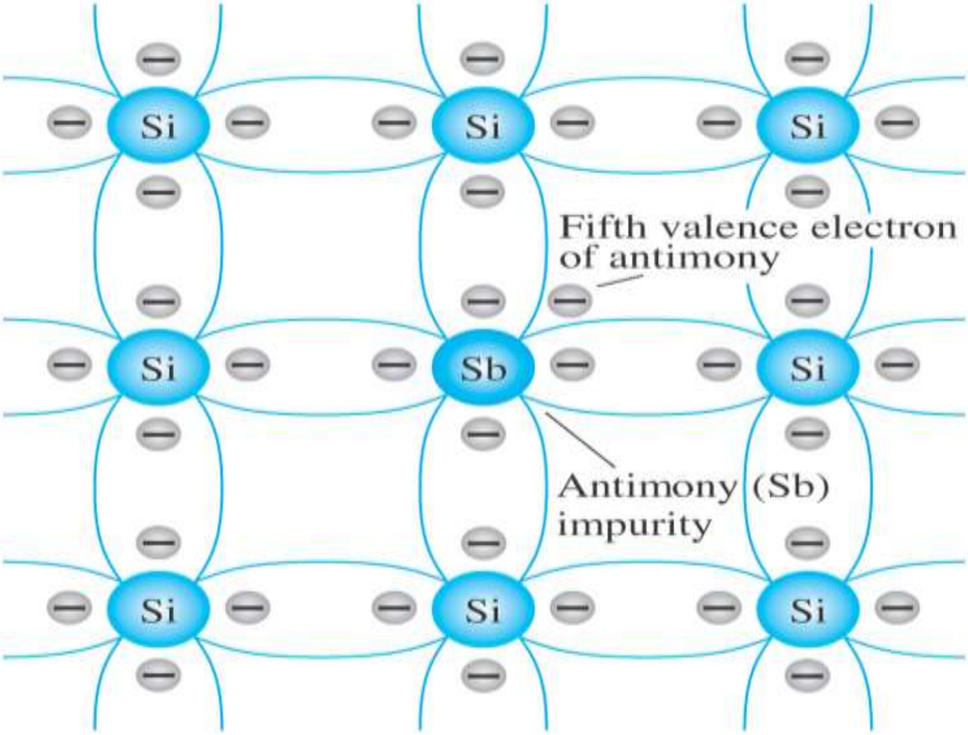


<u>*p*-type</u> materials make the silicon (or germanium) atoms more positive. It is Doped by adding impurities elements that have THREE valence electrons

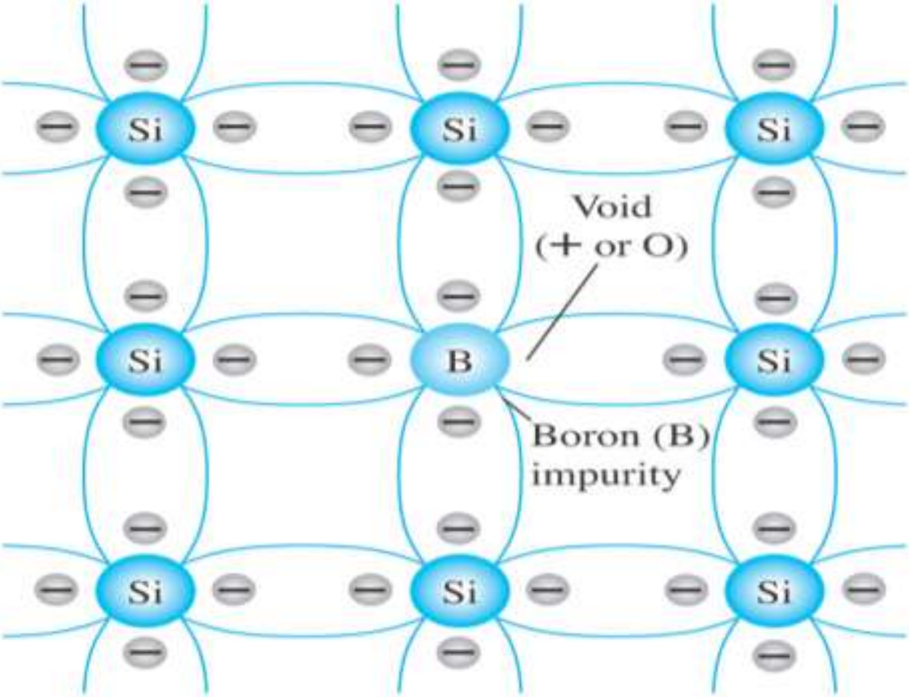
For Si, group –III atoms with 3 valence electrons (such as B). At room temperature, each acceptor releases 1 hole that is available to conduction.



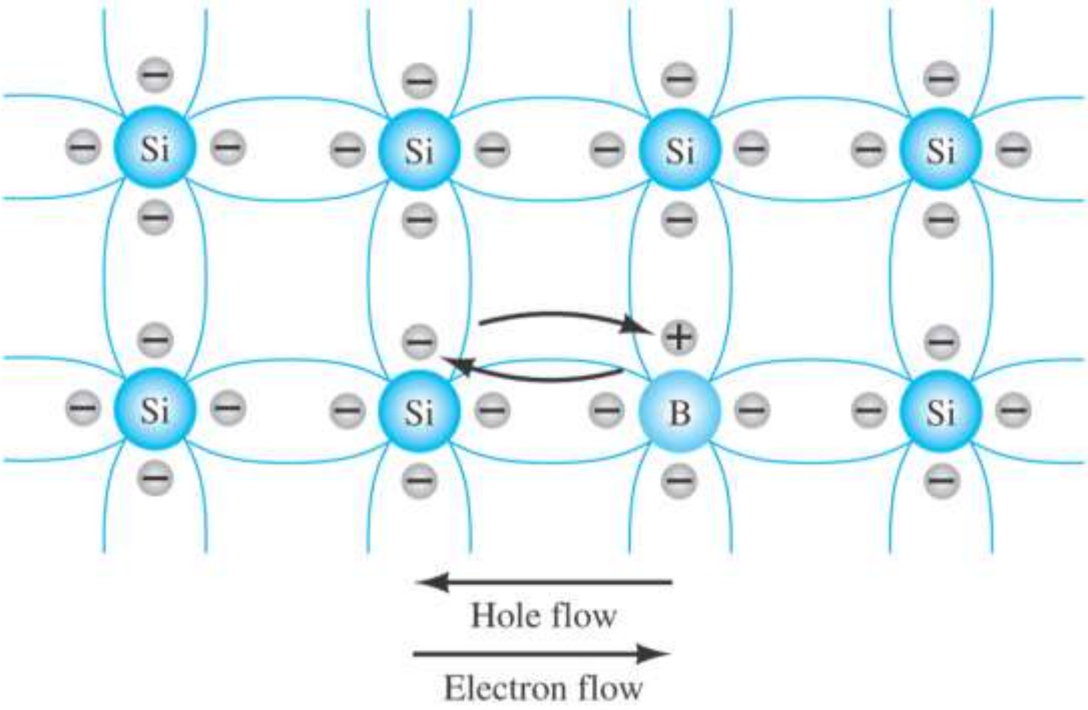
<u>Adding impurity in n-type material</u>



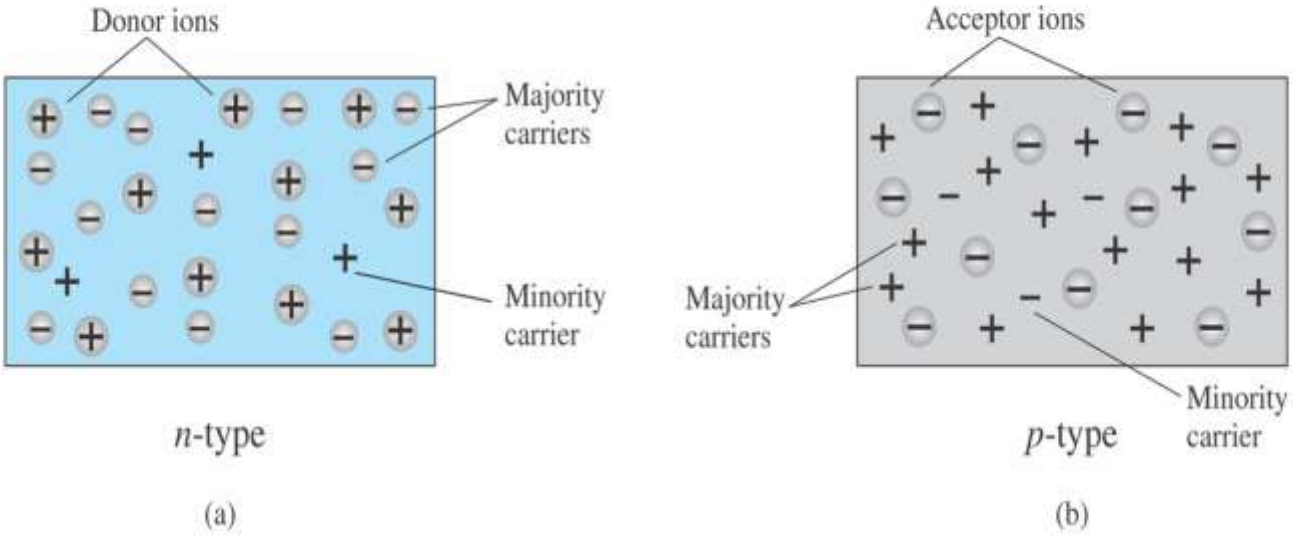
Adding Boron impurity in p-type material



Electron versus hole flow



(a) n-type material; (b) p-type material



Define:

$$N_a \equiv \text{acceptor concentration } [cm^{-3}]$$

- If $N_a \ll n_i$, doping irrelevant ($intrinsic$ semiconductor) $\rightarrow n_o = p_o = n_i$

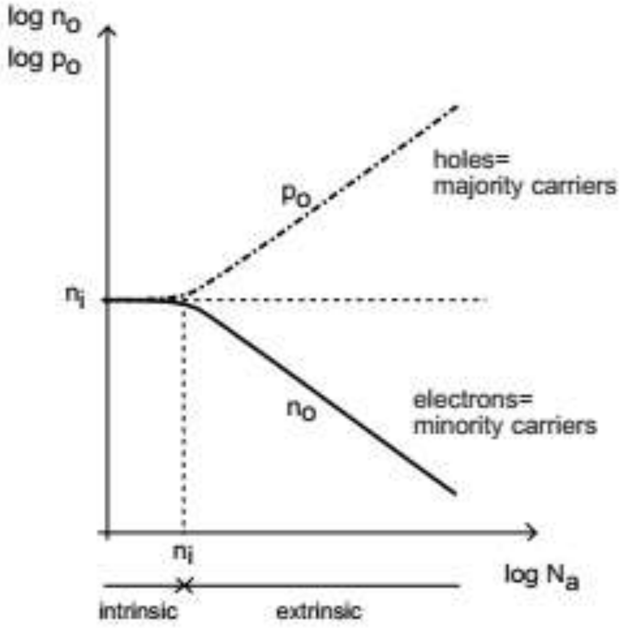
- If $N_a \gg n_i$, doping controls carrier concentrations (*extrinsic* semiconductor) →

$$p_o = N_a \qquad\qquad n_o = \frac{n_i^2}{N_a}$$

Note: $p_o \gg n_o$: *p-type semiconductor*

Example:
$N_a = 10^{16}\ cm^{-3} \rightarrow p_o = 10^{16}\ cm^{-3},\ n_o = 10^{4}\ cm^{-3}$.

In general: $N_a \sim 10^{15} - 10^{20}\ cm^{-3}$



Summary

- In a semiconductor, there are two types of "carriers": electrons and holes
- In thermal equilibrium and for a given semiconductor $n_o p_o$ is a constant that only depends on temperature:

$$n_o p_o = n_i^2$$

- For Si at room temperature:

$$n_i \simeq 10^{10}\ cm^{-3}$$

- *Intrinsic semiconductor*: "pure" semiconductor.

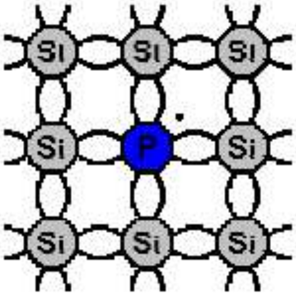
$$n_o = p_o = n_i$$

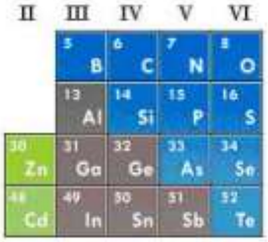
- Carrier concentrations can be engineered by addition of "dopants" (selected foreign atoms):
  - n-type semiconductor:

$$n_o = N_d, \qquad p_o = \frac{n_i^2}{N_d}$$

  - p-type semiconductor:

$$p_o = N_a, \qquad n_o = \frac{n_i^2}{N_a}$$





II	III	IV	V	VI
	5 B	6 C	7 N	8 O
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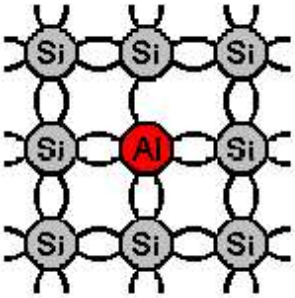

- P or As impurities.
- 5 e^- in outer shell.
- 4 e^- for bonds, one e^- left-over (free).
- Donor impurity
  - (donates e^-)
- N-type silicon

- Al or B impurities.
- 3 e^- in outer shell
- 3 e^- for bonds, one hole left-over (free)
- Acceptor impurity

- P-type silicon