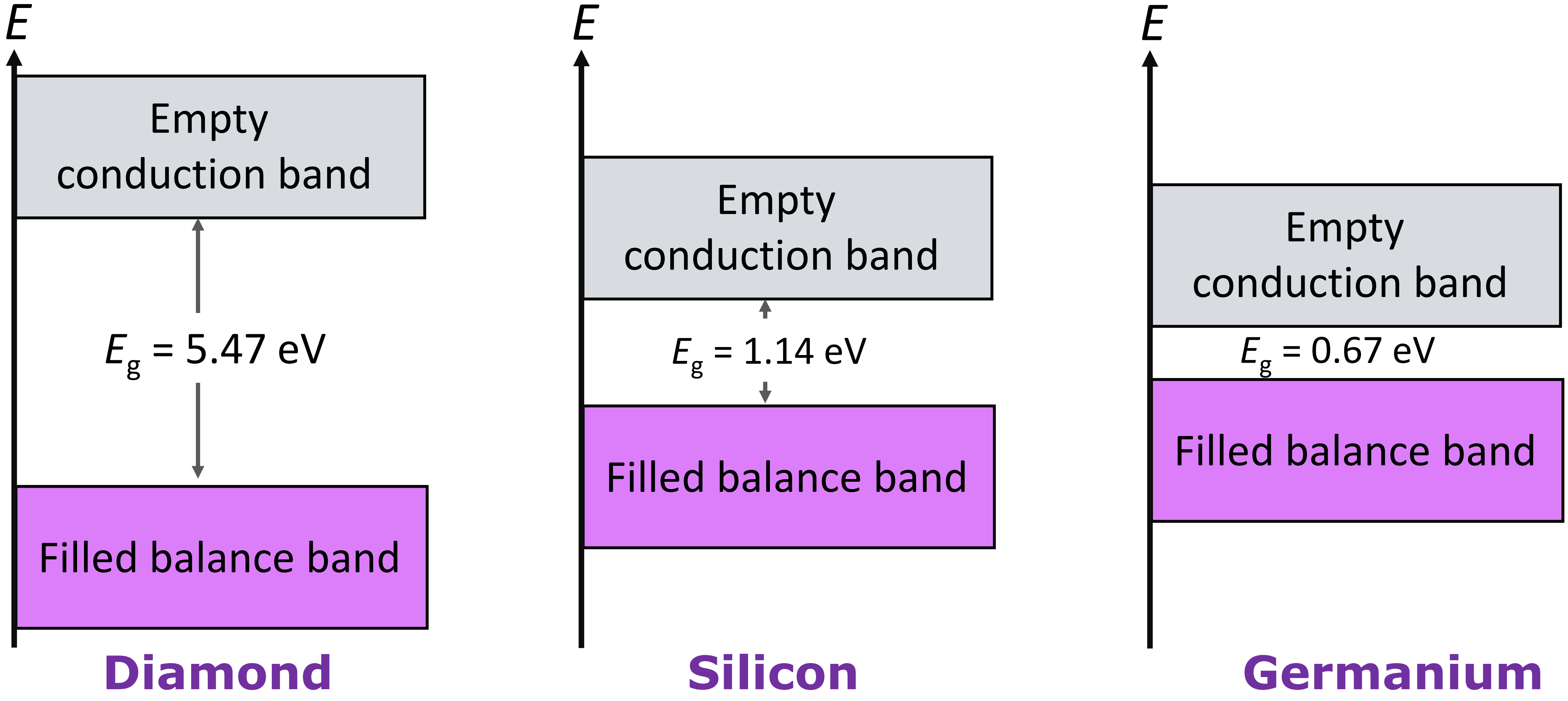
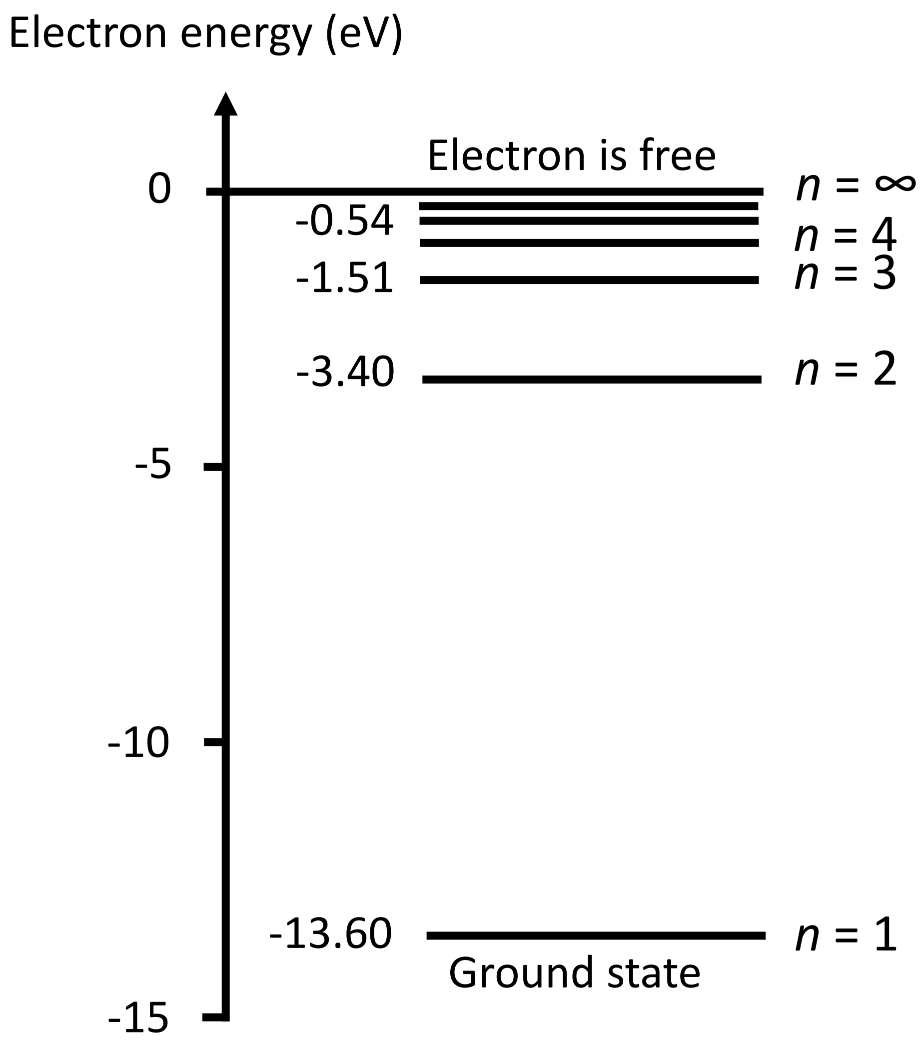
Formation of energy band

Dr Mohammad Abdur Rashid

Semiconductor



Energy levels of electron in hydrogen atom

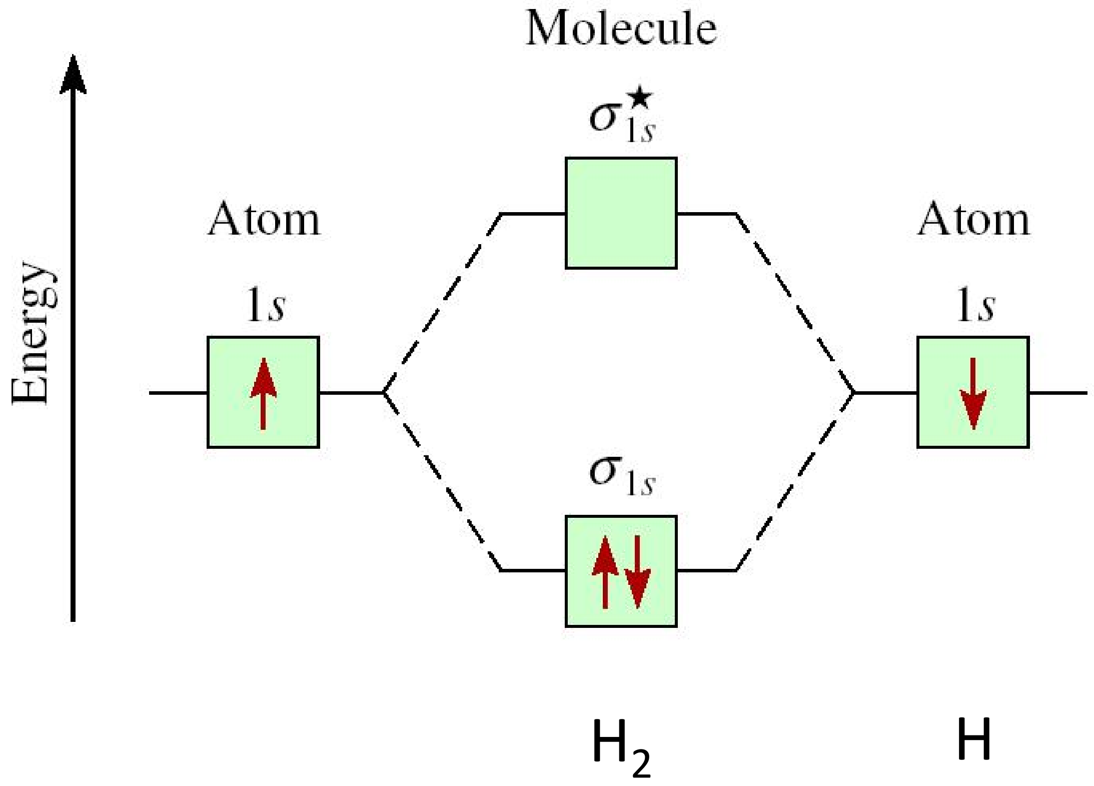


For electrons in an atom only a set of discrete energies is allowed.

Formation of molecule

When two atoms are brought together

- Atomic energy levels split
- Molecular orbitals are formed



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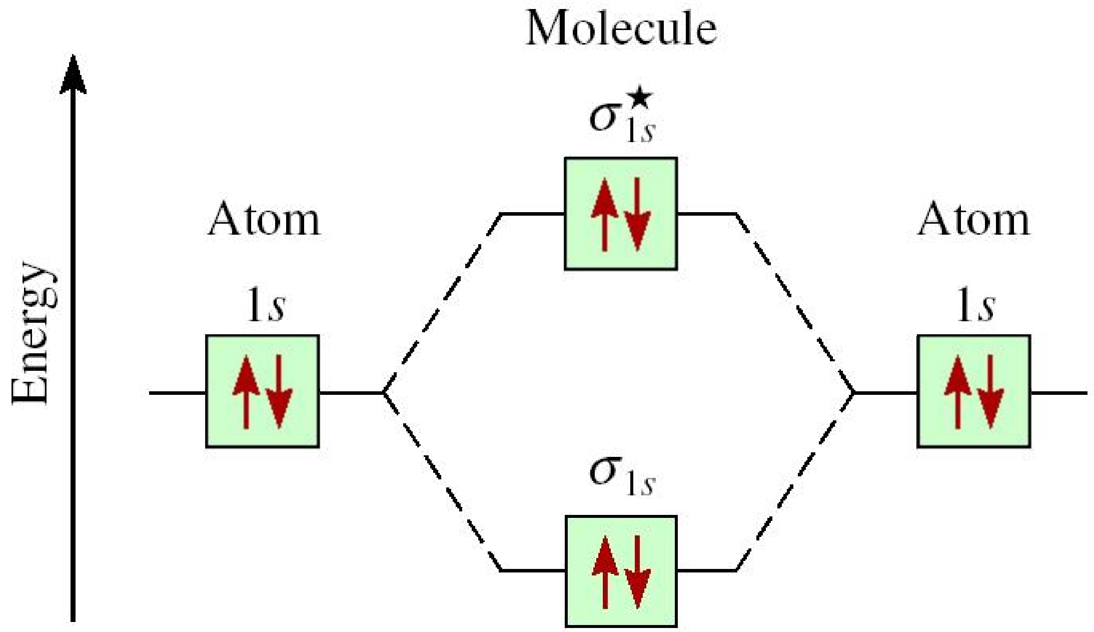

He-He system

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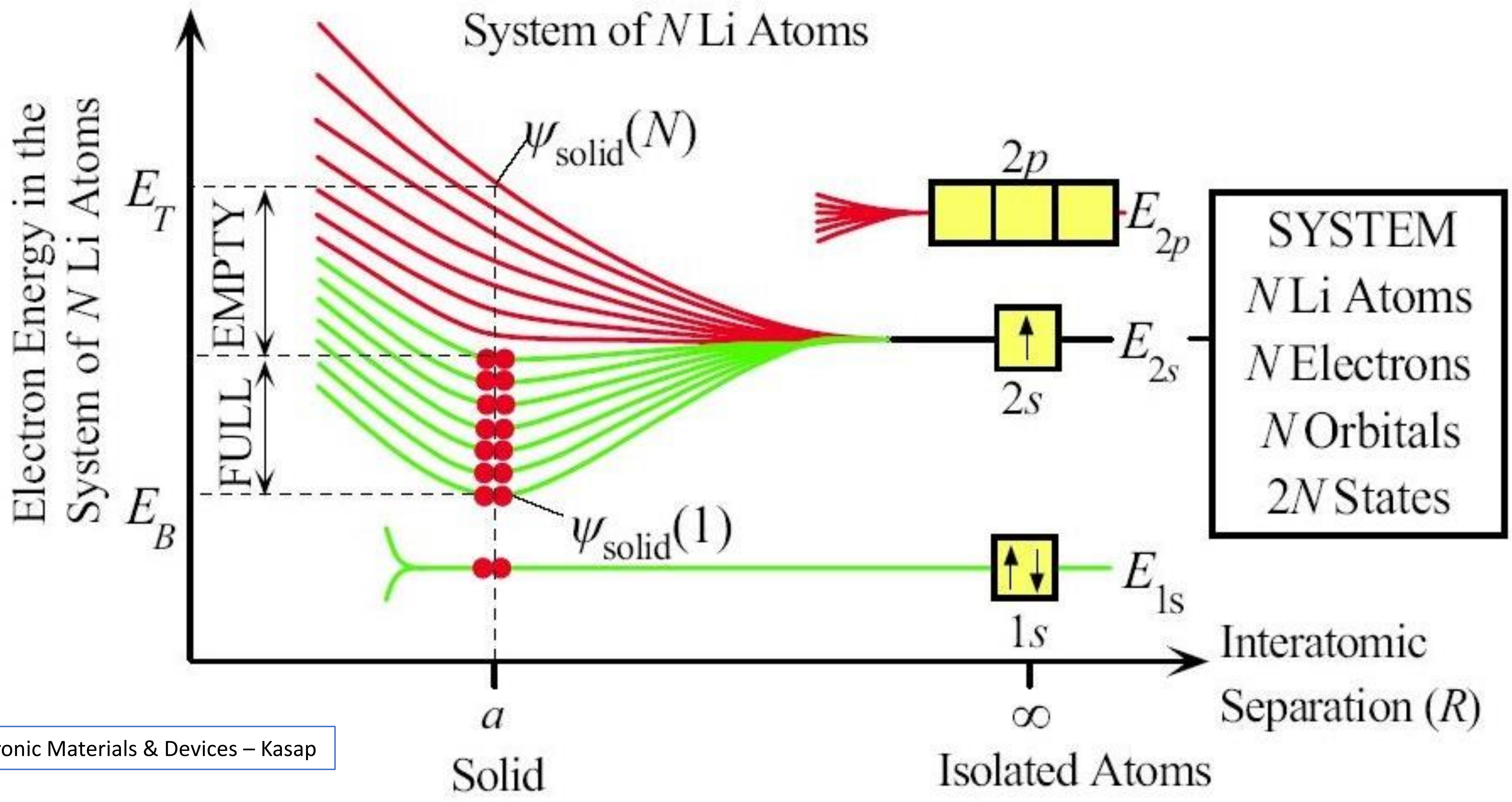
Formation of solid - Lithium



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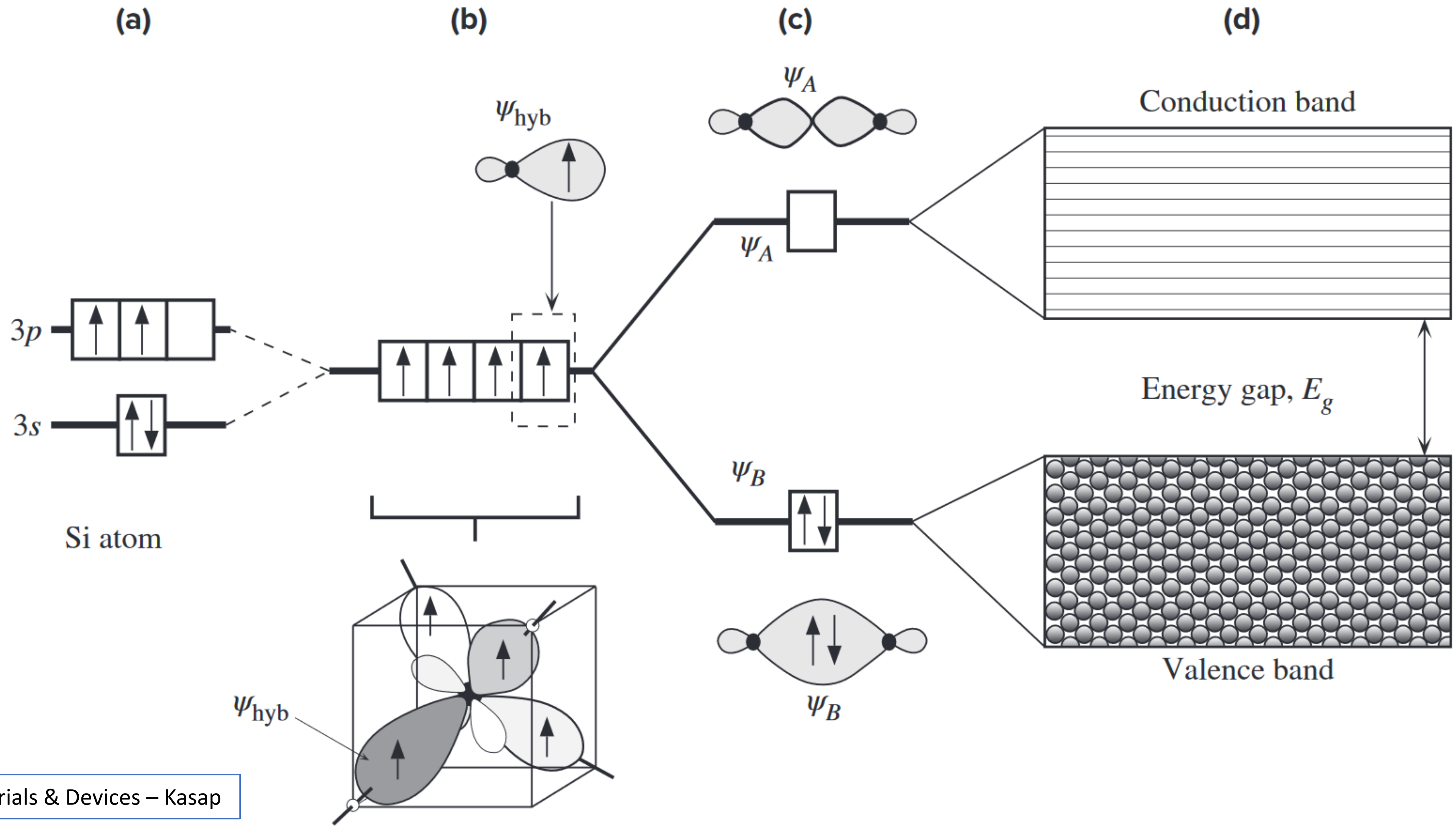
Formation of solid – Silicon crystal



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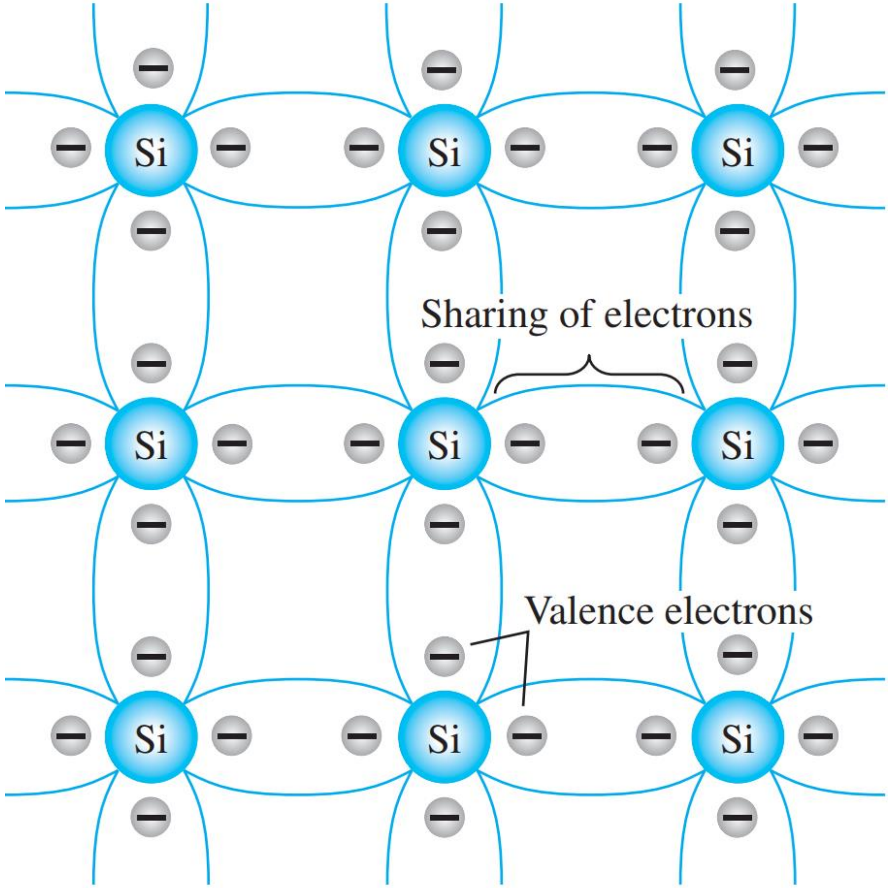
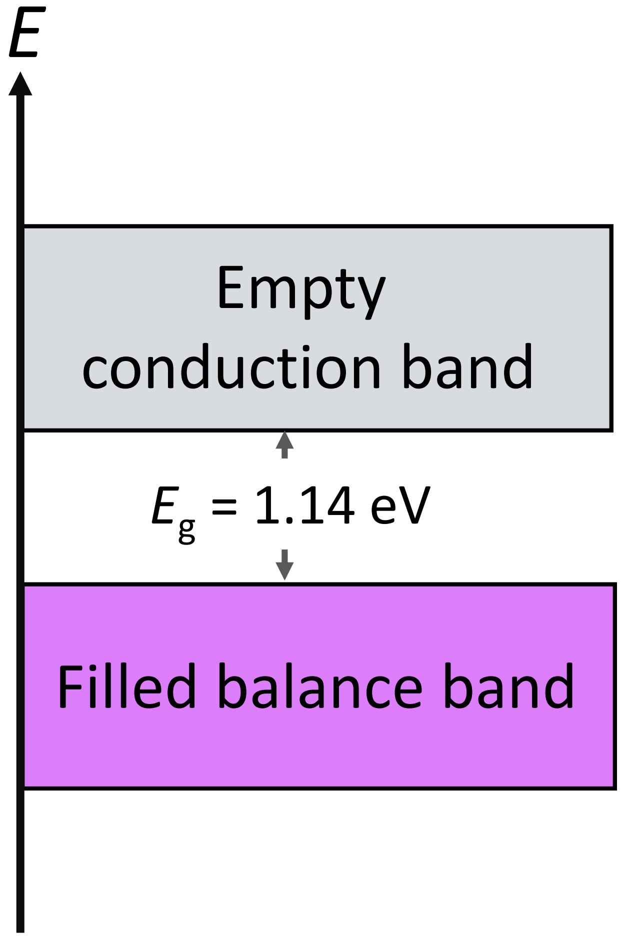
Covalent bonding of the silicon atom

At $T = 0$ K

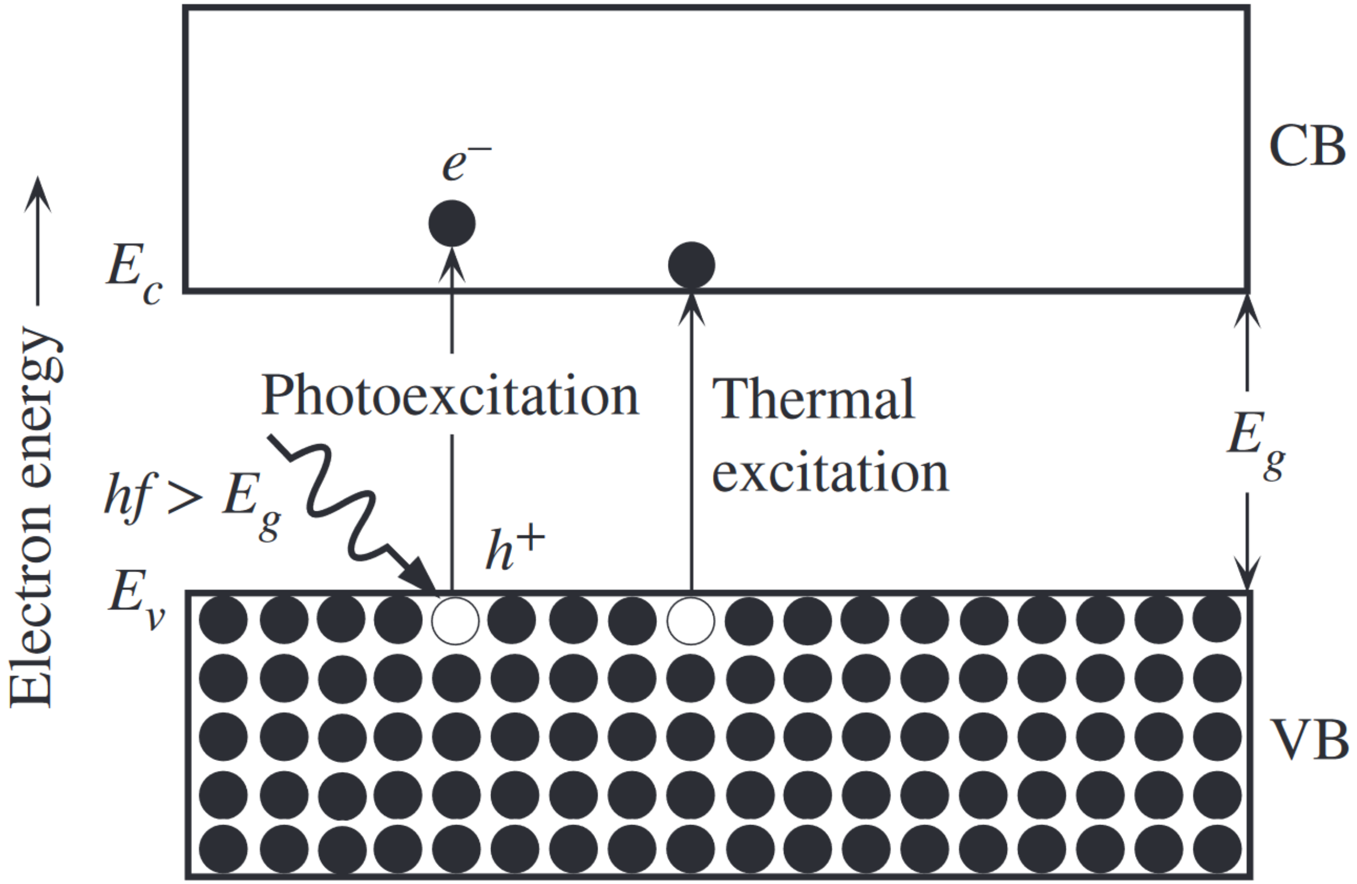


Electronic Devices and Circuit Theory – Boylestad, Nashelsky



Well

At room temperature



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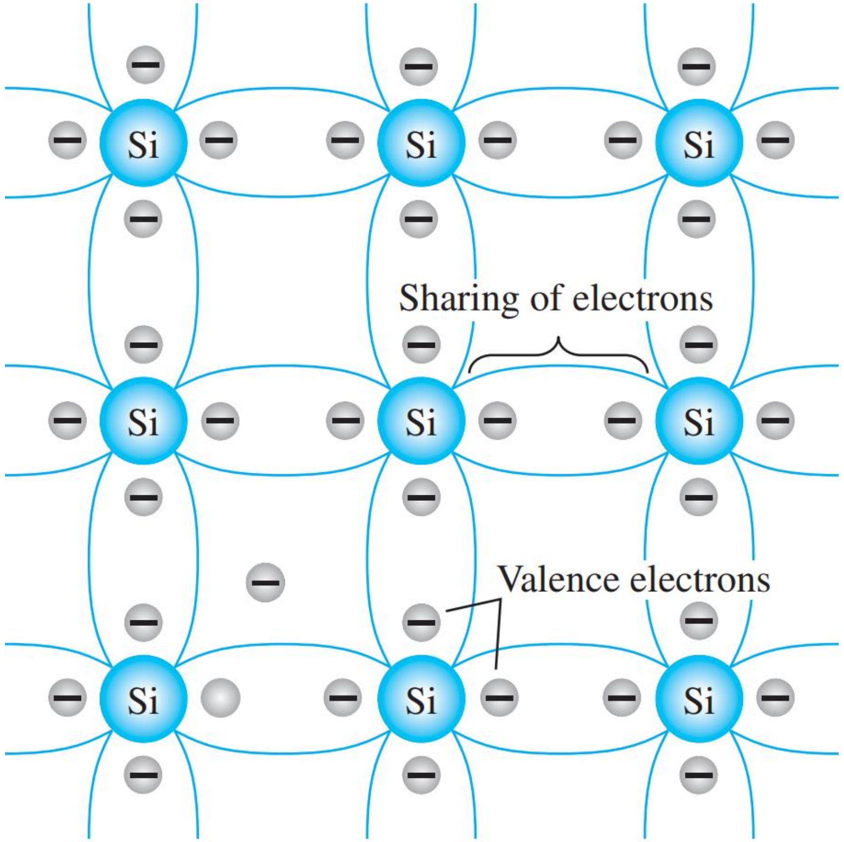
Electron and Hole in intrinsic silicon

At room temperature there are approximately 1.5×10^{10} free carriers in 1 cm^3 of *intrinsic* silicon.



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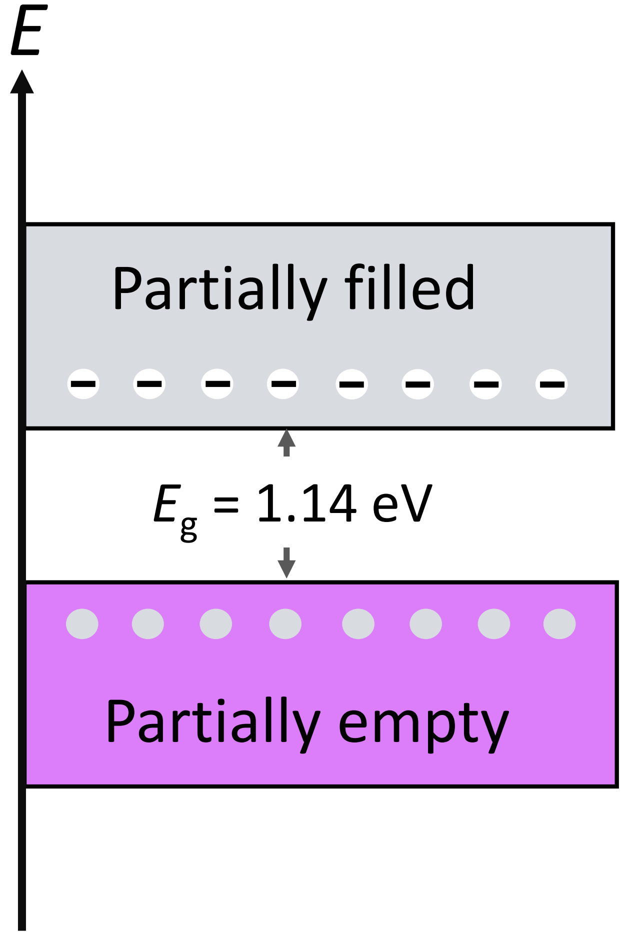

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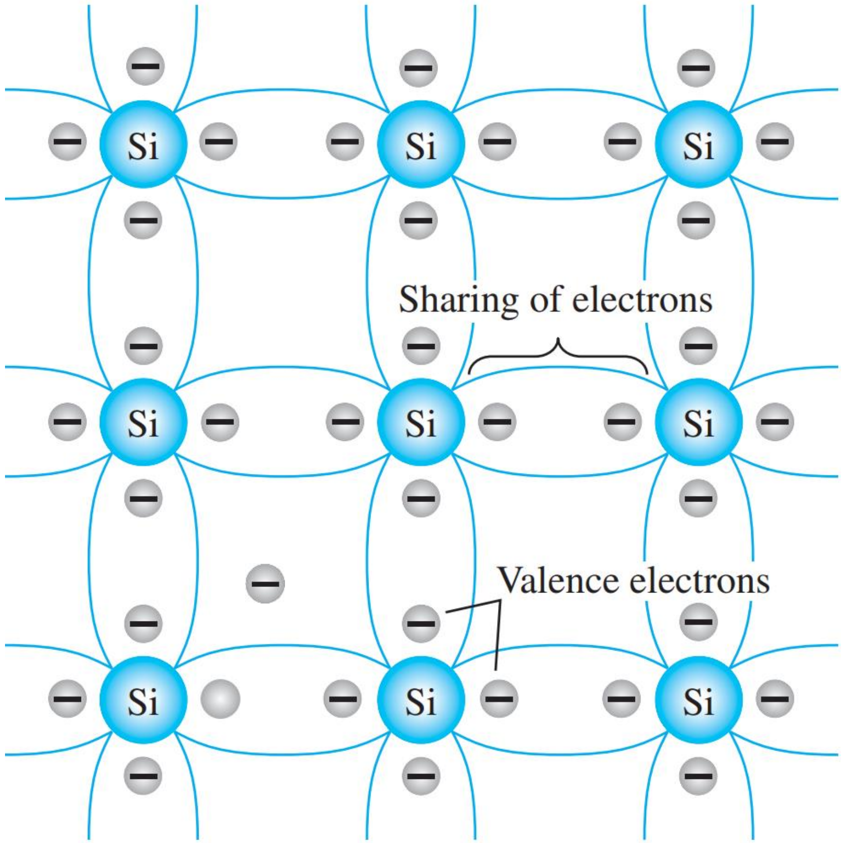

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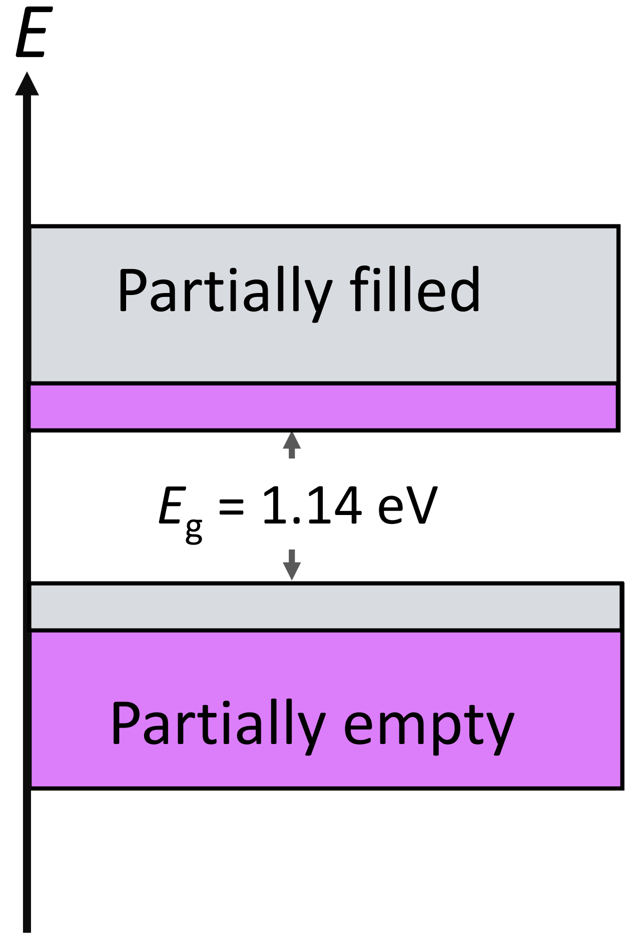
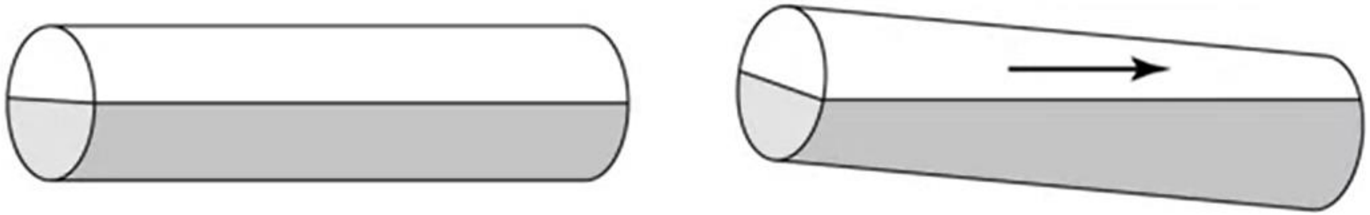


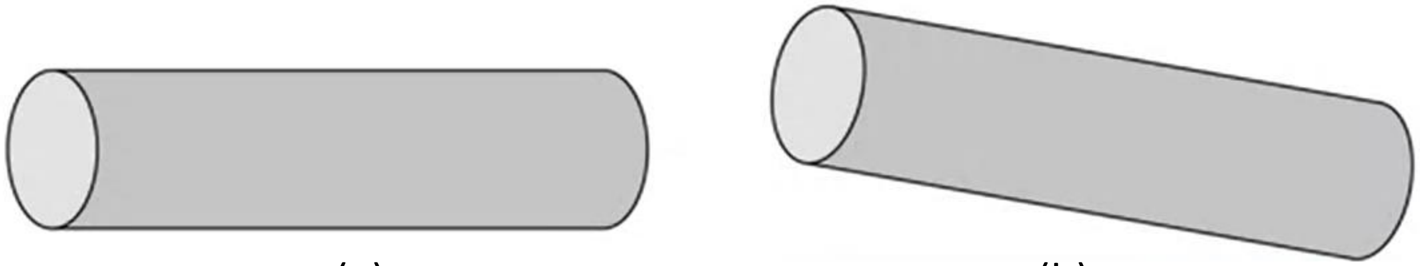
Fluid motion in a glass tube

- Half filled band
- Good electric conductors



(a) (b)

- Completely full or completely empty band
- Poor electric conductors

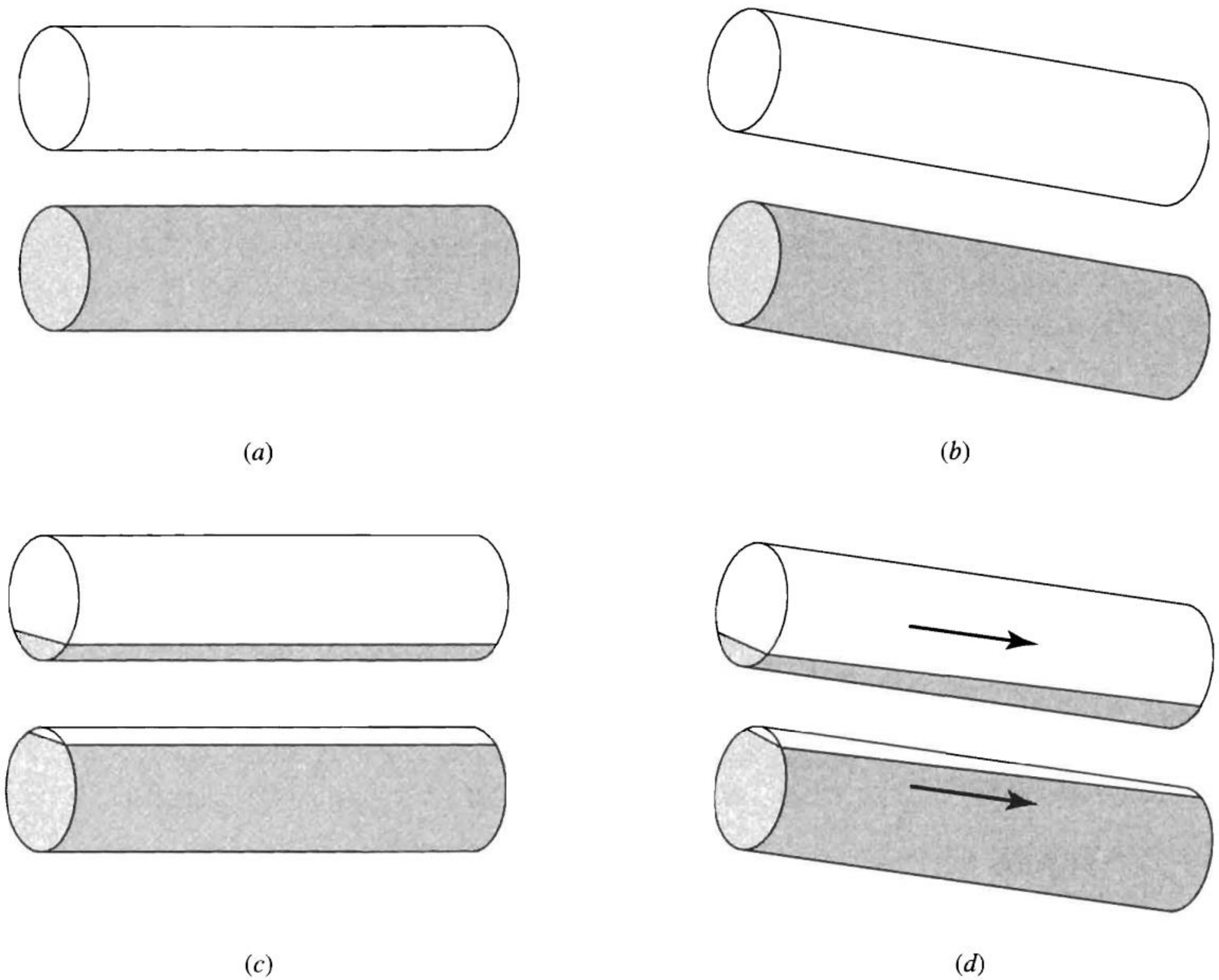


(a) (b)

Device Electronics for Integrated Circuits –Muller, Kamins, Chan

Fluid motion in a glass tube

Fluid can move in both tubes if some of it is transferred from the filled tube to the empty one, leaving unfilled volume in the lower tube.

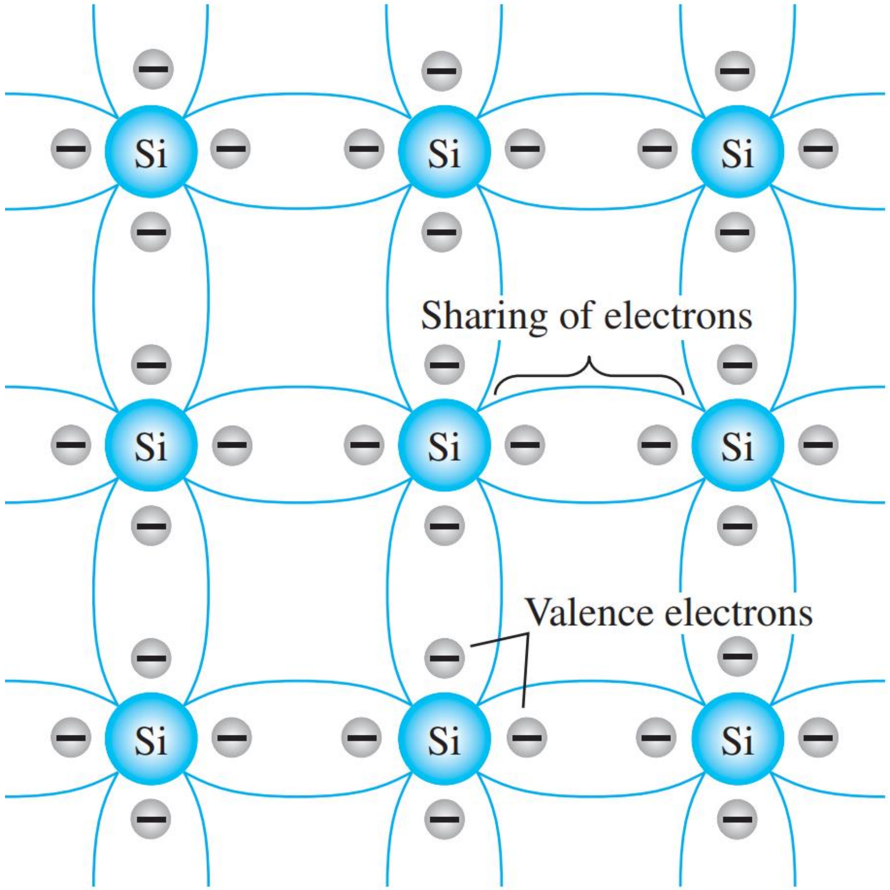


Device Electronics for Integrated Circuits –Muller, Kamins, Chan

Definition of semiconductor

The solids that are insulator at the temperature of 0 K but whose energy band gap is of such a size that thermal excitation leads to observable conductivity at temperature below its melting point are called semiconductor.

Extrinsic semiconductor



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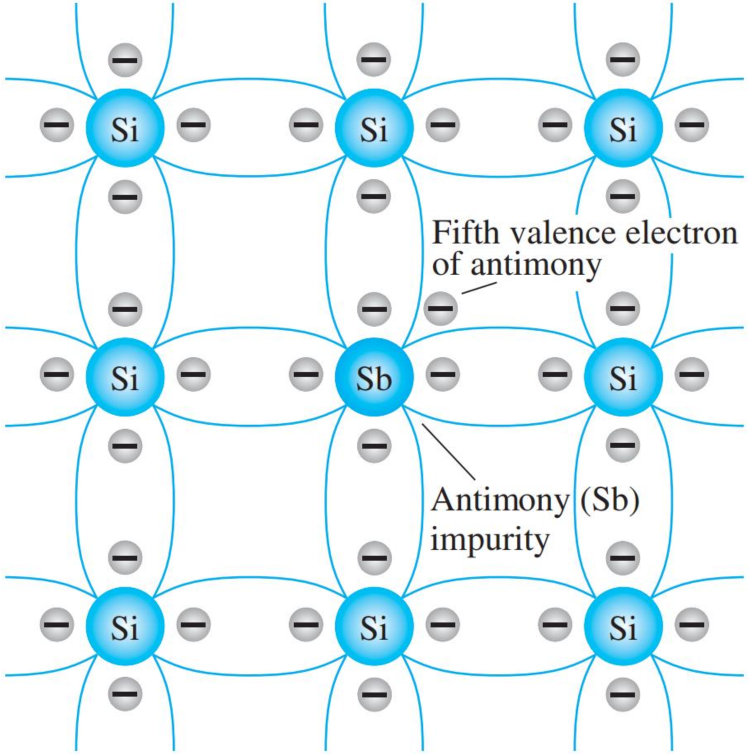
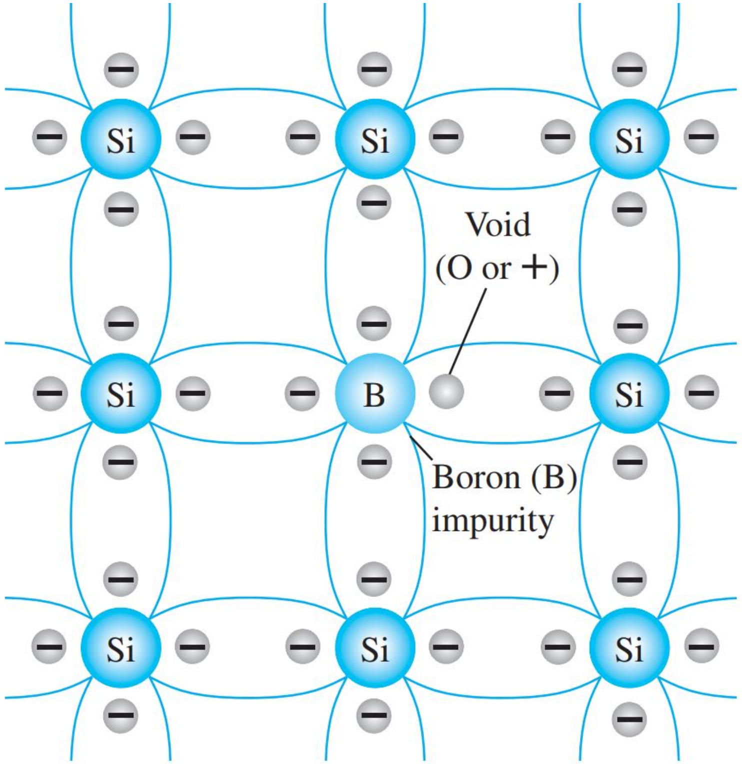
IIB	IIIA	IVA	VA	VIA
	5 B	6 C	7 N	8 O
	13 Al	14 Si	15 P	16 S
30 Zn	31 Ga	32 Ge	33 As	34 Se
48 Cd	49 In	50 Sn	51 Sb	52 Te

Extrinsic semiconductor

n-type material





p-type material

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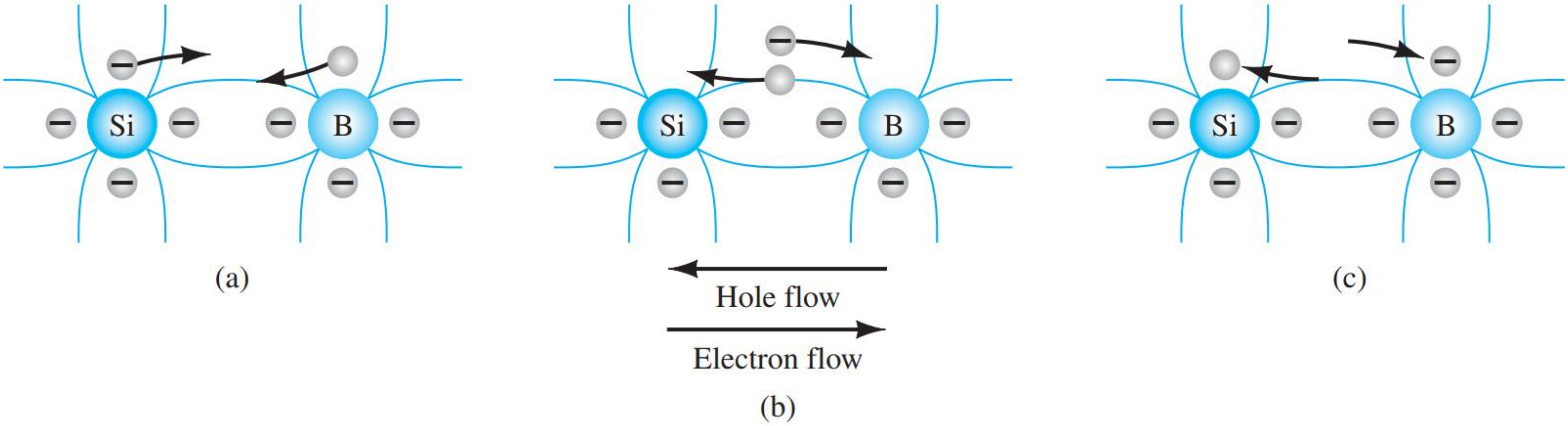
Electron versus Hole Flow



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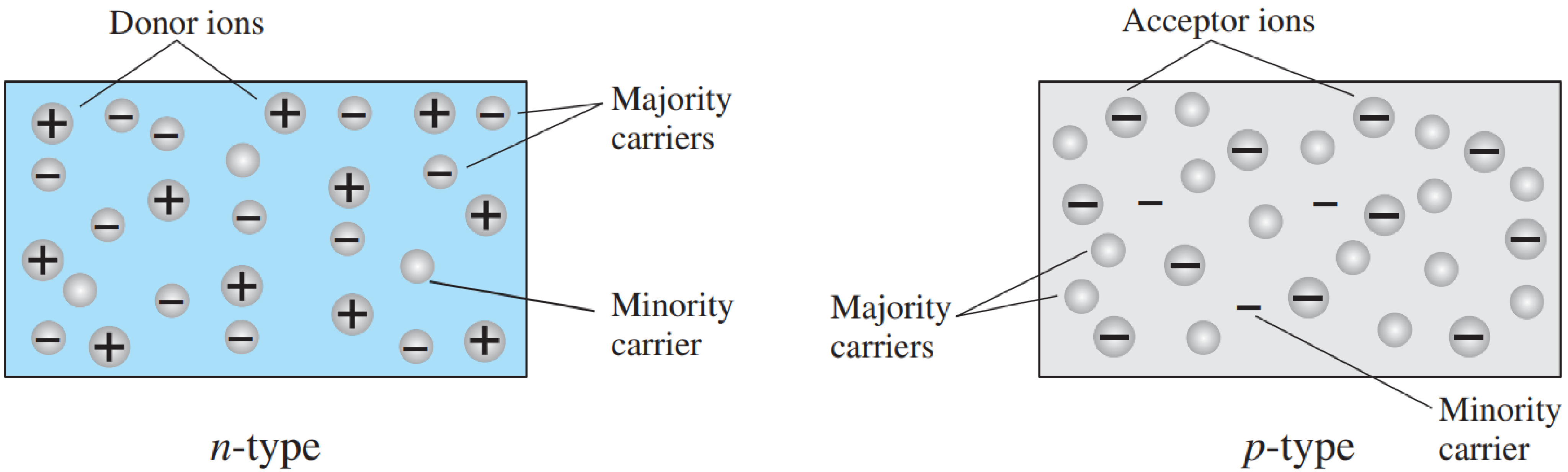
Majority and Minority Carriers



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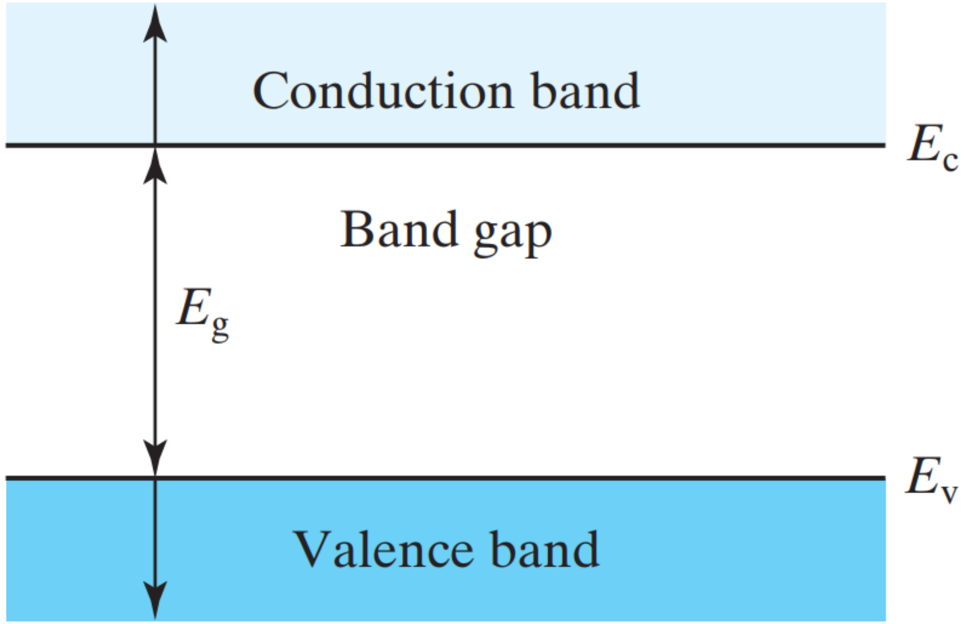
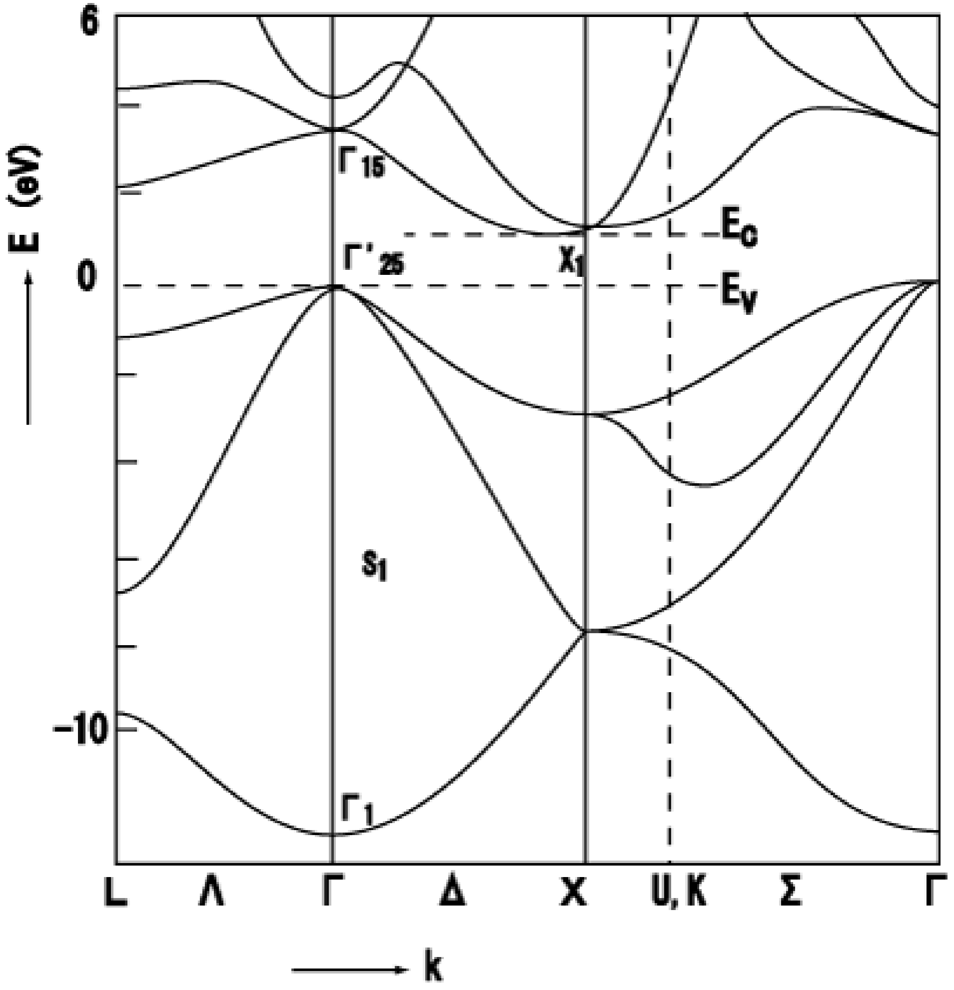
Energy band diagram

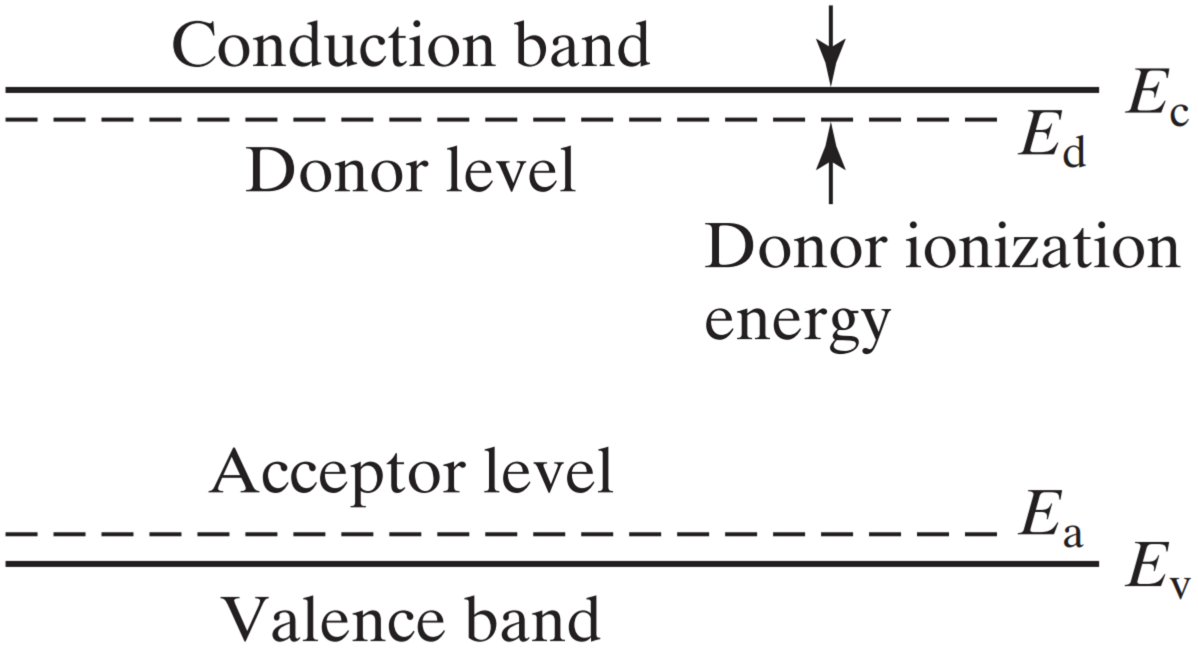


Modern Semiconductor Devices for Integrated Circuits – C. Hu



Chelikowsky et al., Phys. Rev. B 10, 5095 (1974)

Energy band diagram



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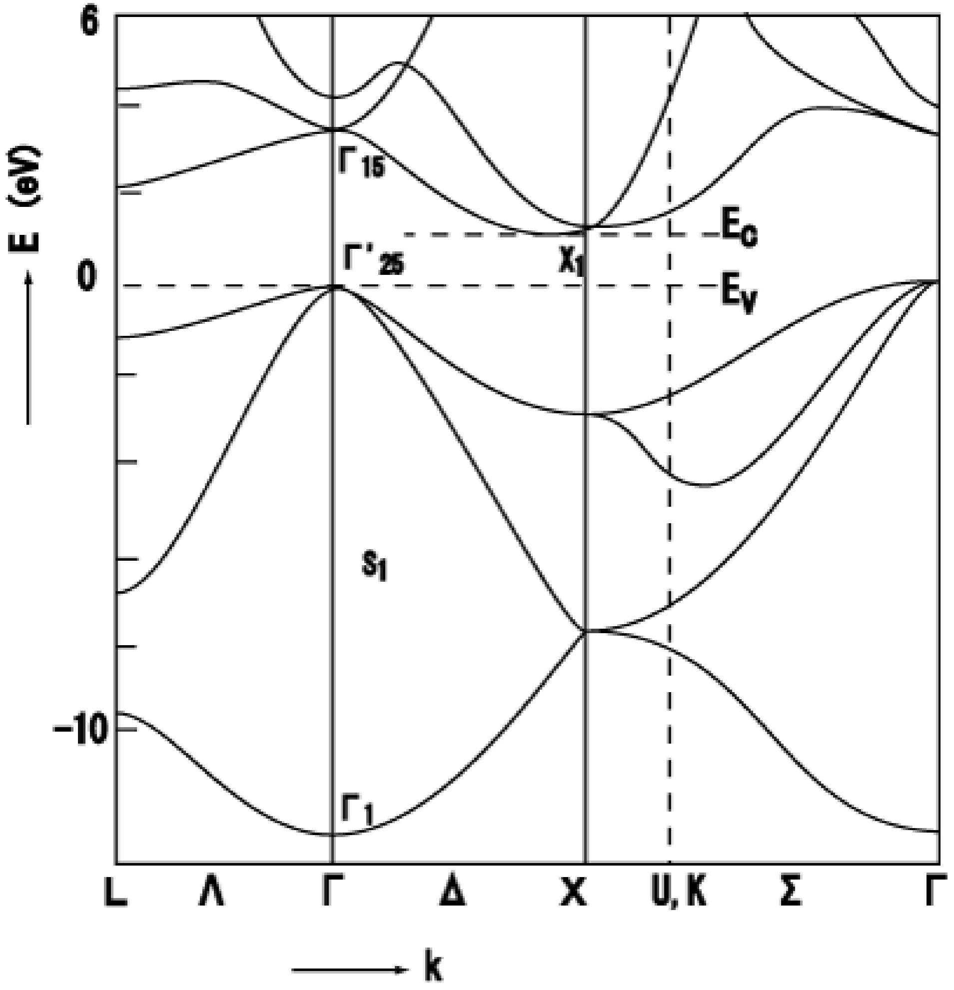
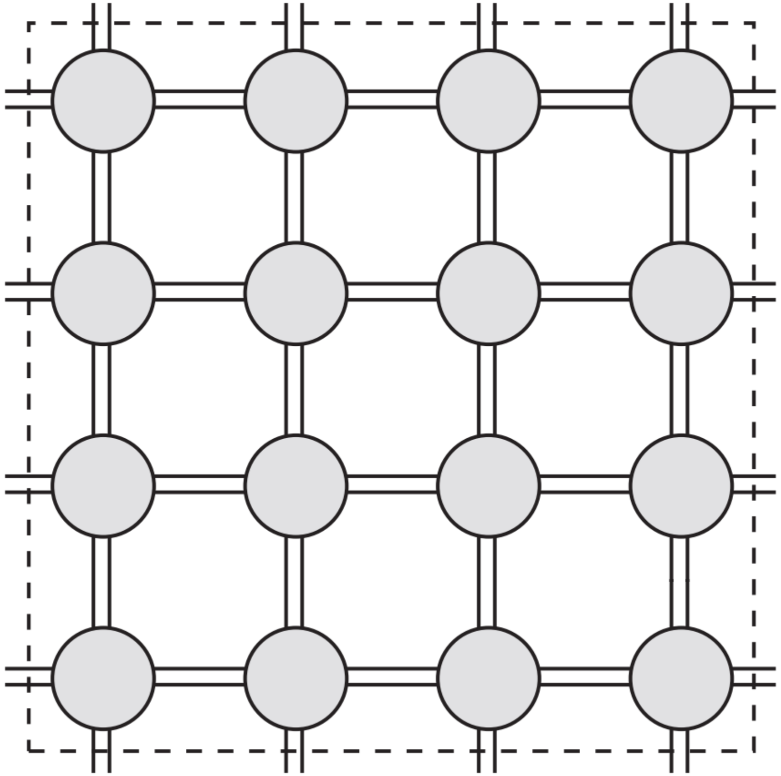


Chelikowsky et al., Phys. Rev. B 10, 5095 (1974)

Two-dimensional view of the Si crystal



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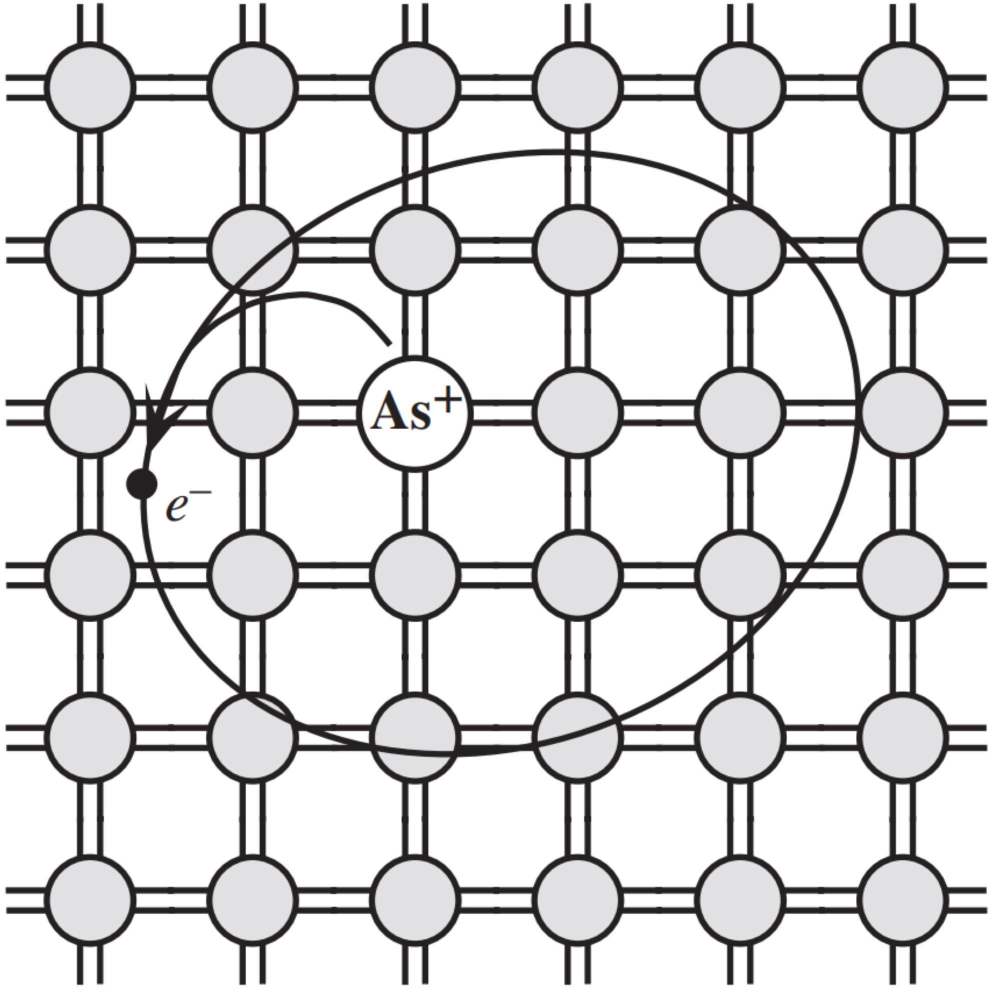
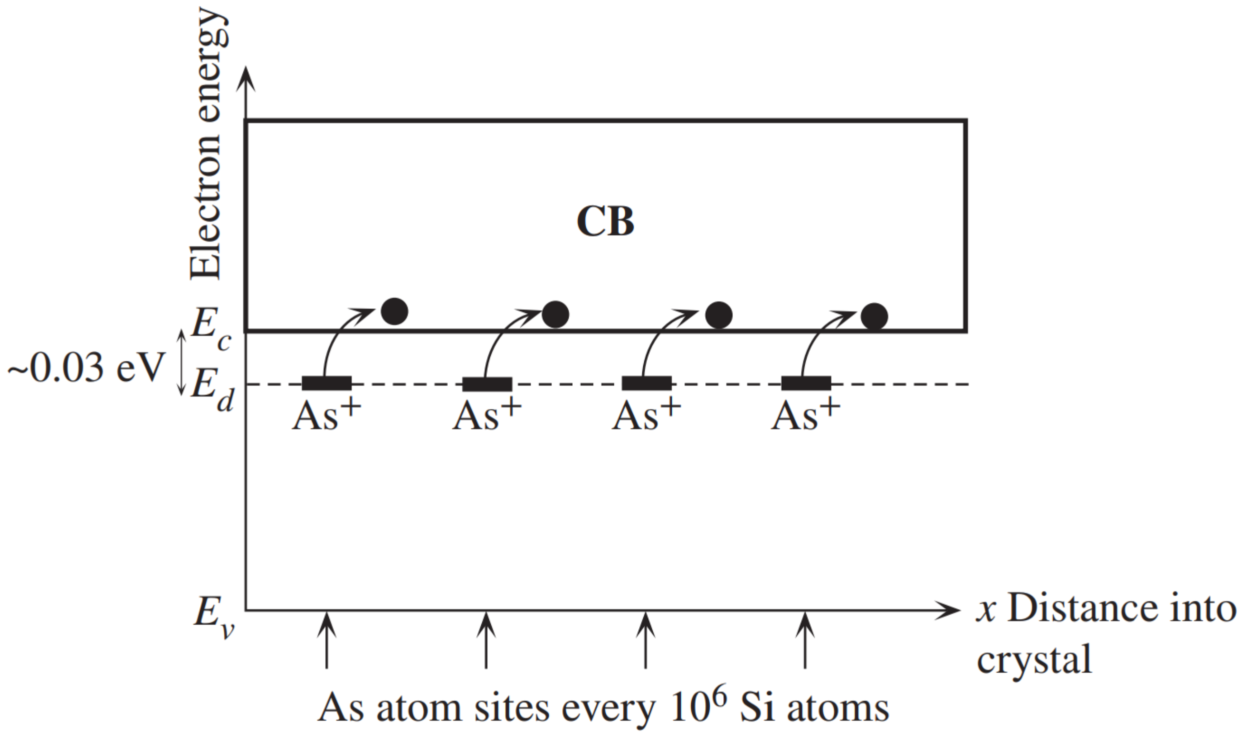
A two-dimensional pictorial view of the Si crystal showing covalent bonds as two lines where each line is a valence electron.

Arsenic-doped Si crystal





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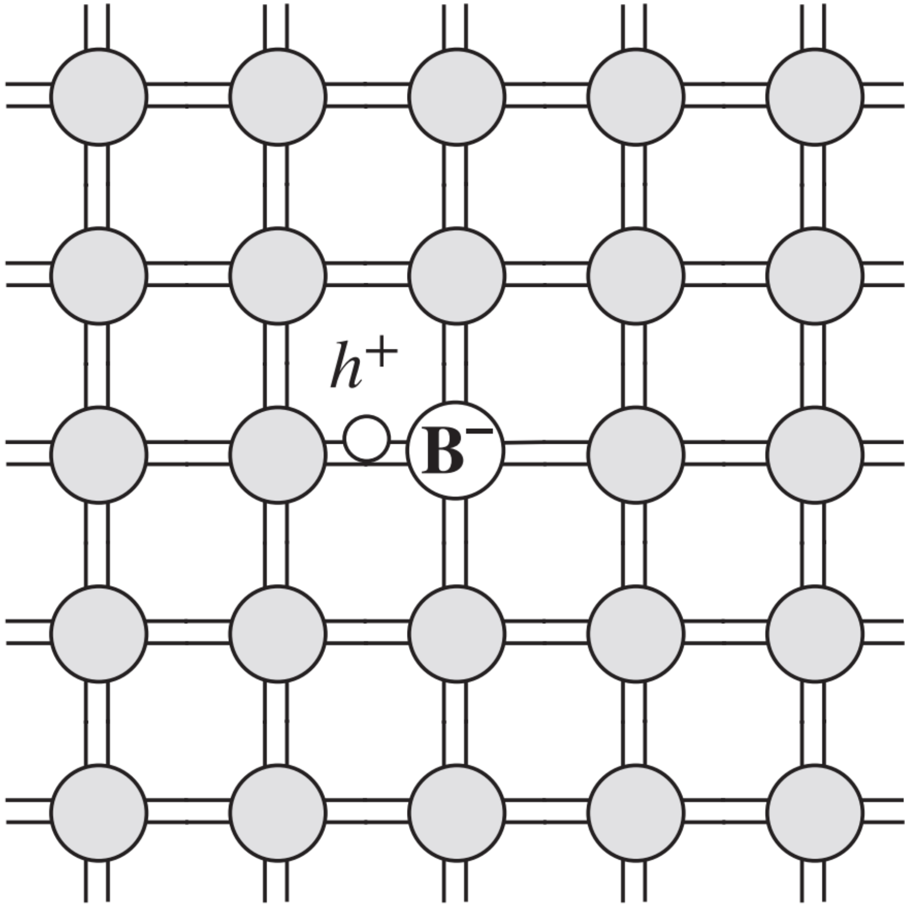
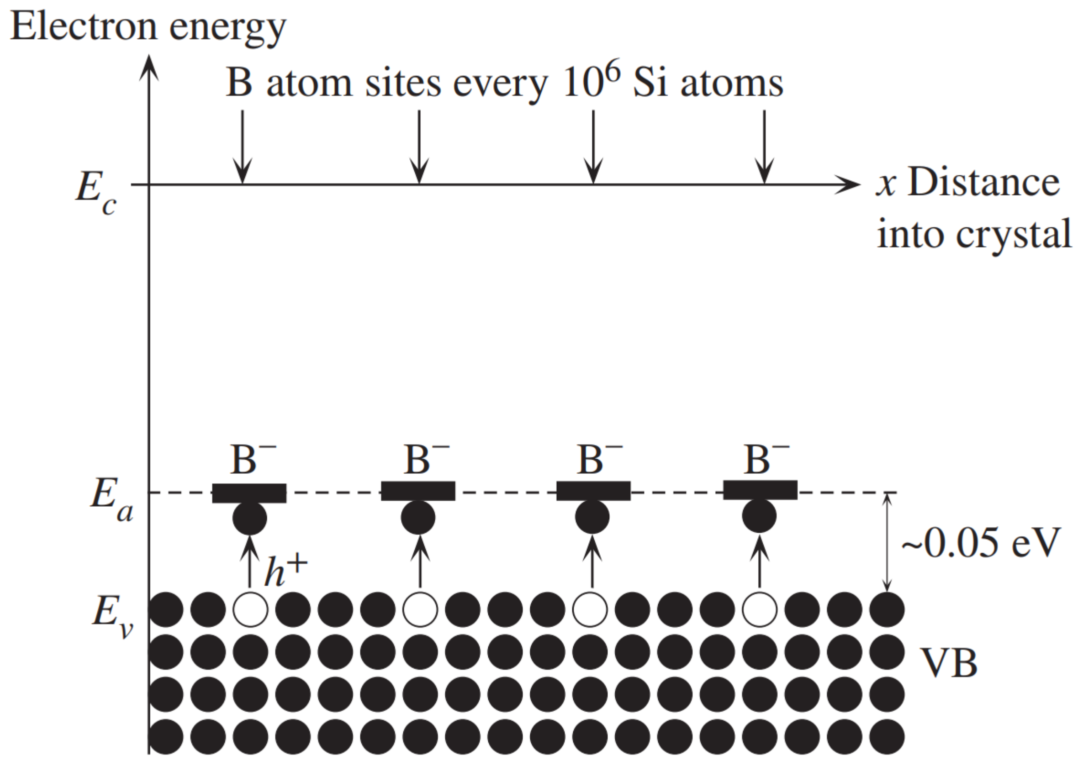
Boron-doped Si crystal





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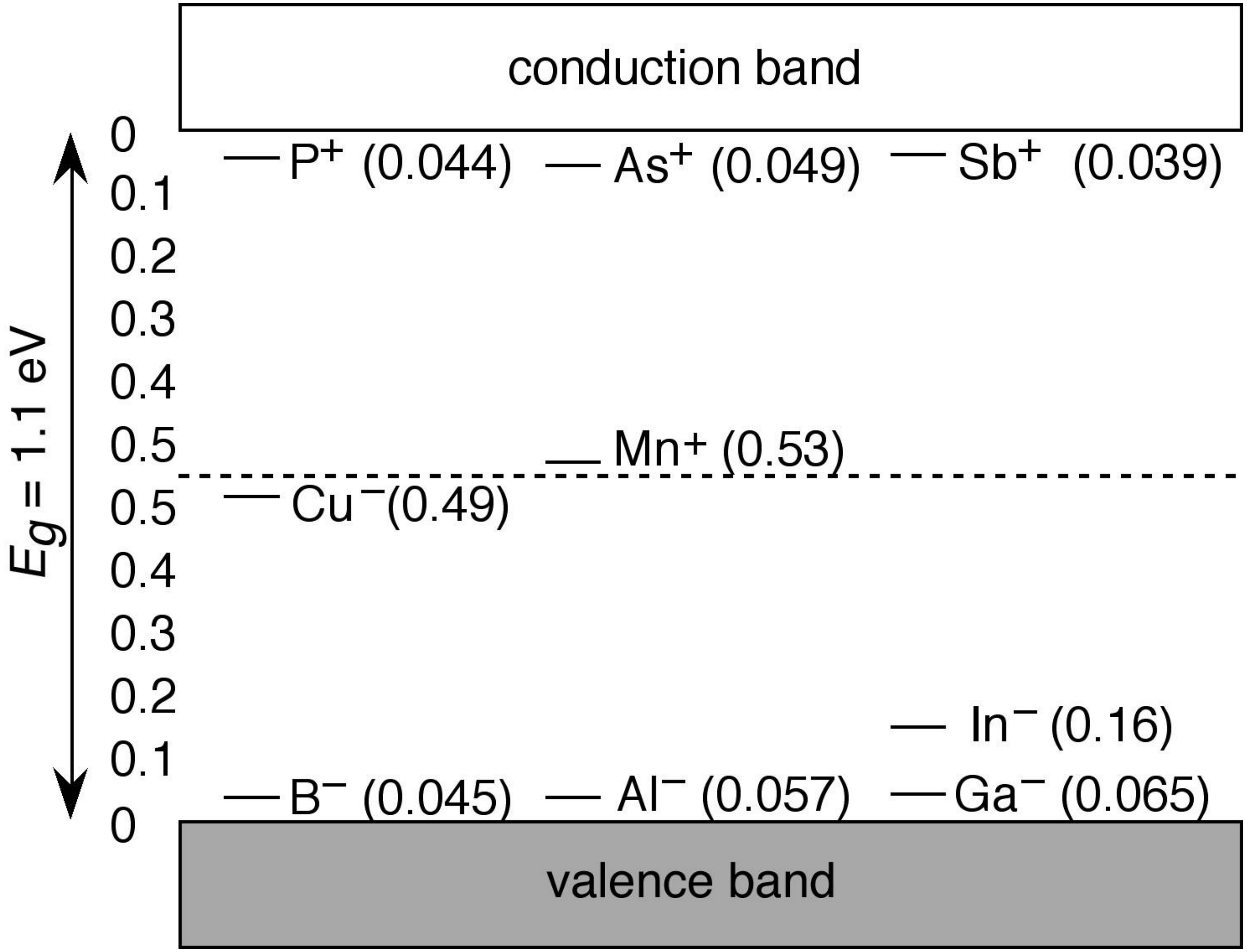
Strong and weak donors and acceptors



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The effective mass

The effective mass is a quantum mechanical quantity that behaves in the same way as the inertial mass in classical mechanics.

$$m_e^* = \frac{F_{\text{ext}}}{a_{\text{crystal}}}$$

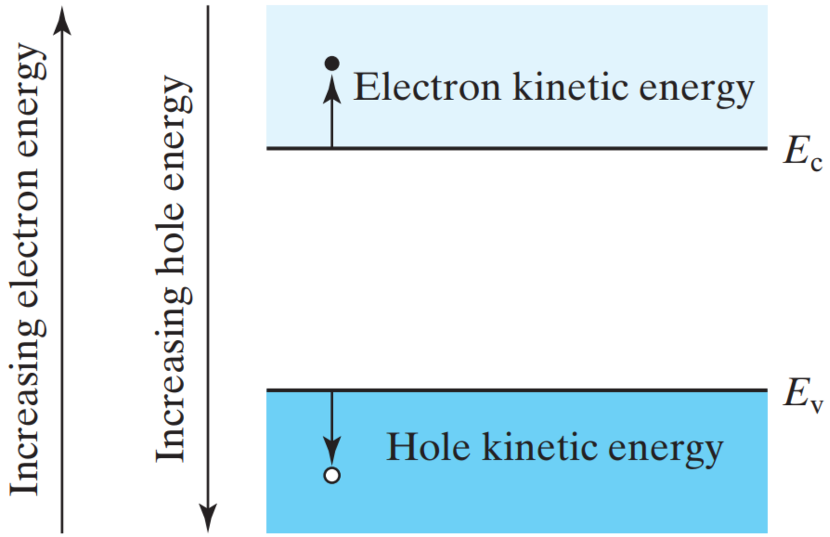
		Germanium	Silicon	GaAs
Smallest energy bandgap at 300 K	E_g (eV)	0.66	1.12	1.424
Electron effective mass for density of states calculations	$\frac{m^*_{e,dos}}{m_0}$	0.55	1.08	0.067
Hole effective mass for density of states calculations	$\frac{m^*_{h,dos}}{m_0}$	0.37	0.811	0.45
Electron effective mass for conductivity calculations	$\frac{m^*_{e,cond}}{m_0}$	0.12	0.26	0.067
Hole effective mass for conductivity calculations	$\frac{m^*_{h,cond}}{m_0}$	0.21	0.386	0.34

Semiconductor Devices – Zeghbroeck

The effective 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

Electron and hole effective masses, m_n and m_p, normalized to the free electron mass



Both electrons and holes tend to seek their lowest energy positions. Electrons tend to fall in the energy band diagram. Holes float up like bubbles in water.

Modern Semiconductor Devices for Integrated Circuits – C. Hu

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