Semiconductors: A general introduction

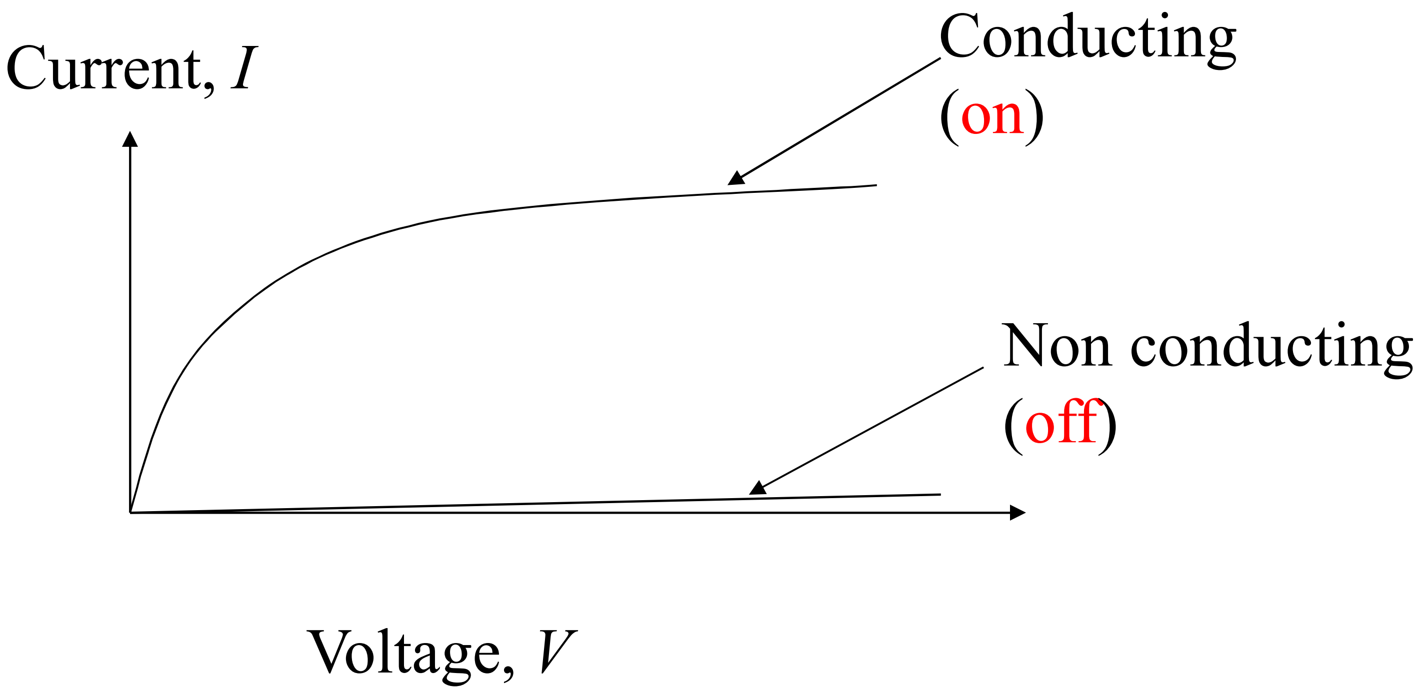
Classification of Materials in terms of electrical resistivity:

Insulators	$10^{10} – 10^{18}$ Ω cm
Semiconductors	$10^{-4} – 10^{8}$ Ω cm
Conductors	$10^{-6} – 10^{-4}$ Ω cm

The uniqueness of semiconductors is that their conductivity can be varied **by us** over a wide range, e.g. by

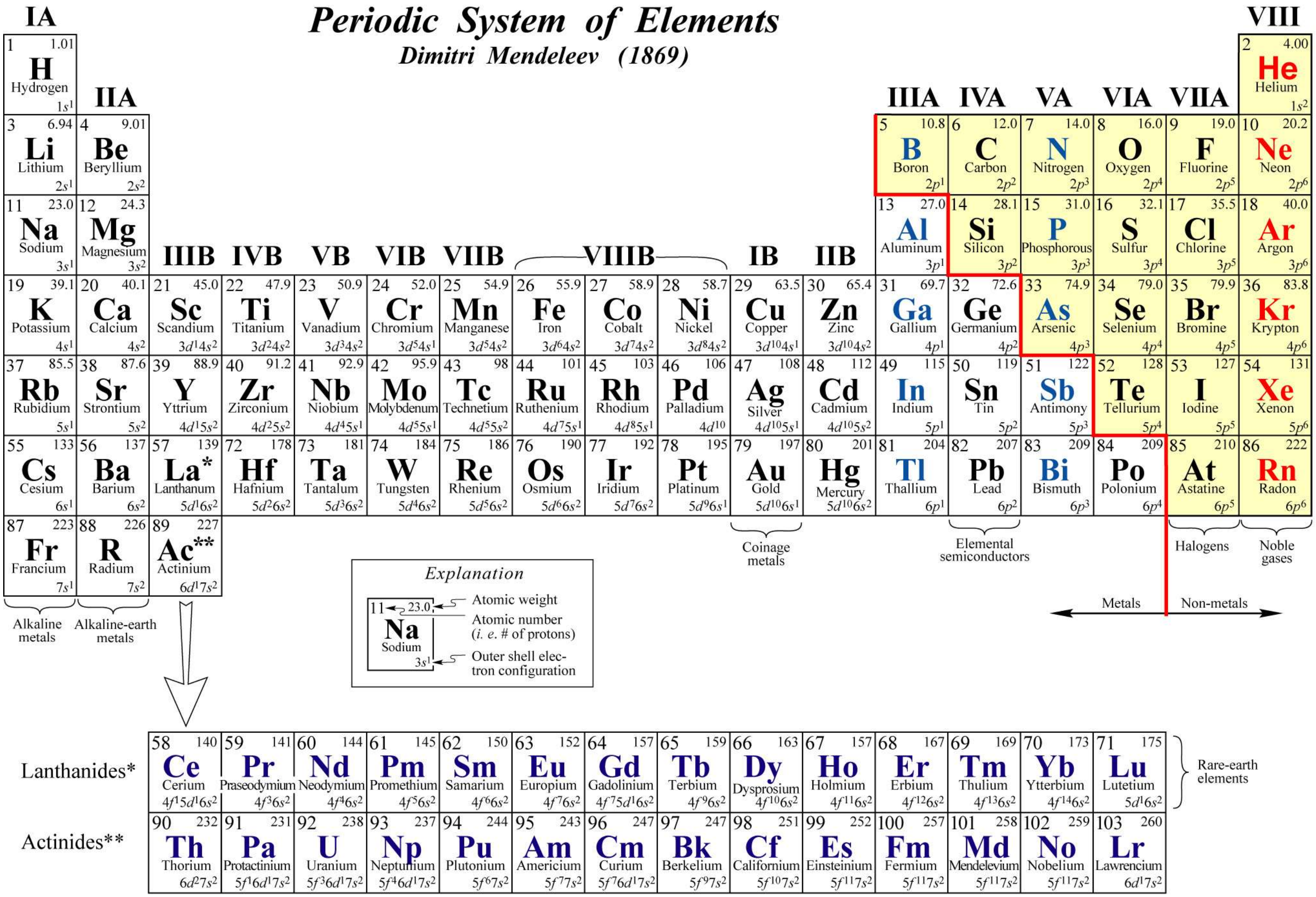
- adding minute quantities of impurities
- by applying electric field
- illumination

Introduction



We can use this as a switch. (Example: Digital computers)

Periodic table of the elements



Note: s-electron shell can be occupied by at most 2 electrons; p-electron shell by at most 6 electrons; d-electron shell by at most 10 electrons; f-electron shell by at most 14 electrons; Noble gases have 2 (He), 10 (Ne), 18 (Ar), 36 (Kr), 54 (Xe), and 86 (Rn) electrons

Abbreviated periodic table of the elements

4 Be	5 B	6 C	7 N	8 O
12 Mg	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
80 Hg	81 Tl	82 Pb	83 Bi	84 Po

Elements

$E_{\text{Si}} = 1.1$ eV

$E_{\text{Ge}} = 0.67$eV

Compounds

$E_{\text{GaAs}} = 1.43$eV

$E_{\text{GaSb}} = 0.7$eV

$E_{\text{GaN}} = 3.4$eV

The most common semiconductor is **Silicon**

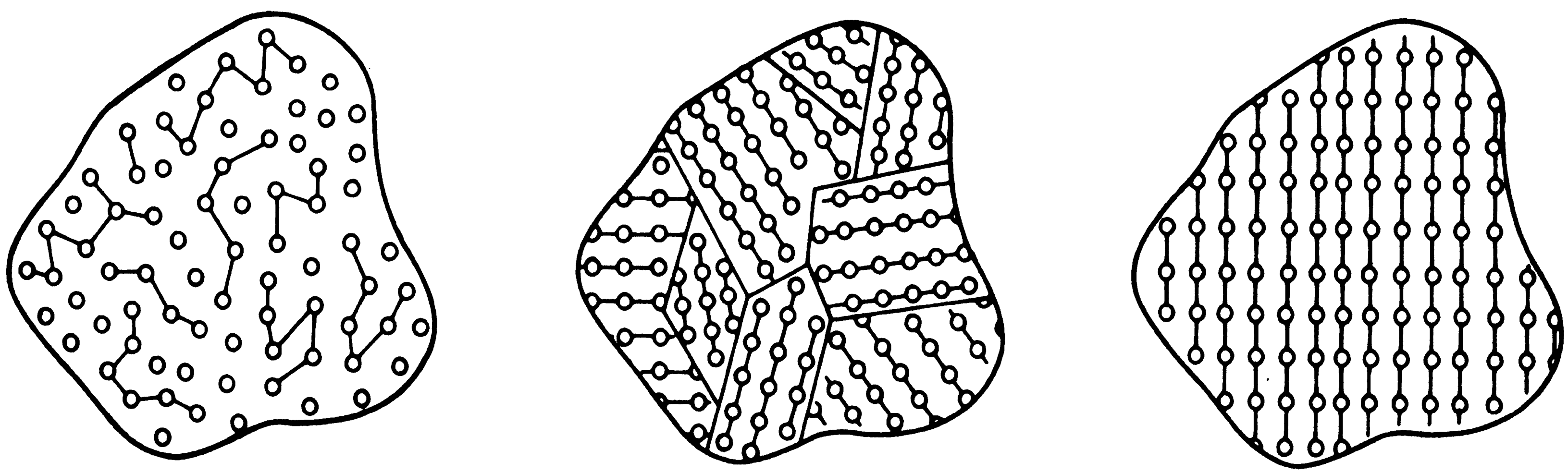
Semiconductor materials

Table 1.1 Semiconductor Materials.

General Classification	*Semiconductor Symbol*	*Name*
(1) Elemental	Si	Silicon
	Ge	Germanium
(2) Compounds		
(a) IV-IV	SiC	Silicon carbide
(b) III-V	AlP	Aluminum phosphide
	AlAs	Aluminum arsenide
	AlSb	Aluminum antimonide
	GaN	Gallium nitride
	GaP	Gallium phosphide
	GaAs	Gallium arsenide
	GaSb	Gallium antimonide
	InP	Indium phosphide
	InAs	Indium arsenide
	InSb	Indium antimonide
(c) II-VI	ZnO	Zinc oxide
	ZnS	Zinc sulfide
	ZnSe	Zinc selenide
	ZnTe	Zinc telluride
	CdS	Cadmium sulfide
	CdSe	Cadmium selenide
	CdTe	Cadmium telluride
	HgS	Mercury sulfide
(d) IV-VI	PbS	Lead sulfide
	PbSe	Lead selenide
	PbTe	Lead telluride
(3) Alloys		
(a) Binary	$Si_{1-x}Ge_x$	
(b) Ternary	$Al_xGa_{1-x}As$	(or $Ga_{1-x}Al_xAs$)
	$Al_xIn_{1-x}As$	(or $In_{1-x}Al_xAs$)
	$Cd_{1-x}Mn_xTe$	
	$GaAs_{1-x}P_x$	
	$Ga_xIn_{1-x}As$	(or $In_{1-x}Ga_xAs$)
	$Ga_xIn_{1-x}P$	(or $In_{1-x}Ga_xP$)
	$Hg_{1-x}Cd_xTe$	
(c) Quaternary	$Al_xGa_{1-x}As_ySb_{1-y}$	
	$Ga_xIn_{1-x}As_{1-y}P_y$	

Crystalline solids

The fact that one can alter the properties of semiconductors over a wide range may have something to do with the atomic arrangement of atoms in these materials. So, let us look at the crystal structure.



(a) Amorphous

No recognizable long-range order

(b) Polycrystalline

Completely ordered in segments

(c) Crystalline

Entire solid is made up of atoms in an orderly array

Figure 1.1

Crystalline solids

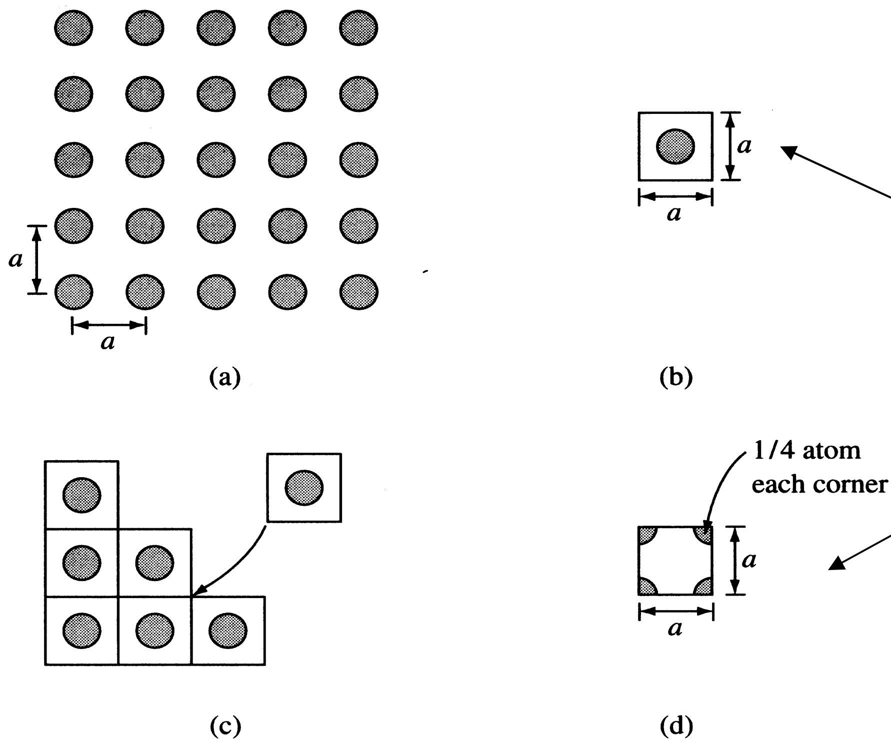
Lattice: Periodic arrangement of atoms. The atomic arrangement determines the macro-properties of the crystal.

Examples:

- Amorphous Si thin film transistors used as switching devices in LCDs
- Polycrystalline Si used as gate in MOSFETs
- Actual active region of MOSFET is fabricated in crystalline Si

Unit cell concept

The ***unit cell*** is a small portion of any given crystal that could be used to reproduce a crystal.



Two different ways of representing a unit cell

Figure 1.2

Simple 3D unit cells

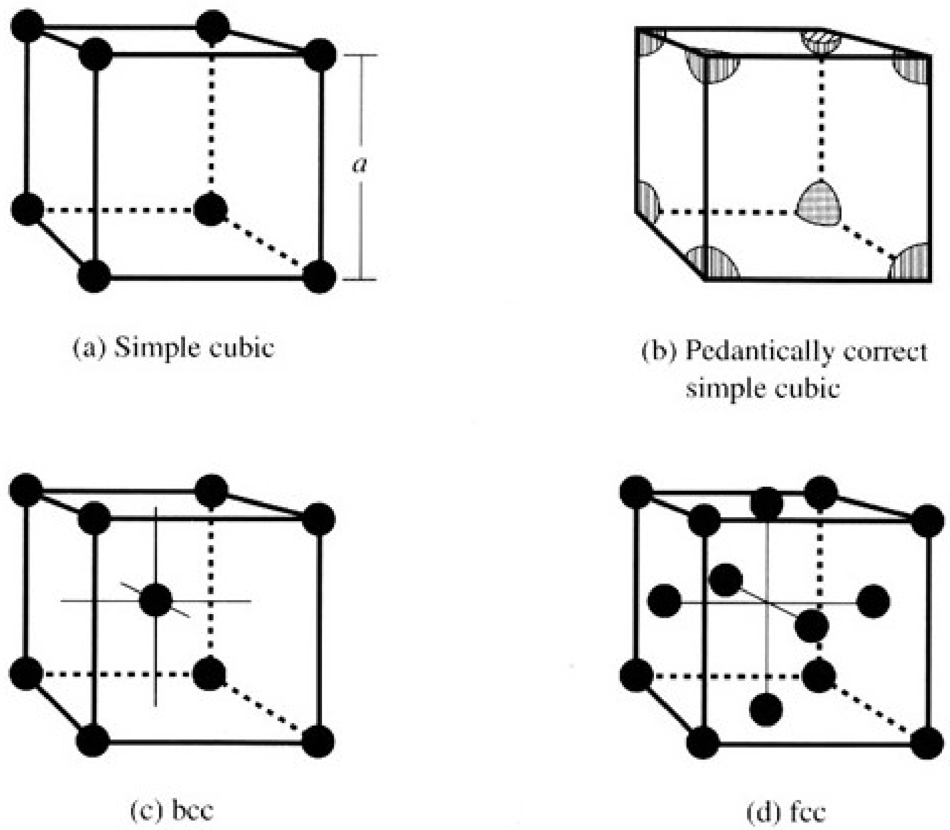


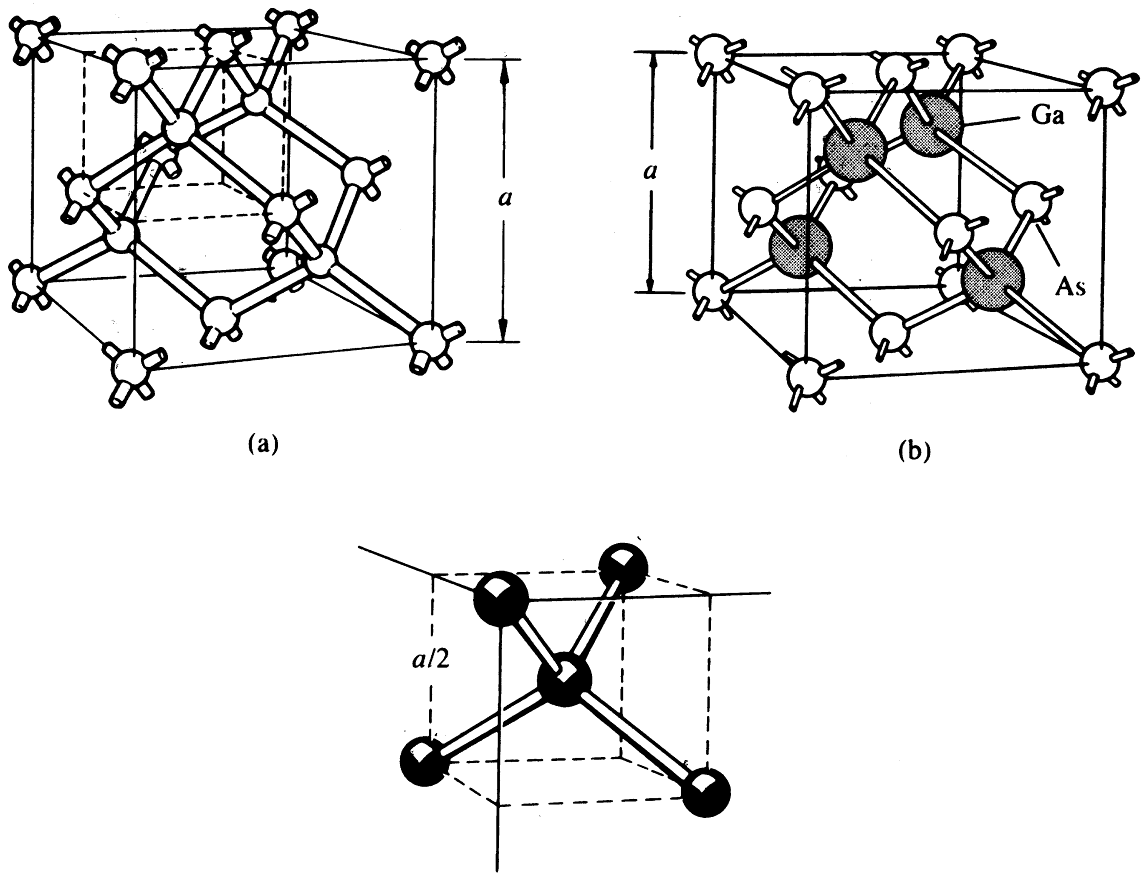
Figure 1.3 Simple three-dimensional unit cells. (a) Simple cubic unit cell. (b) Pedantically correct ~~simple cubic unit cell~~ including only the fractional portion (1/8) of each corner atom actually within the cell cube. (c) Body centered cubic unit cell. (d) Face centered cubic unit cell.

Crystal structure of Si and Ge and other common semiconductors

- 2 FCC lattices displaced by **(**(1/4) a, (1/4) a, (1/4) a**)** along body diagonal*
- 8 atoms per unit cell
- Diamond lattice (also called "zincblende" if interpenetrating FCC lattices are made of different elements like in GaAs)
- Each atom is bonded to 4 other atoms (tetrahedral bonding structure)

* The lattice constant or cubic edge is "a". Generally a is expressed in Angstroms. 1 Å = 10^{-8} cm = 10^{-10} m

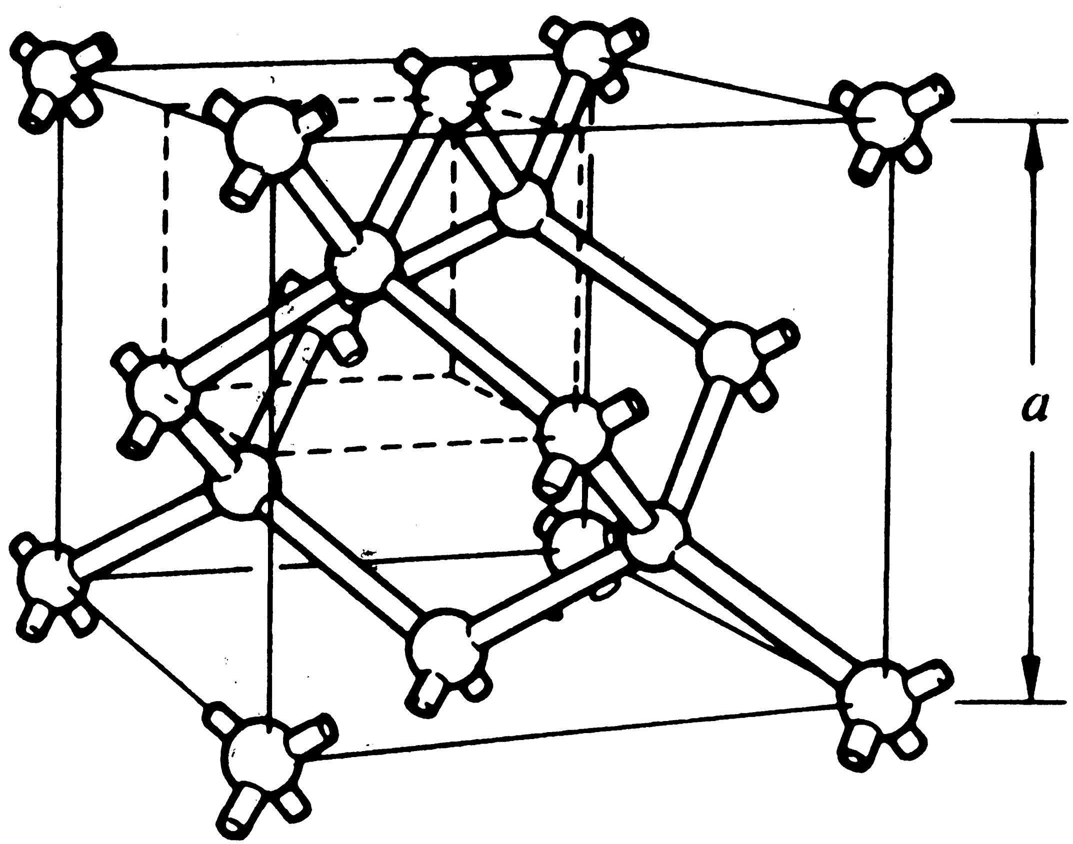
Diamond and zincblende lattice unit cells



(a) (b) (c)

Figure 1.4

Diamond lattice (detail)



(a)

Example

What is the number of Si atoms in 1 cm^3 of Si?

Given is the lattice constant: $a = 5.43$ Å

$$\frac{8\text{ atoms}}{a^3} = 5\times10^{22}\ \frac{\text{atoms}}{\text{cm}^3}$$

What is the density of Si?

Atomic weight of Si = 28.1 i.e. 1 mole ($N_A = 6.023 \times 10^{23}$ atoms) of Si has a mass of 28.1 g

$$\text{Density} = \frac{5\times10^{22}\ \frac{\text{atoms}}{\text{cm}^3} \times 28.1\ \frac{\text{gm}}{\text{mole}}}{6.02\times10^{23}\ \frac{\text{atoms}}{\text{mole}}} = 2.33\ \frac{\text{g}}{\text{cm}^3}$$