I) Structures of Solids

A) Amorphous Solids

random arrangement of particles

- disordered structure

Glass, plastics

B) Crystalline Solids

Particles ordered in well-defined, repeating patterns

- highly ordered structure

Prop. same throughout sample

Specific m.p.

Quartz, diamonds

c) Crystalline Structure

represent by 3-D
array of points

Unit Cell

smallest "piece" of
crystal req. to show
the repeating pattern

Crystal Lattice

long-range pattern shown
by repeating the U.C.

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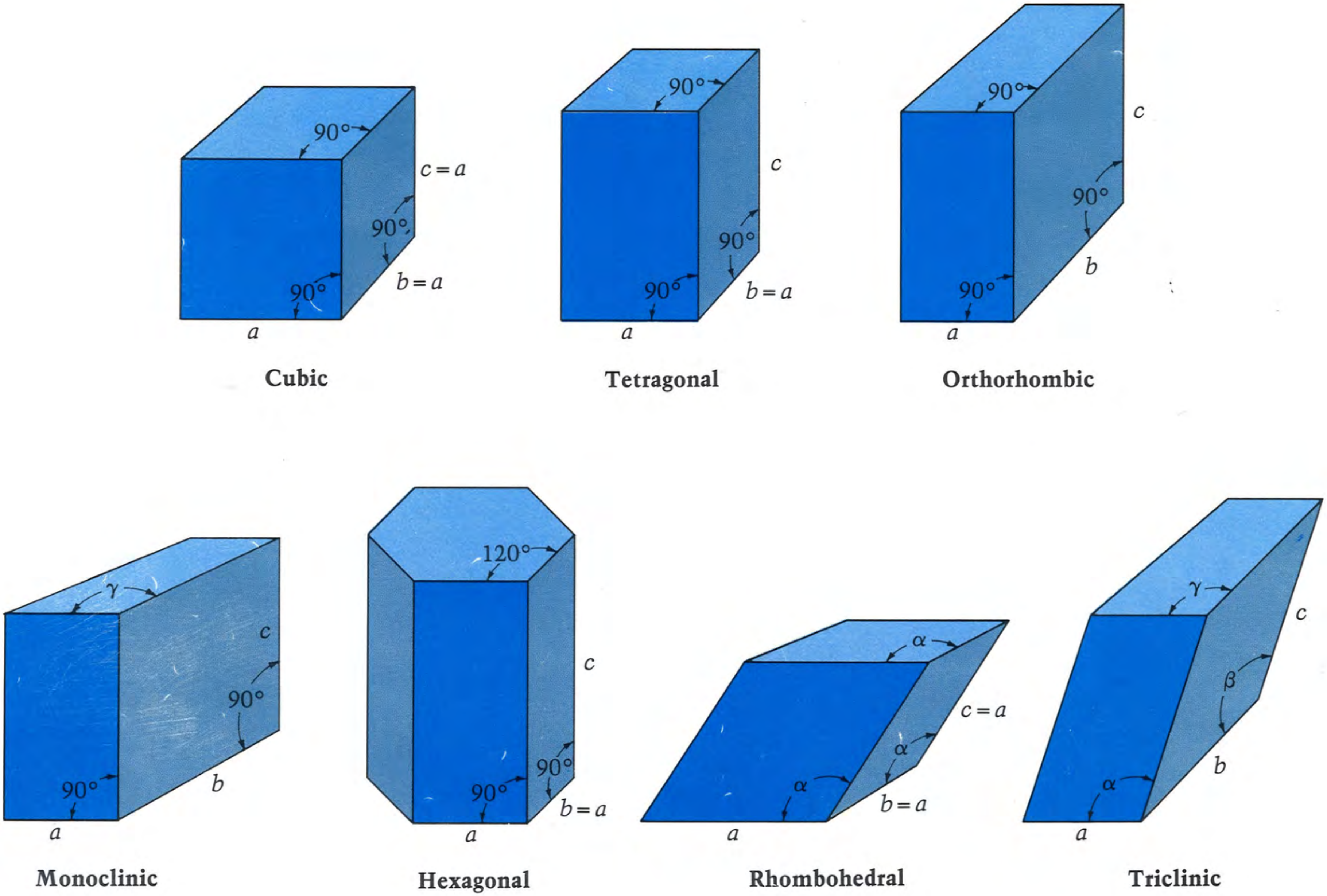
Figure 11.9 Seven unit-cell shapes



D) Cubic Unit Cells

ALL sides of u.c. of equal length
ALL angles = 90°

3 types of cubic unit cells

- differ in placement of particles (lattice points) in the cube.

1) Simple cubic (sc) or Primitive cubic

particles (lattice pts) only at corners of u.c.

Each corner shared by 8 cells in extended lattice

Each corner particle contributes 1/8 of particle to a particular u.c.

Number of particles in a particular sc u.c.:

$$\frac{1}{8}\ \frac{\text{atom}}{\text{corner}} \cdot 8\ \frac{\text{corners}}{\text{u.c.}} = 1\ \frac{\text{atom}}{\text{u.c.}}$$

2) Body-Centered cubic (bcc)

particles at body center plus corners

No. of particles in bcc u.c. =

$$1 \frac{\text{atom}}{\text{center}} \times 1 \frac{\text{center}}{\text{u.c.}} + \left(\frac{1}{8} \times 8\right) = 2 \frac{\text{atoms}}{\text{u.c.}}$$

3) Face-Centered cubic (fcc)

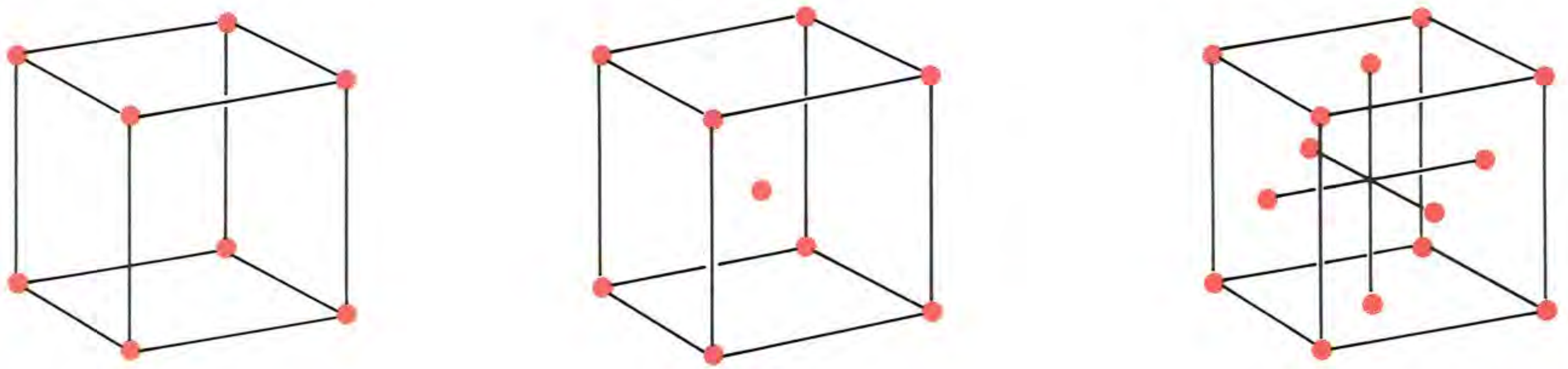
particles at center of each face plus corners

No. of particles in fcc u.c. =

$$\frac{1}{2} \frac{\text{atom}}{\text{face}} \times 6 \frac{\text{faces}}{\text{u.c.}} + \left(\frac{1}{8} \times 8\right) = 4 \frac{\text{atoms}}{\text{u.c.}}$$

Transparency 84

Figure 11.27 Three types of cubic unit cells



Primitive cubic | Body-centered cubic | Face-centered cubic

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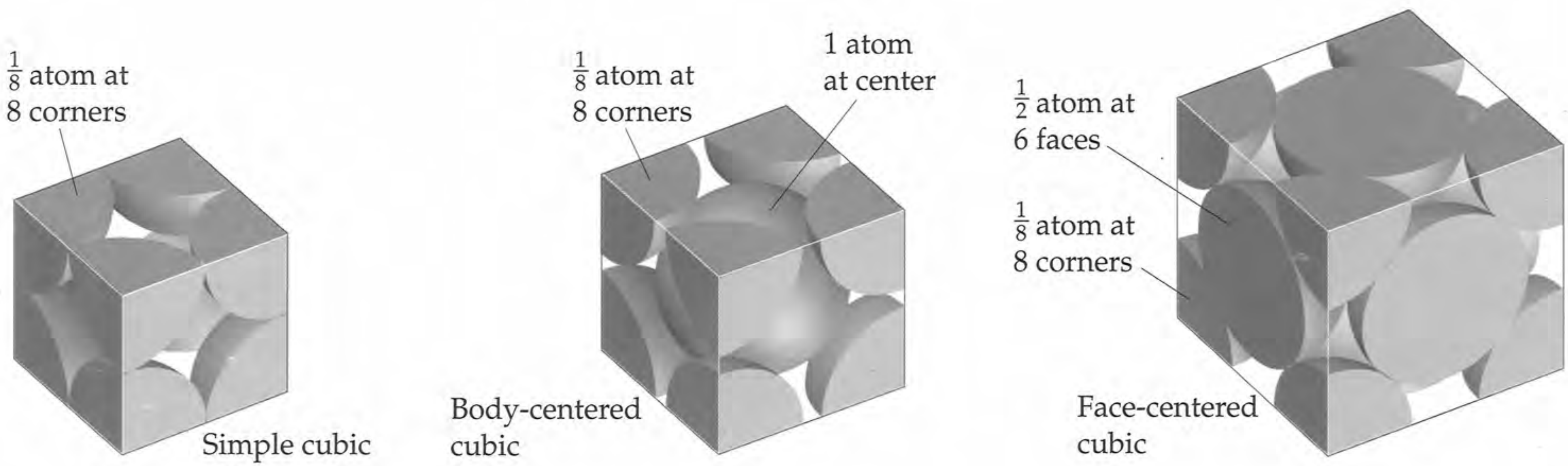
Figure 11.34 Space-filling View of Cubic Unit Cells



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4) Calculations Using Unit Cells

a) Density Calc.

Cr crystallizes as bcc w. edge length of 2.884 Å.
what is the density of Cr?

b) Edge Length Calc.

Ag has a fcc u.c.

$D = 10.6\ g/cm^3$

Determine edge length of u.c.

$$l = V^{1/3}$$

Find volume:

c) Calc. Avogadro's Number, N_A

Li metal is bcc w. edge length of 3.509 Å and density of 0.534 g/cm^3

Calc. N_A

5) Close-Packed Structures

Many particles in solids are spherical or very nearly so.

How can equal-sized spheres pack most efficiently (min. amount of empty space)

layer 1: each sphere surrounded by 6 others

layer 2: spheres rest in depressions formed by 1st layer

layer 3: 2 possible placements

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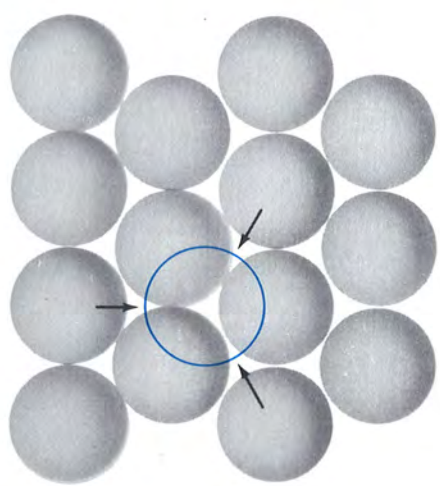
Figure 11.14 Closest packing of spheres

C

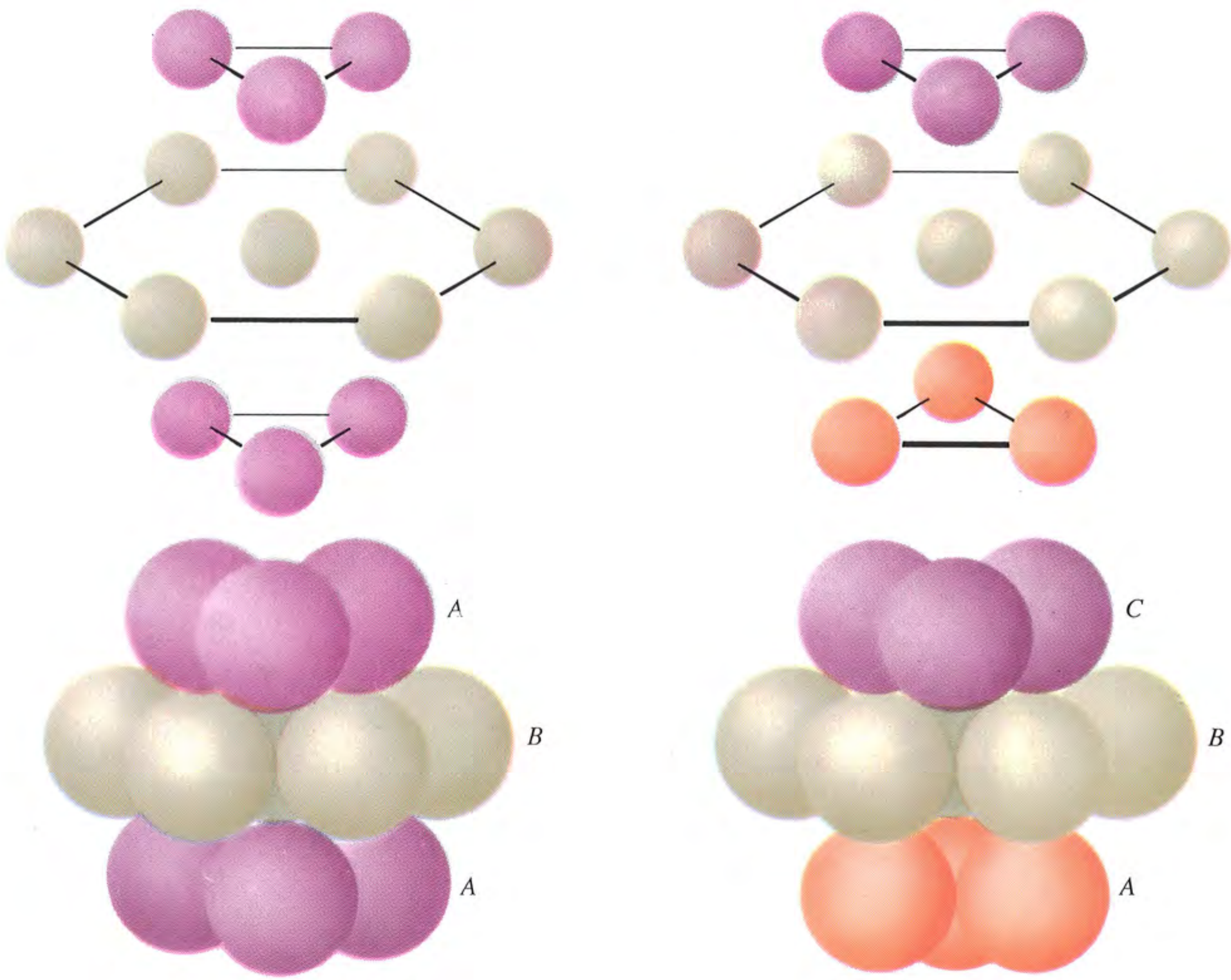


B

A

Transparency 85

Figure 11.33 Hexagonal and cubic close packing



Hexagonal close packing
(*a*)

Cubic close packing
(*b*)

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a) **hexagonal close packing**

3rd layer over 1st layer
so get sequence

ABABAB...

b) **cubic close packing (fcc)**

3rd layer over holes formed by first 2 layers

ABCABC...

Both cases each sphere has a **coordination number** of 12
– number of nearest neighbors

In both close packing structures there is min. of empty space

26% empty space

bcc

Coord. No. = 8

32% empty space

sc

Coord. No. = 6

48% empty space

Relationship between unit cell types, # atoms, coordination no., packing efficiency edge length and particle radius

	sc	bcc	fcc (ccp)	hcp
# atoms/uc	1	2	4	X
coord #	6	8	12	12
% space occupied	52 %	68 %	74 %	74 %
% empty space	48 %	32 %	26 %	26 %
edge length in terms of radius	$l = \frac{4r}{\sqrt{4}}$	$l = \frac{4r}{\sqrt{3}}$	$l = \frac{4r}{\sqrt{2}}$	X

II) Bonding in Solids

Classify types of solids by the types of attractive forces

A) Molecular Solids

IAF - relatively weak

soft, low m.p., nonconducting

most are liquids or gases at room temp.

He(g), $H_2O(l)$, $CO_2(g)$

Note: prop. also depend on ability of molecules to pack efficiently.

Most common: close packing

B) **Covalent Network Solids**

atoms held together by covalent bonds

very hard, high m.p.

entire crystal is one giant molecule

Directional nature of bonds prevents close packing structure
- not most dense solids

Ex Diamond: C is sp^3
(Si, Ge, gray Sn)

Graphite: large flat sheets of benzene like rings (sp^2) stacked on top of each other
sheets held together by IAF

c) Metallic Solids

Array of metal cations held together by mobile e^-.

electron-sea model

Strong attraction depending on size of cation + no. val. e^-

Wide range of hardness + m.p.

Excellent thermal + electrical conduction

Malleable + Ductile

Most common structures are:

hcp, ccp(fcc), bcc

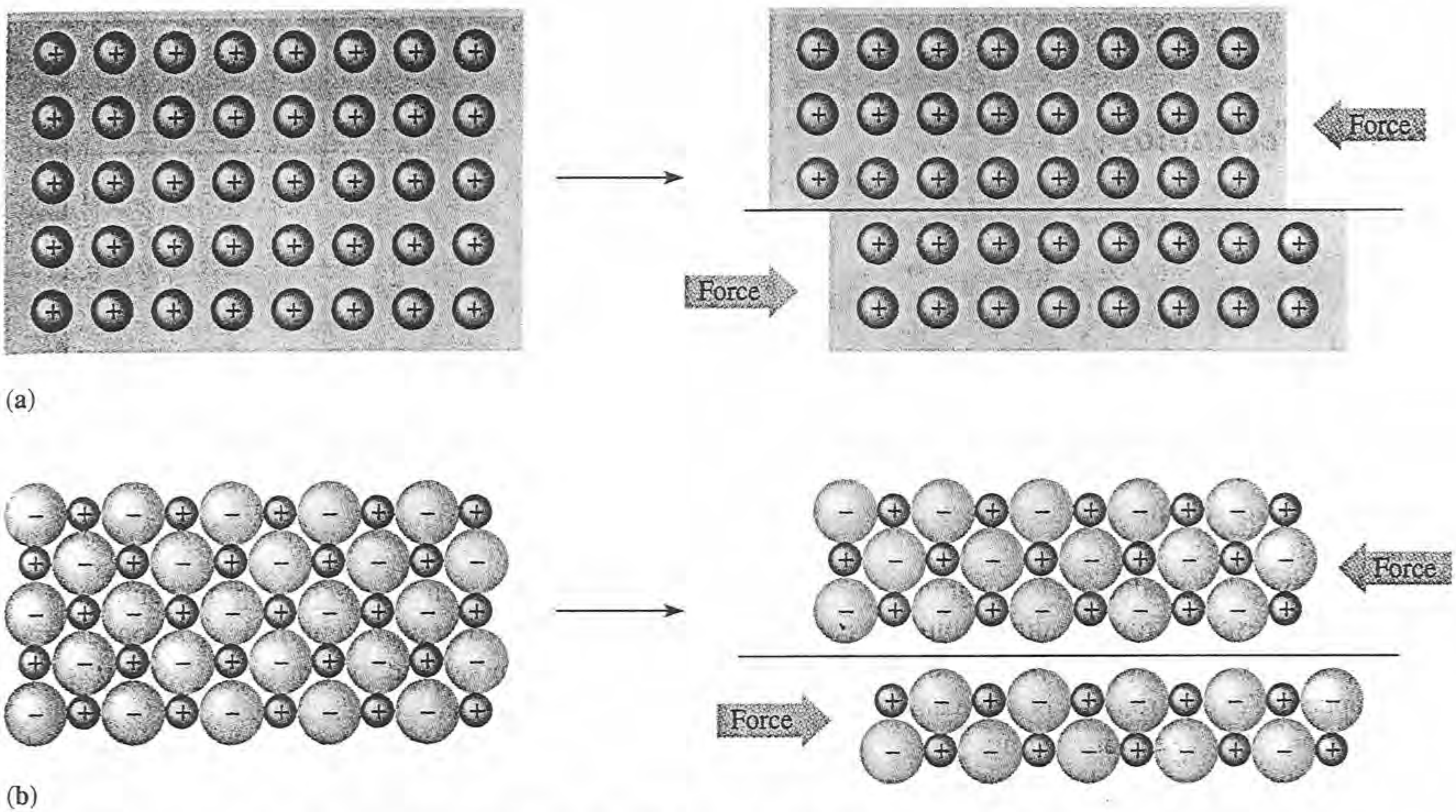


Figure 13-35 (a) In a metal, the positively charged metal ions are immersed in a "sea of electrons." When the metal is distorted (e.g., rolled into sheets or drawn into wires), the environment around the metal atoms is essentially unchanged, and no new repulsive forces occur. This explains why metal sheets and wires remain intact. (b) By contrast, when an ionic crystal is subjected to a force that causes it to slip along a plane, the increased repulsive forces between like-charged ions cause the crystal to break.

Periodic Table of the Elements

Based on $^{12}_{6}C$. Numbers in parentheses are the mass numbers of the most stable isotopes of radioactive elements.

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H 1.0079																	2 He 4.00260
3 Li 6.941	4 Be 9.01218											5 B 10.81	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.998403	10 Ne 20.179
11 Na 22.98977	12 Mg 24.305											13 Al 26.98154	14 Si 28.0855	15 P 30.97376	16 S 32.06	17 Cl 35.453	18 Ar 39.948
19 K 39.0983	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.69	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.22	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.868	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9045	54 Xe 131.29
55 Cs 132.9054	56 Ba 137.3	57* La 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.9665	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.0254	89** Ac 227.0278	104 Unq (261)	105 Unp (262)	106 Unh (263)	107 Uns (262)		109 Une (266)									

*	58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9304	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967
**	90 Th 232.0381	91 Pa 231.0359	92 U 238.02	93 Np 237.0482	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

D) Ionic Solids

Ionic bonds between cations & anions

Strength of bonds depends on charges of ions,

$$E \propto \frac{Q^+ Q^-}{d}$$

Prop. depend on the lattice energy.

High m.p.

NaCl	804°C
MgO	2826°C

Hard & brittle

Solids – non conducting

Liquids – conducting

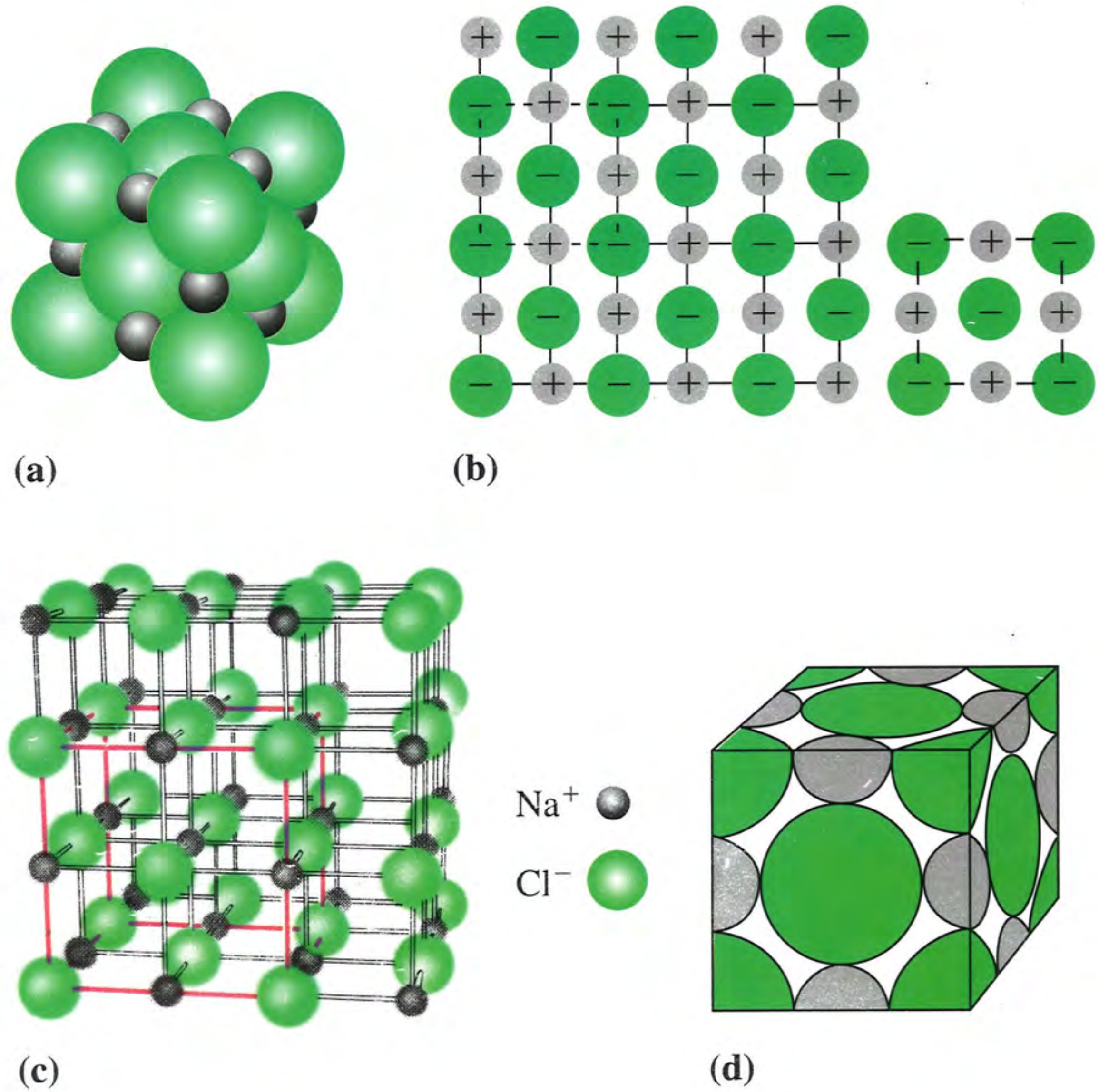
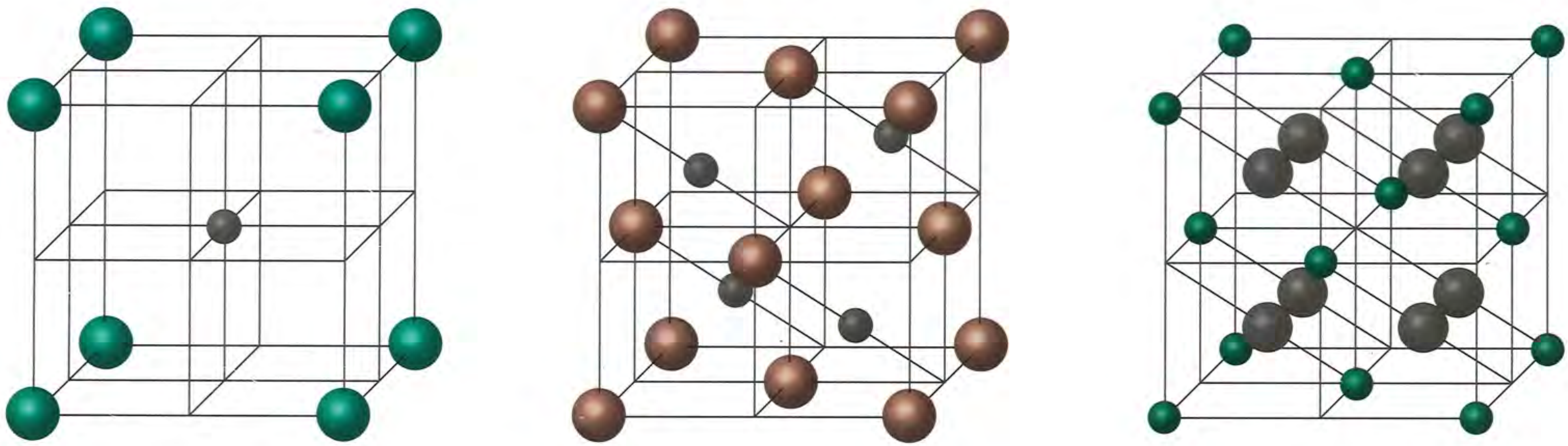

(a)
(b)
Na^+
Cl^-
(c)
(d)

Fig. 11.44 Common Crystal Structures



(a) CsCl (b) ZnS (c) CaF_2

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Table 13-10 ***Characteristics of Types of Solids***

	Metallic	Ionic	Molecular	Covalent
Particles of unit cell	Metal ions in "electron gas."	Anions, cations	Molecules (or atoms)	Atoms
Strongest interparticle forces	Metallic bonds (attractions between cations and e^-'s)	Electrostatic	London, dipole-dipole, and/or hydrogen bonds	Covalent bonds
Properties	Soft to very hard; good thermal and electrical conductors; wide range of melting points. (-39 to 3400°C)	Hard; brittle; poor thermal and electrical conductors; high melting points (400 to 3000°C)	Soft; poor thermal and electrical conductors; low melting points (-272 to 400°C)	Very hard; poor thermal and electrical conductors;* high melting points (1200 to 4000°C)
Examples	Li, K, Ca, Cu, Cr, Ni (metals)	NaCl, $CaBr_2$, K_2SO_4 (typical salts)	CH_4 (methane), P_4, O_2, Ar, CO_2, H_2O, S_8	C (diamond, graphite), SiO_2 (quartz) mostly group 4A (C, Si, Ge, Gray Sn, SiC) and a few others (BN, GeO_2)

**Exceptions: diamond is a good conductor of heat; graphite is soft and conducts electricity well.*