



Materials That Are Solids

- **Solids** : Four bonding classifications
 - **Covalent bonding**, which forms **network covalent solids** (sometimes called simply "covalent solids" as in diamond and silicon dioxide)
 - **Ionic bonding**, which forms **ionic solids***
 - **Metallic bonding**, which forms **metallic solids***
 - **Weak intermolecular bonding**, which forms **molecular solids***

Ionic bonding: ionic solids*

- a) Observations: Types of Crystals
Packing of Spheres
- b) Radius Ratios for Ions Tucked into Holes
- c) Experimental Lattice Energies from
Thermodynamics: Born-Haber Cycle
- d) Theoretical from (Coulombic) Interactions

Metallic bonding: metallic solids*

- a) Observations: Structural Types
Packing of Spheres
- b) Metal-metal bonding in extended structures
- c) HOMO-LUMO gaps and Semi-conductors
- d) Types of Alloys

Weak intermolecular bonding, which forms molecular solids**Close Packing of Spheres;*

Chapter 4—Weller . . . Armstrong

The Structures of Simple Solids: Metals and Ionic Salts

1. How do we know? X-ray Crystallography
2. What do we know? Ordered arrays of repeating units;
lattices and unit cells.



William H. Bragg
Nobel Prize Physics, 1915



William L. Bragg
Nobel Prize Physics, 1915

6.33

Bragg's Law: $n\lambda = 2d \sin\theta$

Direction of X-ray wave propagation, wavelength = λ

Reflected (scattered) X-rays

Lattice plane

Inter-plane spacing, d

Lattice plane

$d \sin\theta$ $d \sin\theta$

λ

Direction of wave propagation

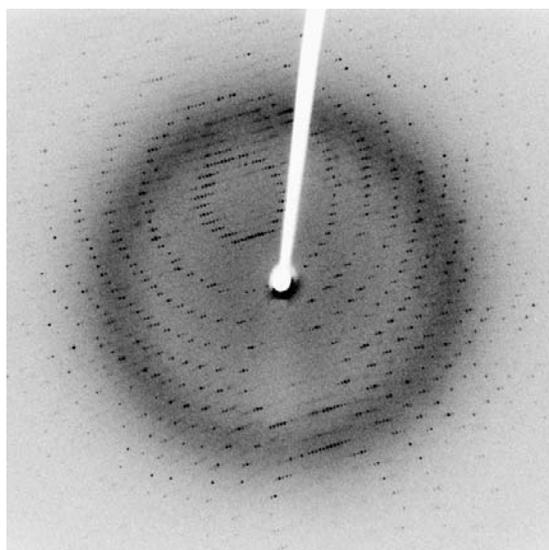
Two waves are in-phase

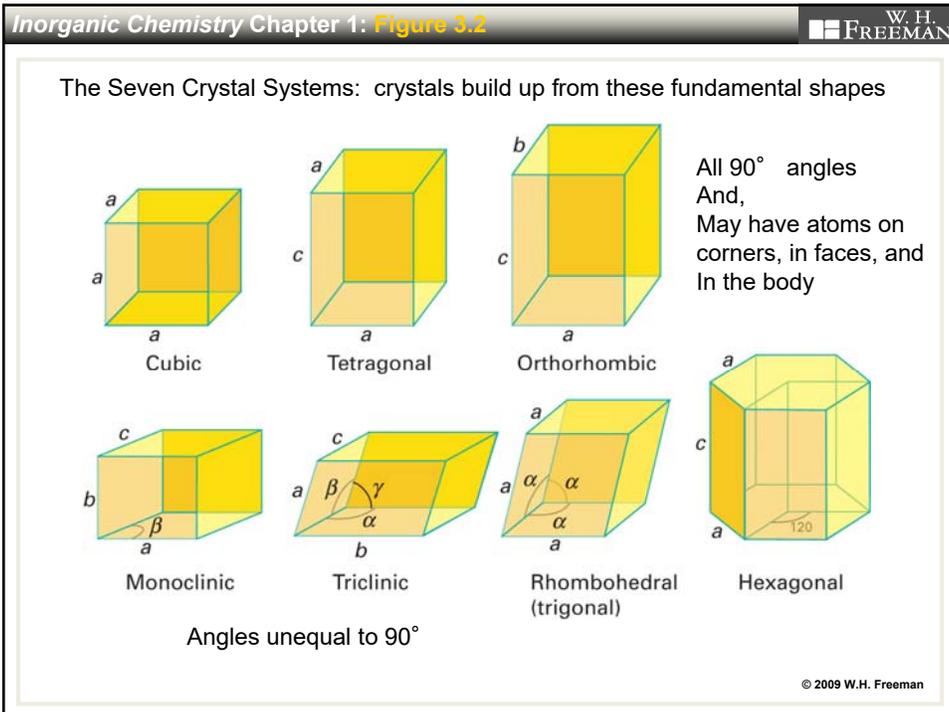
Two waves are out-of-phase

Box 6.5 Determination of structure: X-ray diffraction.

Housecroft and Sharpe, *Inorganic Chemistry*, 3rd Edition © Pearson Education Limited 2008

Following Bragg's law, each dot (or reflection) in this diffraction pattern forms from the constructive interference of X-rays passing through a crystal. The data can be used to determine the crystal's atomic structure.

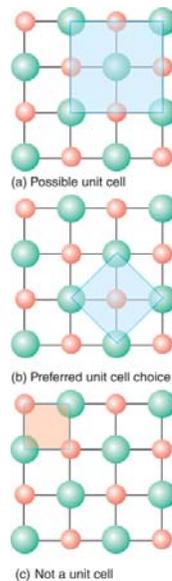




CHAPTER 3: FIGURE 3.1

Unit Cell: The simplest repeating structural unit.

a **unit cell** is the smallest unit of volume that contains all of the structural and symmetry information to build-up the macroscopic structure of the lattice by [translation](#).



CHAPTER 3: FIGURE 3.3

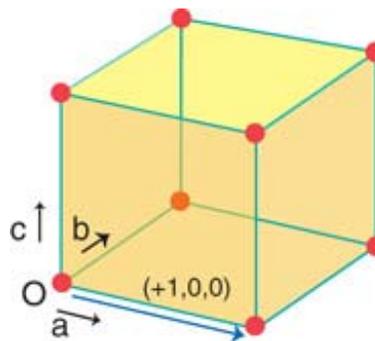
Counting ions in the unit cell: Simple Cubic

“Primitive”

Counting ions in the unit cell:

Each corner is shared with 8 other unit cells. Contributes $1/8$ to this unit cell. Therefore there is :

$8 \times 1/8 = 1$ atom in this unit cell.



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CHAPTER 3: FIGURE 4.4

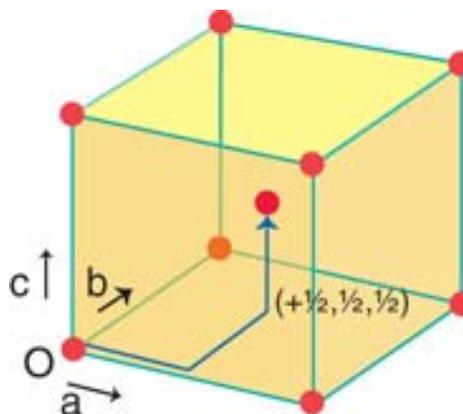
Counting ions in the unit cell: Body-centered cubic

Each corner is shared with 8 other unit cells. Contributes $1/8$ to this unit cell.

Each atom within the cell belongs only to that cell and contributes one to this unit cell.

Therefore there is :

$8 \times 1/8 = 1$ and $1 \times 1 = 1$;
a total of 2 atoms in this unit cell.



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CHAPTER 3: FIGURE 3.5

Face-centered cubic

Counting ions in the unit cell:

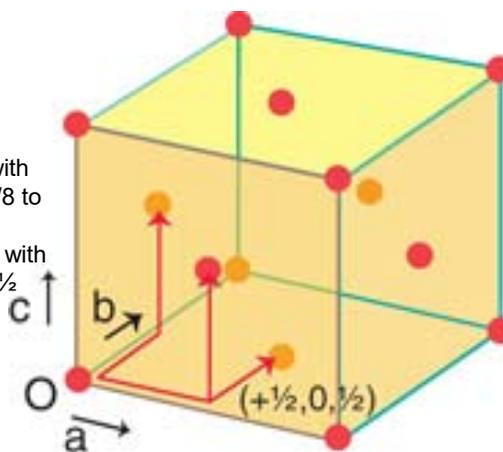
Each corner (red balls) shared with 8 other unit cells. Contributes $1/8$ to this unit cell.

Each face (orange balls) shared with one other unit cell. Contributes $1/2$ to this unit cell. Therefore:

From corners: $8 \times 1/8 = 1$

From faces: $6 \times 1/2 = 3$

Total: 4 atoms or ions in this unit cell.



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CHAPTER 3: FIGURE 3.6

The cubic ZnS structure

Counting:

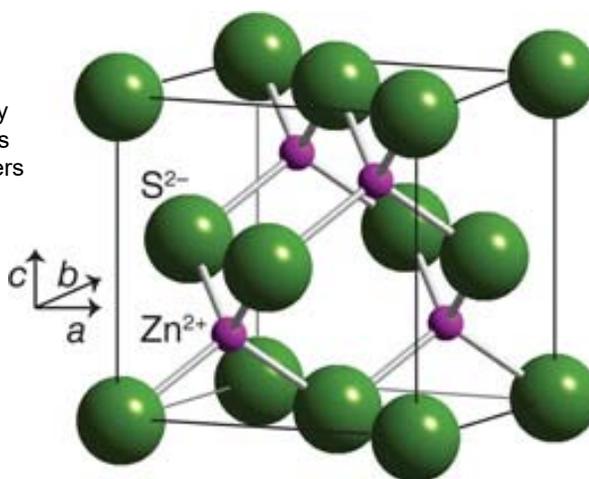
4 Zn ions in body
6 S ions on faces
8 S ions in corners

$6 \times 1/2 = 3$

$8 \times 1/8 = 1$

Total S: 4

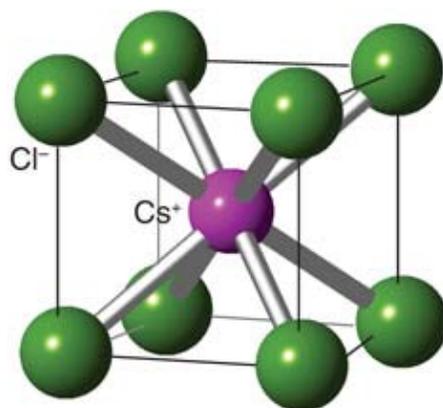
Has to be!!



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CHAPTER 3: FIGURE 3.7

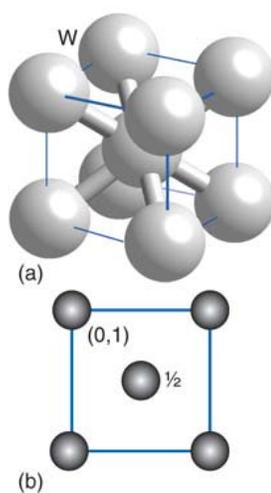
The cubic cesium chloride structure



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CHAPTER 3: FIGURE 3.8

The structure of metallic tungsten looks like CsCl structure!



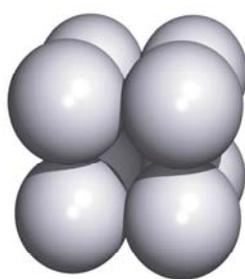
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6.6

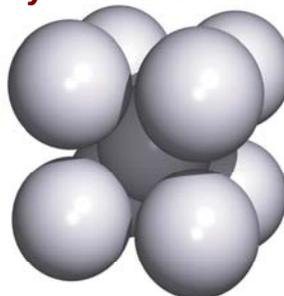
Noble Gases; methane, hydrogen, pure metals

Simple cubic

Body-centered cubic lattice



(a)



(b)

**Inefficient packing; lots of unused space;
52.4 and 68% of space utilized, respectively**

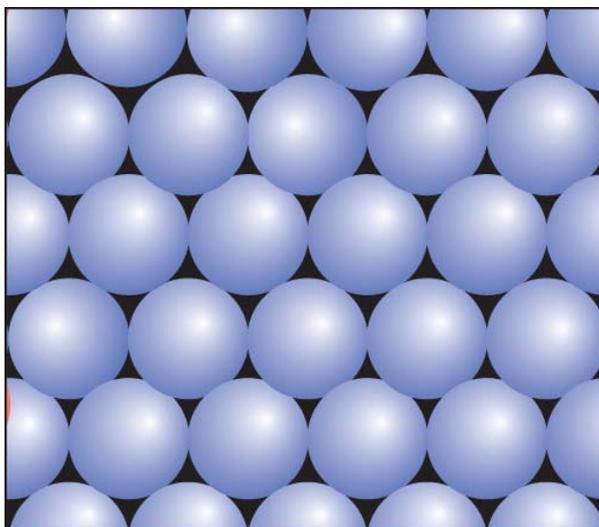
Fig. 6.6 Unit cells of (a) a simple cubic lattice and (b) a body-centred cubic lattice.

Housecroft and Sharpe, *Inorganic Chemistry*, 3rd Edition © Pearson Education Limited 2008

Inorganic Chemistry Chapter 4: **Figure 4.11**

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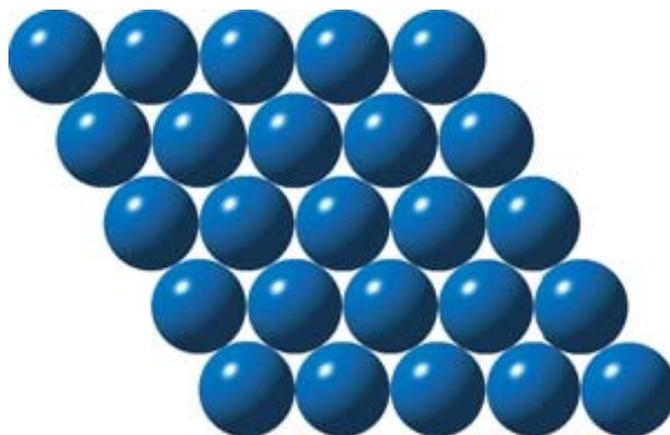
Close Packing of Spheres: Space Efficiency 74%



© 2009 W.H. Freeman

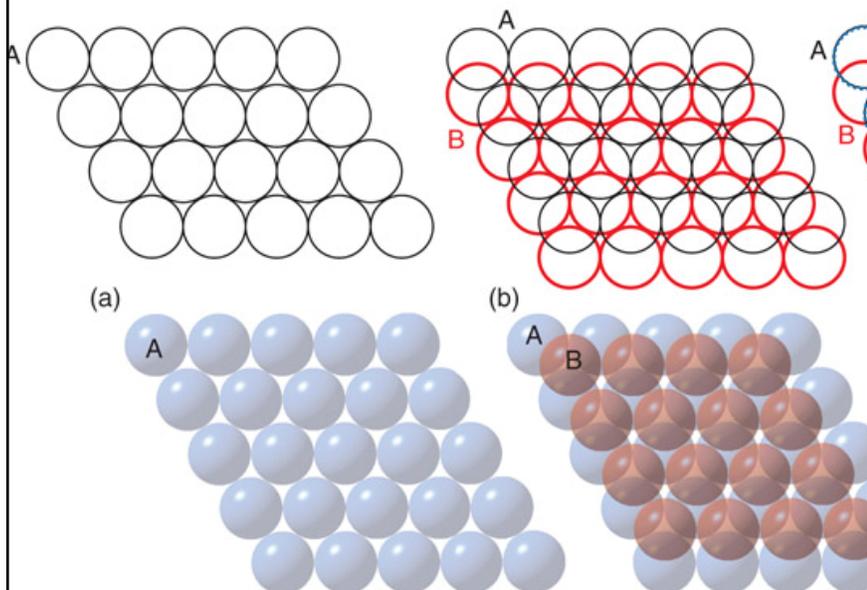
CHAPTER 3: FIGURE 4.11

Close Packing of Spheres: one layer. Note “trigonal” holes



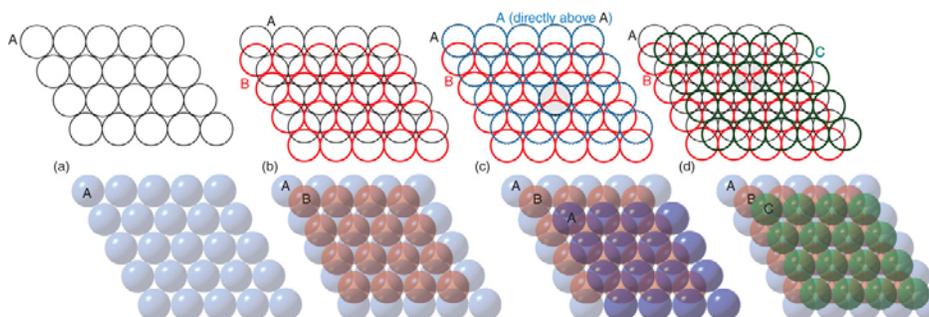
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CHAPTER 3: FIGURE 3.12



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CHAPTER 3: FIGURE 3.12

Close Packing of Spheres: Layer by Layer

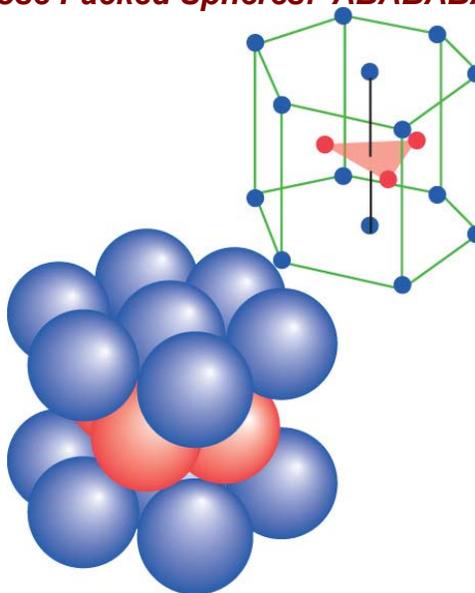
Note: Layers are offset: ABABABABA...; ABCABC

Note: Open spaces are trigonal "holes"; tetrahedral "holes" and octahedral "holes";

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Inorganic Chemistry Chapter 1: Figure 3.13

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Hexagonal Close Packed Spheres: ABABABAB...

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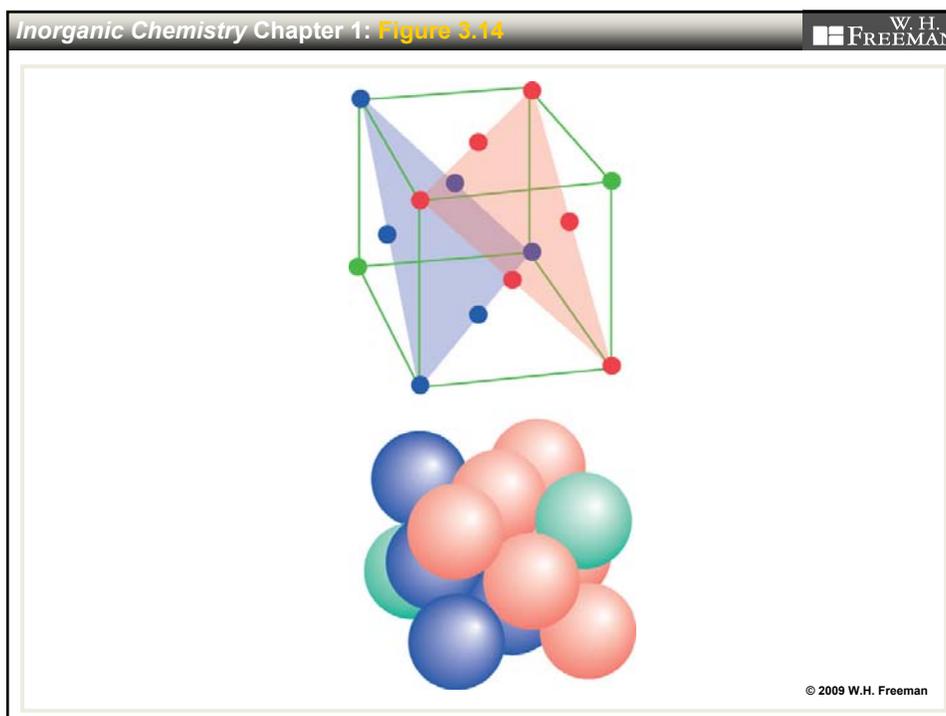
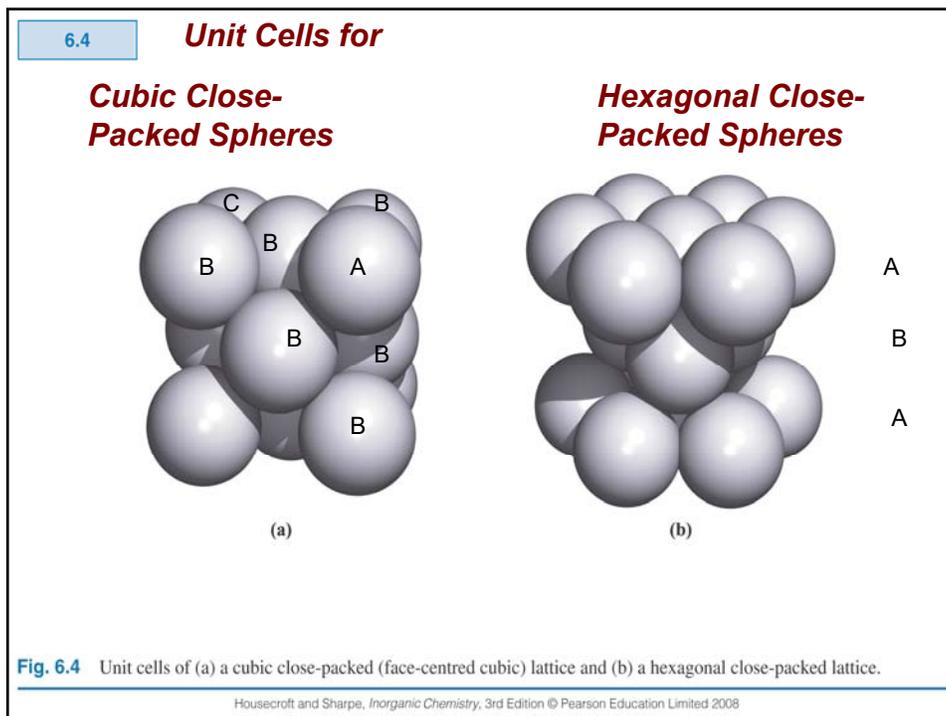


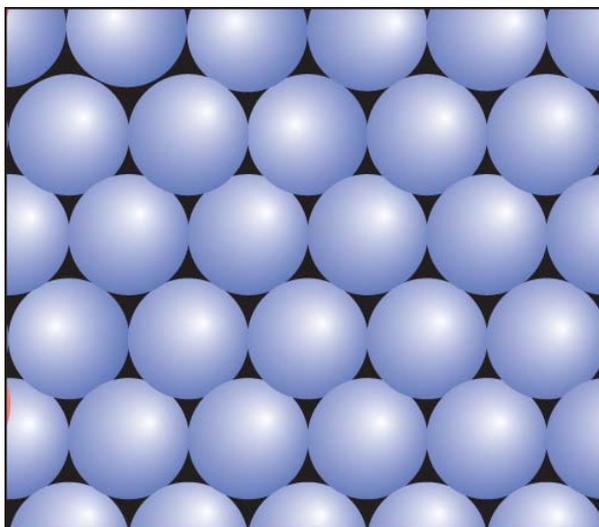
Table 3.2 The crystal structures adopted by metals under normal conditions

Crystal structure	Element
Hexagonal close-packed (hcp)	Be, Ca, Co, Mg, Ti, Zn
Cubic close-packed (ccp)	Ag, Al, Au, Cd, Cu, Ni, Pb, Pt
Body-centred cubic (bcc)	Ba, Cr, Fe, W, alkali metals
Primitive cubic (cubic-P)	Po

What are the characteristics of the metals that might be correlated with their crystal structures?

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Filling Holes in Close Packings

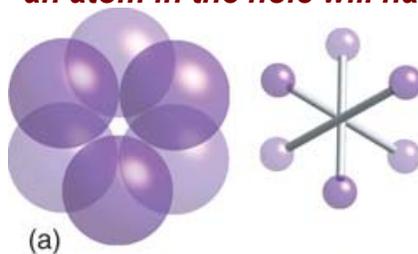


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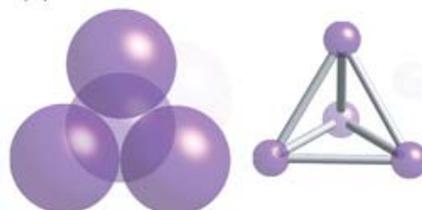
CHAPTER 3: FIGURE 3.17

**An Octahedral Hole and a Tetrahedral Hole:
an atom in the hole will have**

Coordination
No. of 6.



(a)

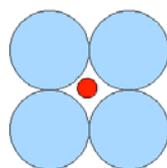


(b)

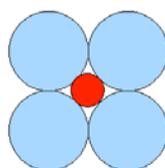
Coordination
No. of 4.

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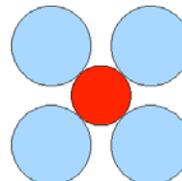
Unstable



Stability Limit



Stable



● Anion

● Cation

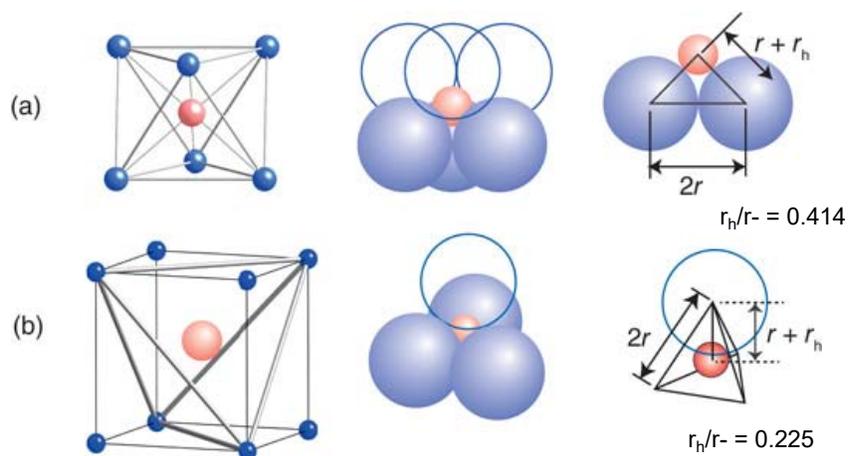
- Stability limit for Oh hole is 0.414*

*This is the radius ratio of hole size to size of sphere.

**The larger the radius ratio, the larger the size of the cation
and hence the larger the coordination number should be.**

CHAPTER 3: FIGURE 3.19

Radius Ratios are guides to matches of hole size and spheres.



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Inorganic Chemistry Chapter 1: Table 4.6

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**Prediction of structures of ionic salts from
Radius Ratios: (r_+/r_-)**

Table 3.6 The correlation of structural type with radius ratio

Radius ratio (γ)	CN for 1:1 and 1:2 stoichiometries	Binary AB structure type	Binary AB ₂ structure type
1	12	None known	None known
0.732–1	8:8 and 8:4	CsCl	CaF ₂
0.414–0.732	6:6 and 6:3	NaCl (ccp), NiAs (hcp)	TiO ₂
0.225–0.414	4:4	ZnS (ccp and hcp)	

CN denotes coordination number.

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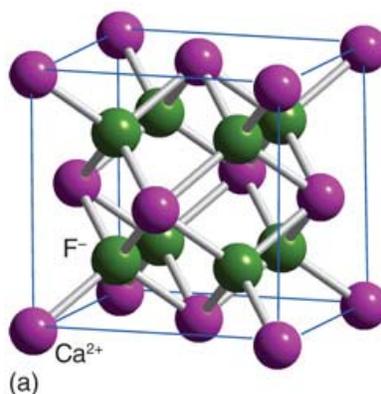
Table 6.8 Limiting radius ratios for five common ionic lattices

Lattice Type	R.R. = r_+/r_-	1/R.R. r_-/r_+
1:1 Stoichiometry		
Zinc blende	0.225	4.44
Rock salt	0.414	2.41
Cesium chloride	0.732	1.37
1:2 Stoichiometry		
Rutile	0.414	2.41
Fluorite	0.732	1.37

Rutile: Titanium Dioxide—most common natural form
 Fluorite: Calcium Fluoride

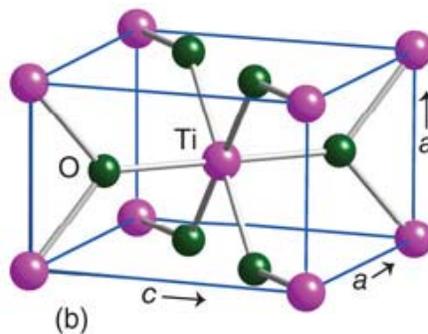
CHAPTER 3: FIGURE 3.38

The Calcium Fluoride, CaF_2 , or fluorite structure Ccp with all Td holes filled.



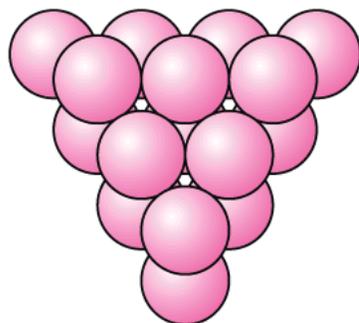
CHAPTER 3: FIGURE 3.39

The Rutile Structure: TiO_2
hcp with $\frac{1}{2}$ Oh holes filled



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Filling Holes in Close Packings



Close-packed arrays possess an equal number of octahedral "holes" and twice as many tetrahedral "holes".

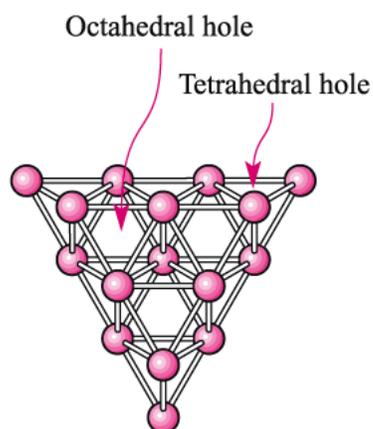


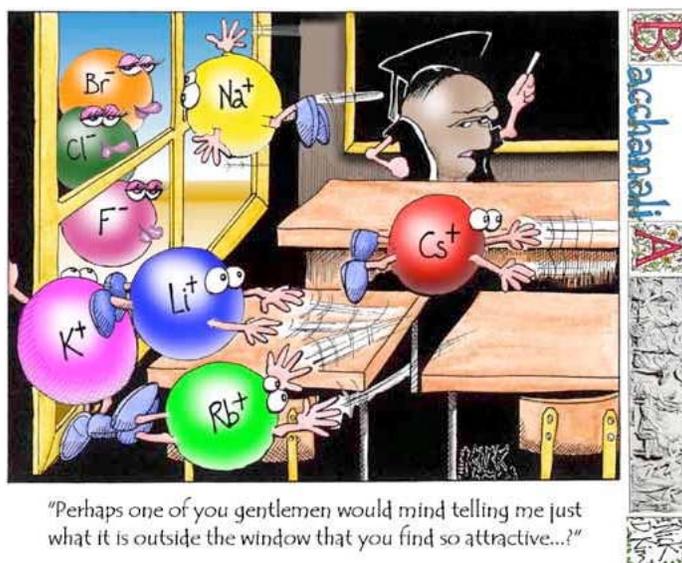
Table 6.9 Calculated versus observed structures of salts, based on radius ratios

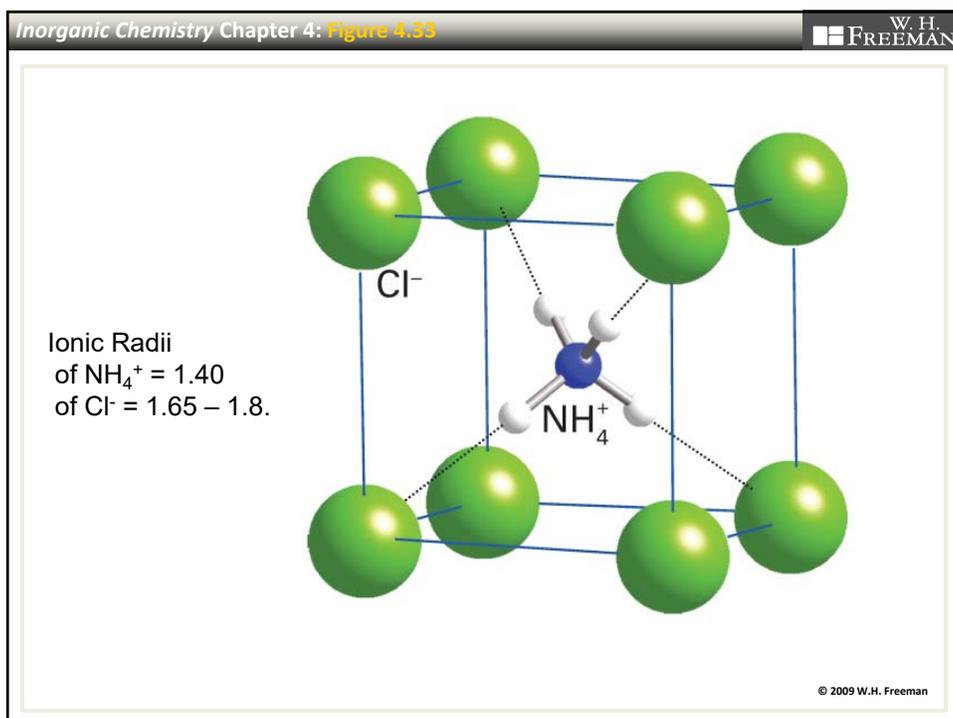
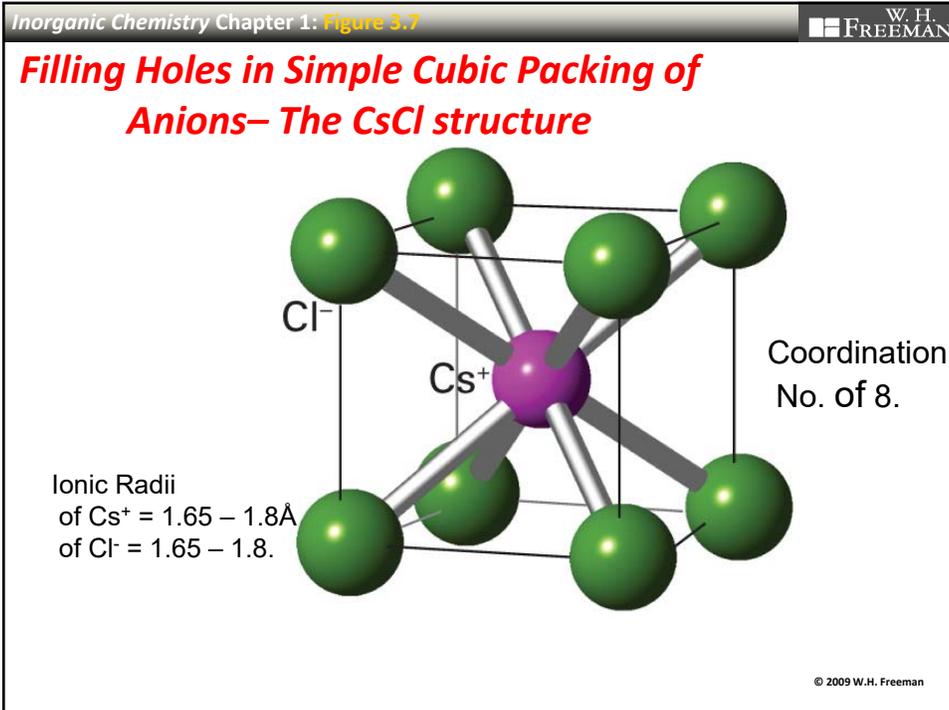
Compound	R.R.	Lattice Type		Compound	R.R.	Lattice Type	
		Predicted	Observed			Predicted	Observed
LiF	0.76	CsCl	NaCl	CsF	(0.66)	NaCl	NaCl
LiCl	0.54	NaCl	NaCl	CsCl	(0.93)	CsCl	CsCl
LiBr	0.49	NaCl	NaCl	CsBr	0.99	CsCl	CsCl
LiI	0.44	NaCl	NaCl	CsI	0.88	CsCl	CsCl
NaF	0.97	CsCl	NaCl	BeO	0.47	NaCl	ZnS
NaCl	0.69	NaCl	NaCl	BeS	0.35	ZnS	ZnS
NaBr	0.64	NaCl	NaCl	MgO	0.68	NaCl	NaCl
NaI	0.56	NaCl	NaCl	MgS	0.51	NaCl	NaCl
KF	(0.78)	CsCl	NaCl	CaO	0.90	CsCl	NaCl
KCl	0.91	CsCl	NaCl	CaS	0.67	NaCl	NaCl
KBr	0.84	CsCl	NaCl	AlP	0.32	ZnS	ZnS
KI	0.74	CsCl	NaCl	TlCl	0.98	CsCl	CsCl
RbF	(0.72)	NaCl	NaCl	ZnS	0.52	NaCl	ZnS
RbCl	0.99	CsCl	NaCl	CdS	0.64	NaCl	ZnS
RbBr	0.91	CsCl	NaCl	HgS	0.68	NaCl	ZnS
RbI	0.81	CsCl	NaCl				

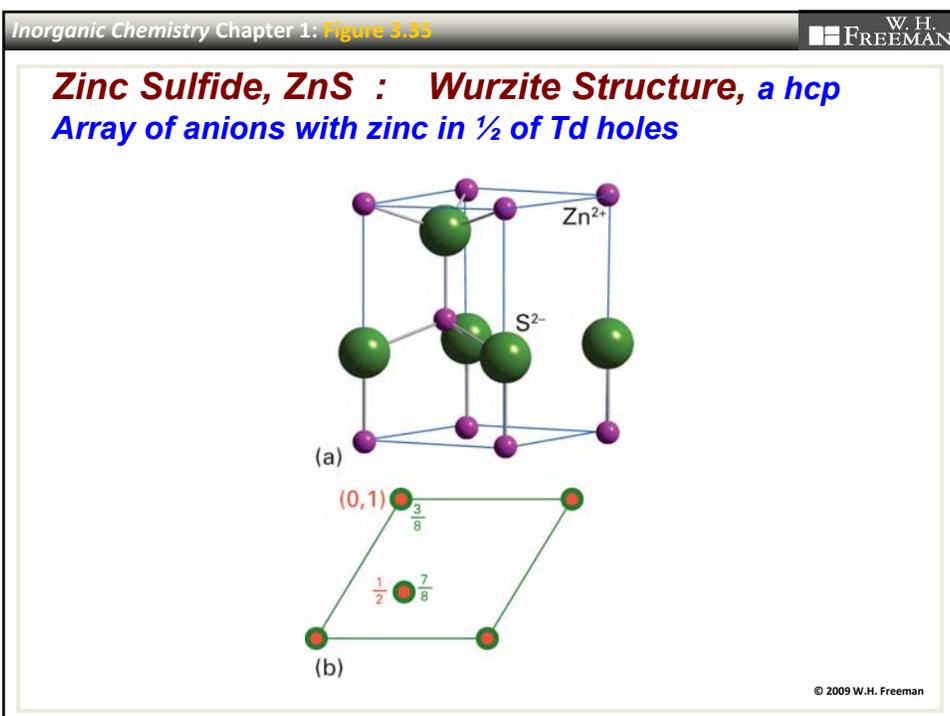
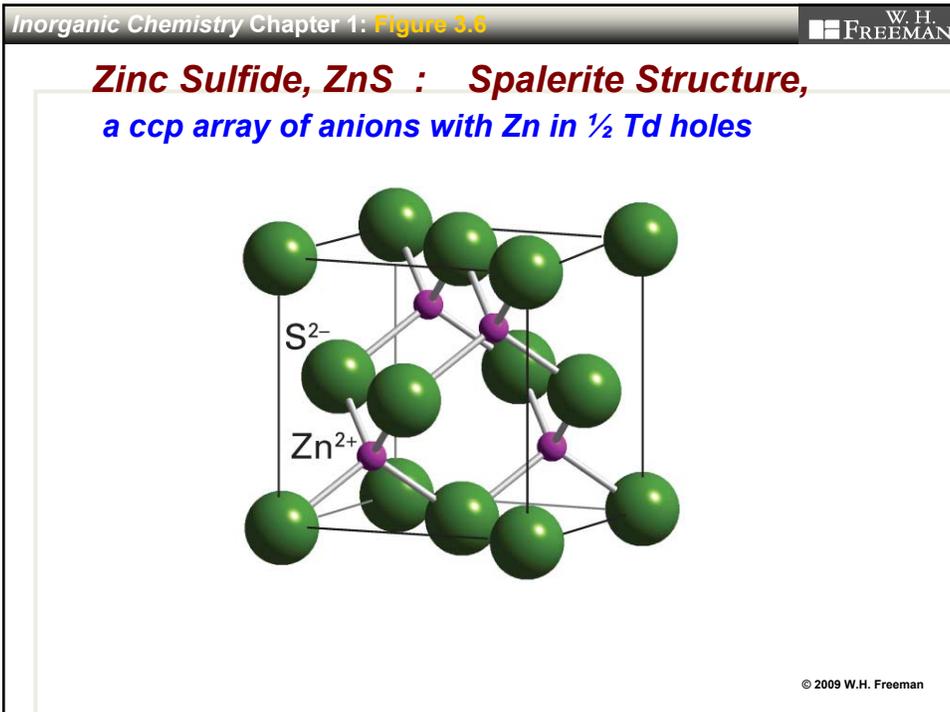
Note: Values in parentheses correspond to $1/R.R. = r_-/r_+$.

Source: Nathan, L. C. *J. Chem. Educ.* 1985, 62, 215.

NaCl structure particularly stable!

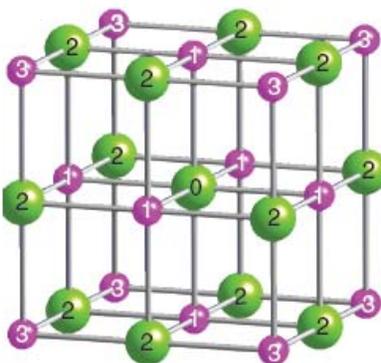






CHAPTER 3: FIGURE B3.5

**Filling Holes in Cubic Close Packing of Anions—
The NaCl structure type: All Oh holes are filled**



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Inorganic Chemistry Chapter 1: Table 3.5

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Table 3.5 The relation of structure to the filling of holes

Close-packing type	Hole filling	Structure type (exemplar)
Cubic (ccp)	All octahedral	Rock salt (NaCl)
	All tetrahedral	Fluorite (CaF ₂)
	Half octahedral	CdCl ₂
	Half tetrahedral	Sphalerite (ZnS)
Hexagonal (hcp)	All octahedral	Nickel arsenide (NiAs); with some distortion from perfect hcp CdI ₂
	Half octahedral	Rutile (TiO ₂); with some distortion from perfect hcp
	All tetrahedral	No structure exists: tetrahedral holes share faces
	Half tetrahedral	Wurtzite (ZnS)

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Inorganic Chemistry Chapter 1: **Table 3.4** W. H. FREEMAN

Table 3.4 The crystal structures of compounds

Crystal structure	Example*
Antifluorite	K_2O , K_2S , Li_2O , Na_2O , Na_2Se , Na_2S
Caesium chloride	$CsCl$, TlI , $CsAu$, $CsCN$, $CuZn$, NbO
Fluorite	CaF_2 , UO_2 , HgF_2 , LaH_2 , PbO_2
Nickel arsenide	$NiAs$, NiS , FeS , $PtSn$, CoS
Perovskite	$CaTiO_3$ (distorted), $SrTiO_3$, $PbZrO_3$, $LaFeO_3$, $LiSrH_3$, $KMnF_3$
Rock salt	$NaCl$, KBr , RbI , $AgCl$, $AgBr$, MgO , CaO , TiO , FeO , NiO , $SnAs$, $LiCl$, ScN
Rutile	TiO_2 , MnO_2 , SnO_2 , WO_2 , MgF_2 , NiF_2
Sphalerite (zinc blende)	ZnS , $CuCl$, CdS , HgS , GaP , $InAs$
Spinel	$MgAl_2O_4$, $ZnFe_2O_4$, $ZnCr_2S_4$
Wurtzite	ZnS , ZnO , BeO , MnS , AgI , AlN , SiC , NH_4F

*The substance in bold type is the one that gives its name to the structure.

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Ionic bonding: ionic solids*

- Observations: Types of Crystals
Close Packing of Spheres
- Radius Ratios for Ions Tucked into Holes
- Experimental Lattice Energies from Thermodynamics: Born-Haber Cycle**
- Theoretical from (Coulombic) Interactions

Metallic bonding: metallic solids*

- Observations: Structural Types
Close Packing of Spheres
- Metal-metal bonding in extended structures
- HOMO-LUMO gaps and Semi-conductors
- Types of Alloys

Weak intermolecular bonding, which forms molecular solids*

Close Packing of Spheres;

Energetics of Ionic Bonding: Lattice Energy

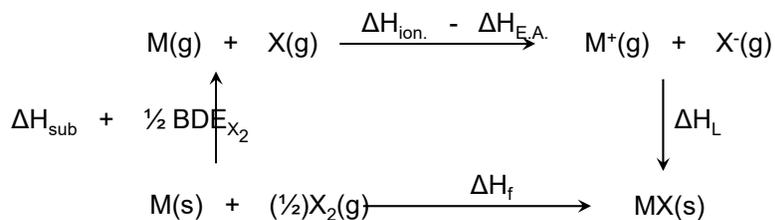
ΔH_L : Enthalpy for separation of salt to ions



How to experimentally measure?

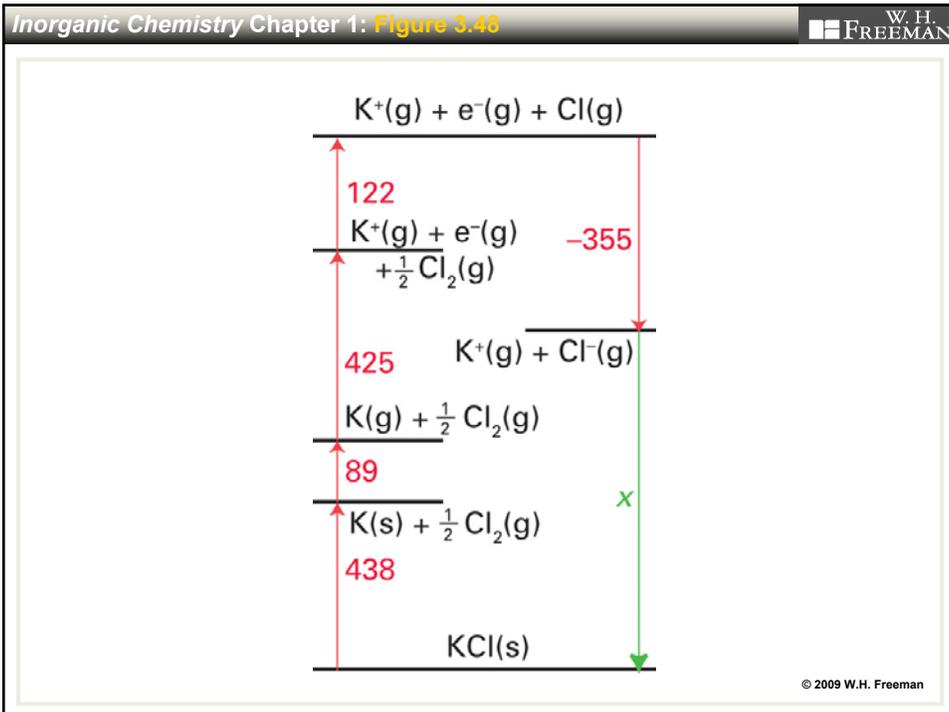
Use a Thermodynamic Cycle

Thermochemical (Born-Haber) Cycle



Values for NaCl (kJ/mol)

ΔH_{sub} : Sublimation Enthalpy of Metal (298 K)	108
$\frac{1}{2} \text{BDE}_{\text{X}_2}$: Dissociation Energy of X_2 bond (298 K)	242
$\Delta H_{\text{ion.}}$: Ionization Enthalpy of Metal M	496
$\Delta H_{\text{E.A.}}$: Electron Affinity Enthalpy of X atom	349
ΔH_L : Enthalpy for separation of salt to ions	
ΔH_f : Enthalpy of formation from elements	



Inorganic Chemistry Chapter 1: Table 3.7

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Table 3.7 Lattice enthalpies of some simple inorganic solids

Compound	Structure type	$\Delta H_{\text{f}}^{\text{exp}} / (\text{kJ mol}^{-1})$	Compound type	Structure	$\Delta H_{\text{f}}^{\text{exp}} / (\text{kJ mol}^{-1})$
LiF	Rock salt	1030	SrCl ₂	Fluorite	2125
LiI	Rock salt	757	LiH	Rock salt	858
NaF	Rock salt	923	NaH	Rock salt	782
NaCl	Rock salt	786	KH	Rock salt	699
NaBr	Rock salt	747	RbH	Rock salt	674
NaI	Rock salt	704	CsH	Rock salt	648
KCl	Rock salt	719	BeO	Wurtzite	4293
KI	Rock salt	659	MgO	Rock salt	3795
CsF	Rock salt	744	CaO	Rock salt	3414
CsCl	Caesium chloride	657	SrO	Rock salt	3217
CsBr	Caesium chloride	632	BaO	Rocksalt	3029
CsI	Caesium chloride	600	Li ₂ O	Antifluorite	2799
MgF ₂	Rutile	2922	TiO ₂	Rutile	12150
CaF ₂	Fluorite	2597	CeO ₂	Fluorite	9627

Consequences of Lattice Enthalpies

- Electrostatic component stabilizing ionic solids gives us

$$\text{Lattice energy} \propto \frac{[Z_A \cdot Z_B]}{d} \rightarrow \text{lattice spacing}$$

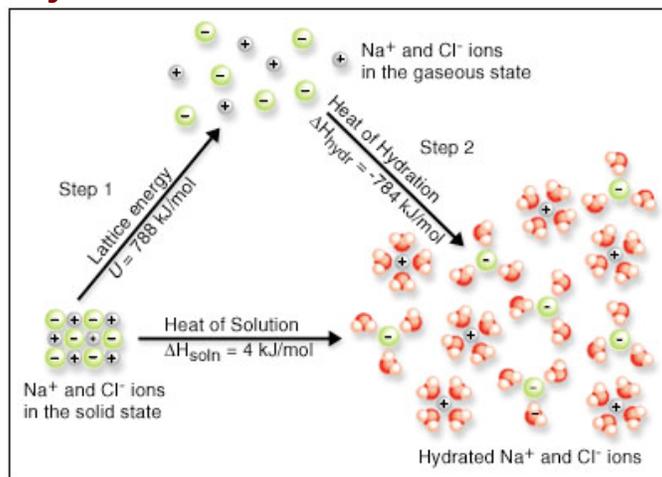
- ◆ Thermal stabilities: “Large Cations stabilize large Anions”.

Effects of charge and size on lattice energies reflected in melting points

melting points (°C)

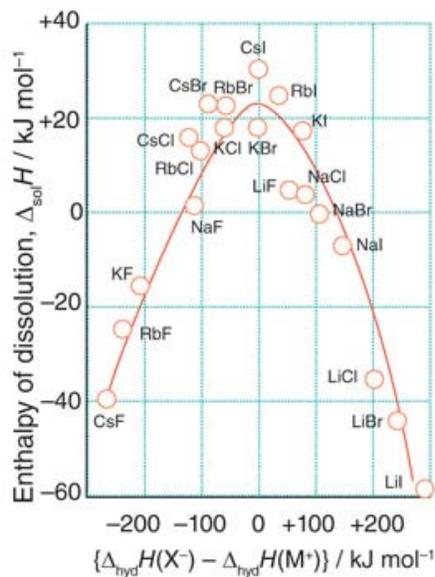
NaF	993	CaF ₂	1423	MgO	2800
NaCl	801	SrCl ₂	872	CaO	2580
NaBr	747	Li ₂ O	>1700	SrO	2430
KCl	770	Na ₂ O	1275 (subl)	BaO	1923

Consequences of Lattice Energies: Solubility

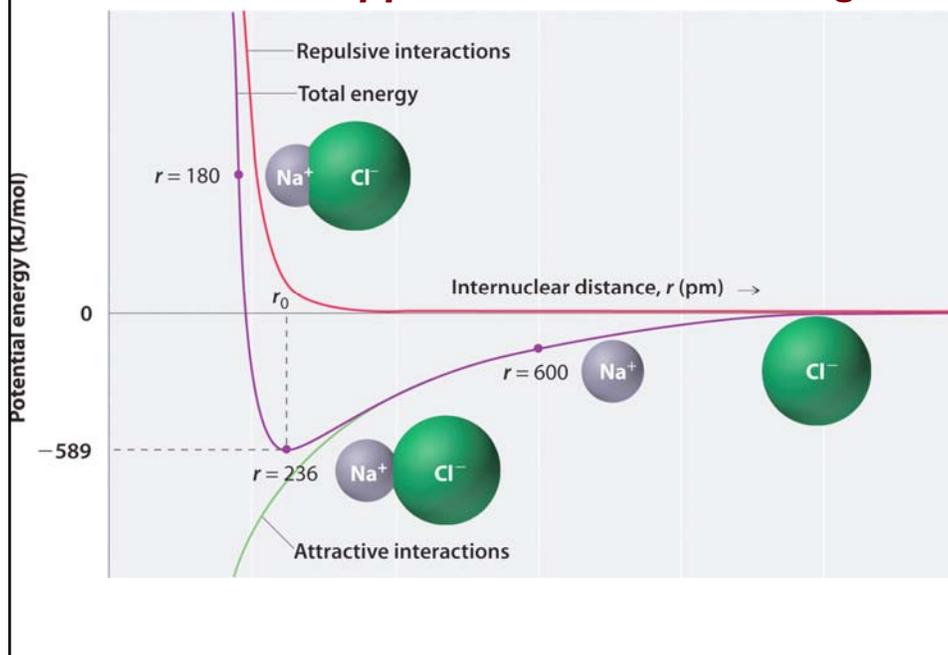


Rule: Compounds that contain ions of widely different radii are generally Soluble in water (typically radius of M⁺ < radius of X⁻ by 0.8Å)

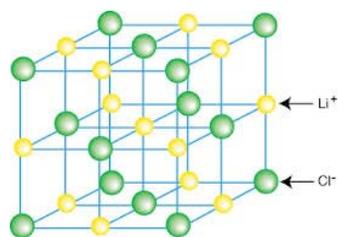
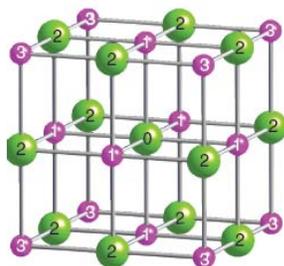
CHAPTER 3: FIGURE 3.51



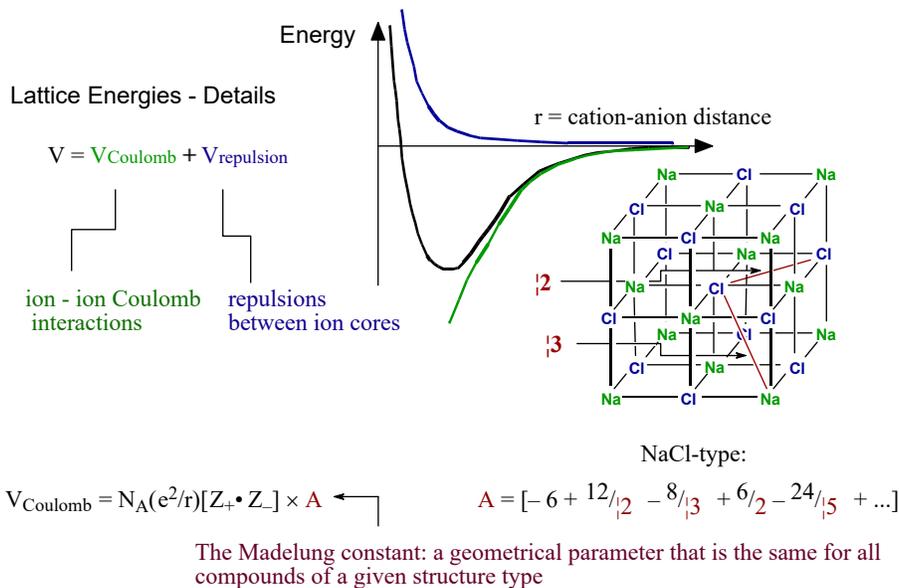
Theoretical Approach to Lattice Energies



CHAPTER 3: FIGURE B3.5



Theoretical Approach to Lattice Energies



Theoretical Derivation of Lattice Energy, $E_L \Rightarrow U$

The attractive potential of an ion pair (+/-) at distance r is

$$E_c = \frac{z_+ z_- e^2}{r}$$

In a crystal lattice there will be more interactions (attractive, repulsive) than in a single ion pair:

$$E_c = \frac{Az_+ z_- e^2}{r}$$

Madelung constant

For a mol of ion pairs, including the Born term for repulsion between e^- clouds of close ions,

$$E = E_c + E_{\text{rep}} \quad E = \frac{NAz_+ z_- e^2}{r} + \frac{NB}{r^n}$$

constant
characteristic of cation/anion, evaluated from crystal compressibility

Equilibrium ion separation (r_e) is determined by a balance of electrostatic attraction and repulsion:

$$\left(\frac{dE}{dr}\right)_{r=r_e} = 0 = \frac{-NAz_+ z_- e^2}{r_e^2} - \frac{nNB}{r_e^{n+1}}$$

Substitution of B gives the Born equation:

$$E_L = \frac{Ne^2 Az_+ z_-}{r_e} \left(1 - \frac{1}{n}\right) \quad E_L = \Delta H_L$$

If $z_+ = +1, z_- = -1, r_e = 3 \text{ \AA}, n = 9, A = 1$

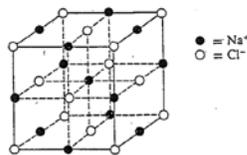
$$E_L = -100 \text{ kcal/mol}$$

evaluation of Madelung constant

example: NaCl

for each ion:

- 6 counterions at r_e
- 12 ions of same charge at $r_e\sqrt{2}$
- 8 counterions at $r_e\sqrt{3}$
- 6 ions of same charge at $2r_e$



$$A = 6 - \frac{12}{\sqrt{2}} + \frac{8}{\sqrt{3}} - \frac{6}{2} + \frac{24}{\sqrt{5}} + \dots \rightarrow 1.748$$

(series converges slowly)

$$E_L = 1.748N \frac{e^2 z_+ z_-}{r_e} \left(1 - \frac{1}{n}\right)$$

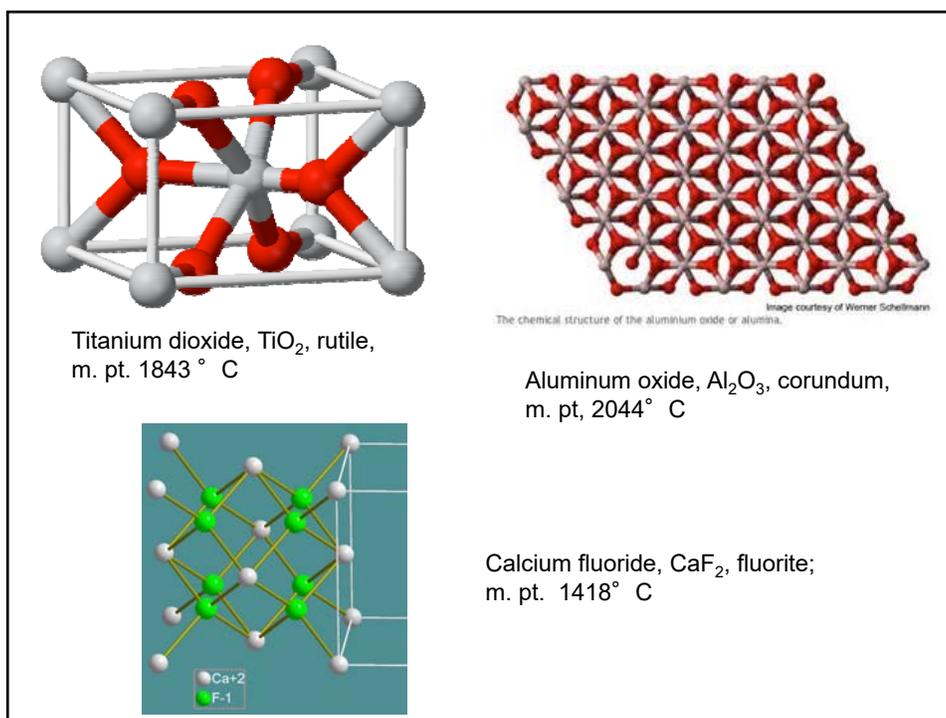
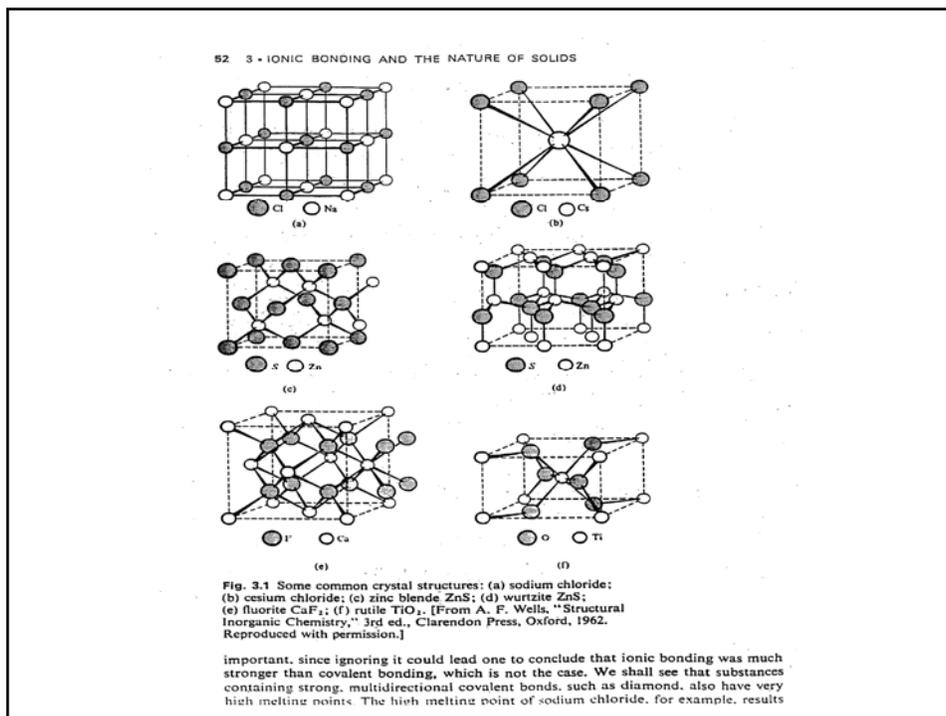
Madelung constants depend solely on the geometry of the crystal.

structure	A
rock-salt	1.748
CsCl	1.763
sphalerite	1.638
wurtzite	1.641
fluorite	2.519
antifluorite	2.519
cuprite	2.221

* Comparison of calculated and experimental lattice enthalpies is an evaluation of the extent of ionic bonding (ionicity) in the crystal.

Table 3.8 Madelung constants

Structural type	A
Caesium chloride	1.763
Fluorite	2.519
Rock salt	1.748
Rutile	2.408
Sphalerite	1.638
Wurtzite	1.641

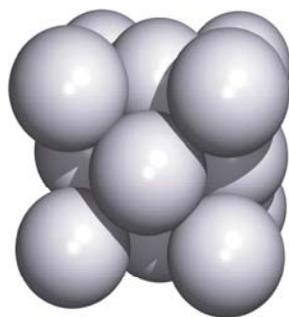


Metals and Semi-Conductors

6.4

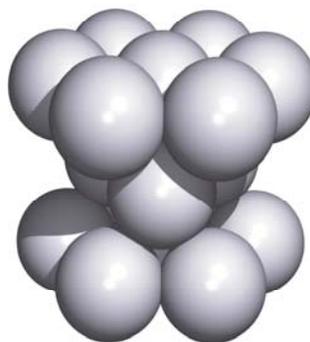
Unit Cells for

Cubic Close-Packed Spheres



(a)

Hexagonal Close-Packed Spheres



(b)

Fig. 6.4 Unit cells of (a) a cubic close-packed (face-centred cubic) lattice and (b) a hexagonal close-packed lattice.

Housecroft and Sharpe, *Inorganic Chemistry*, 3rd Edition © Pearson Education Limited 2008

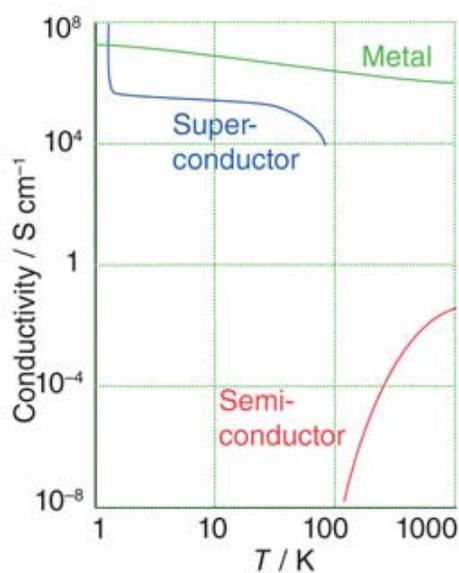
Table 3.2 The crystal structures adopted by metals under normal conditions

Crystal structure	Element
Hexagonal close-packed (hcp)	Be, Ca, Co, Mg, Ti, Zn
Cubic close-packed (ccp)	Ag, Al, Au, Cd, Cu, Ni, Pb, Pt
Body-centred cubic (bcc)	Ba, Cr, Fe, W, alkali metals
Primitive cubic (cubic-P)	Po

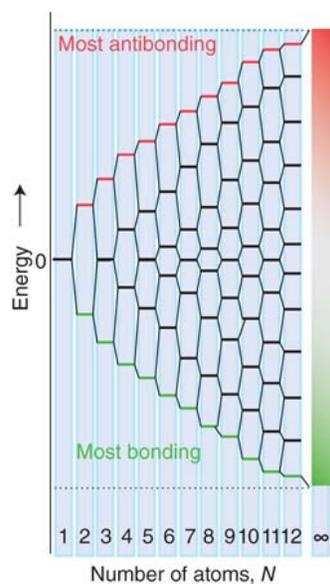
What are the characteristics of the metals that might be correlated with their crystal structures? What is metallic Bonding? Can MO theory describe it? Account for properties?

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CHAPTER 3: FIGURE 3.60

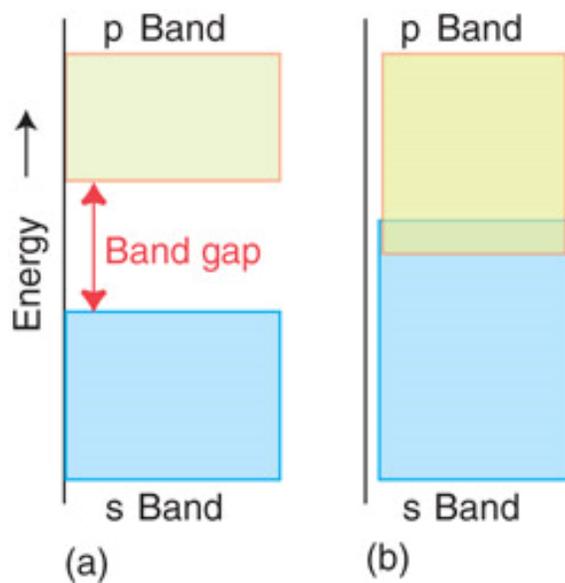


CHAPTER 3: FIGURE 3.63

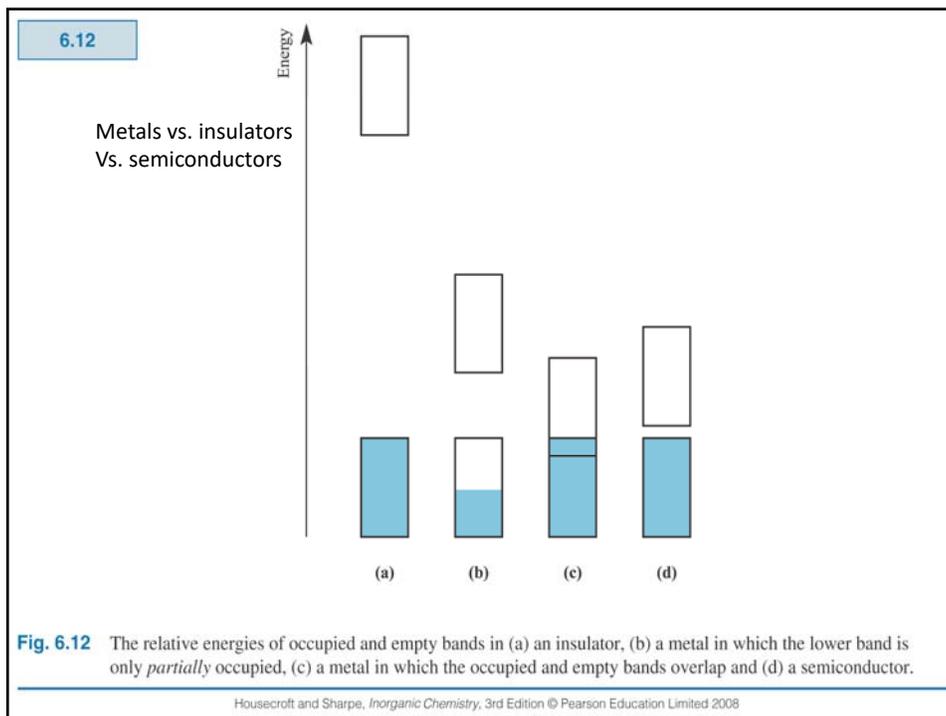


INORGANIC CHEMISTRY 6E | SHRIVER | WELLER | OVERTON | ROURKE | ARMSTRONG
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CHAPTER 3: FIGURE 3.65



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CHAPTER 3: TABLE 3.13

Typical Band Gaps

Material	E_g /eV
Carbon (diamond)	5.47
Silicon carbide	3.00
Silicon	1.11
Germanium	0.66
Gallium arsenide	1.35
Indium arsenide	0.36

Semiconductors

The diagram shows two energy levels: a lower valence band (black) and an upper conduction band (white). An arrow labeled 'Thermal energy' points from the valence band to the conduction band, with the text 'promote e⁻'s' below it. A vertical arrow on the left is labeled 'Energy'.

- Energy from heat (thermal equilibrium), gives (virtually Boltzmann-like) distribution of excited states where some electrons are promoted.
- When electrons have been promoted (heat, light), the material will begin to conduct.

Semiconductors

- If the band gap becomes small enough, some conductivity can be achieved.
- Band gaps:

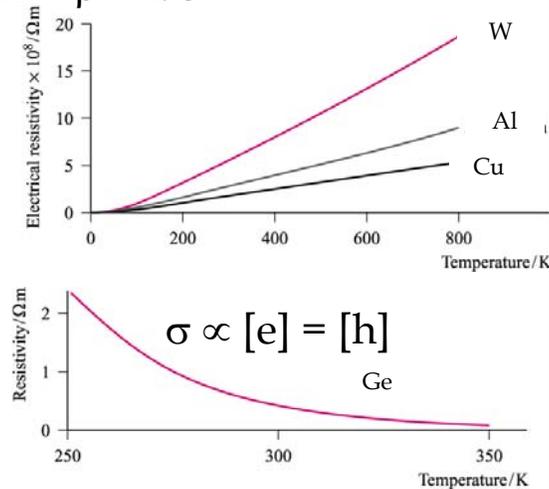
diamond:	580 kJ/mol	($\lambda \sim 206$ nm)
silicon:	105 kJ/mol	($\lambda \sim 1140$ nm)
germanium:	64 kJ/mol	($\lambda \sim 1870$ nm)
- Pure Si or Ge can conduct at high T or if exposed to light.

<https://www.youtube.com/watch?v=kD1O9B5CUUw>

Metals vs Semiconductors

$$\text{Resistivities} = \rho = 1/\sigma$$

- Metals' resistivities increase with T
- Semiconductors' resistivities decrease with T
- However, note the huge difference in scales on these plots!



“Intrinsic” (pure, undoped) Semiconductors

- Moderate band gaps - conductivity is low but increases with temperature:

$$[e][h] = K_{\text{eq}} = e^{-\Delta G^\circ/RT} = (e^{\Delta S^\circ/R})e^{-\Delta H^\circ/RT}$$

$$\Delta H^\circ \approx \Delta E = E_{\text{gap}} \quad \text{also} \quad [e] = [h]$$

$$[e] = [h] \approx (e^{\Delta S^\circ/2R}) \cdot e^{-E_{\text{gap}}/2RT}$$

- Conductivity is thus an activated process in a pure semiconductor.

$$\Rightarrow \text{Plot } \ln \sigma \text{ vs. } (1/T) \text{ to get slope} = E_{\text{gap}}/2$$

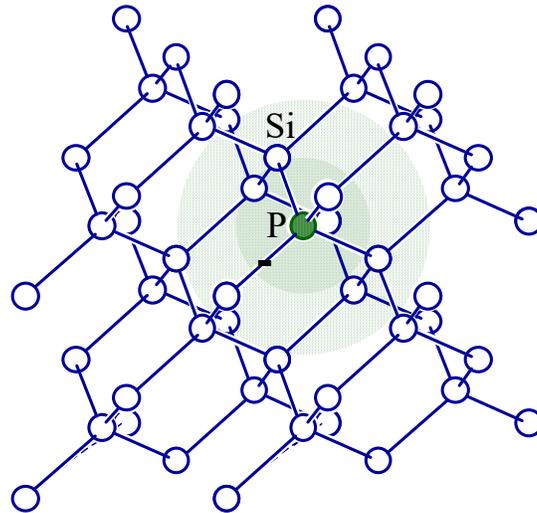
“Extrinsic” (Doped) Semiconductors

- Pure elemental semiconductors (Si, Ge, etc.) are used for devices where light or heat can be supplied to promote electrons.
- More useful devices are made using “doped” semiconductors — appropriate impurities are intentionally added to supply electrons (e.g., P) or holes (e.g., Al) which modify the band gaps and the conductivity can be controlled.

n-Type Semiconductors

- ☒ “Dope” with phosphorus. An electron is “left-over” after forming Si-P bonds.
- The added electrons are easily promoted from the “donor levels” at normal temperatures, so they can serve as charge carriers.
- Typical n-type devices contain on the order of 0.00001% P.

Phosphorus doped into Si: extra electron



n-Type Semiconductors

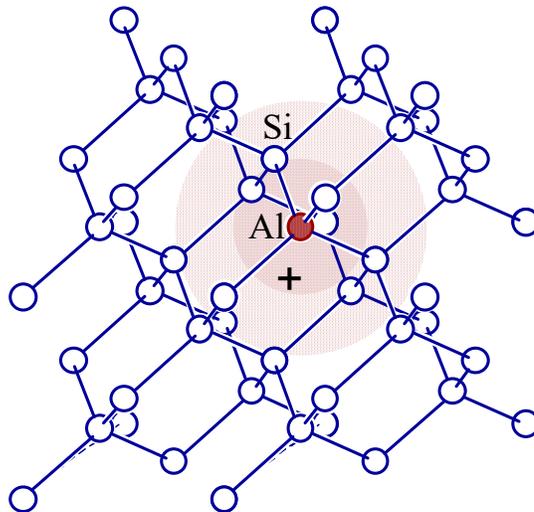


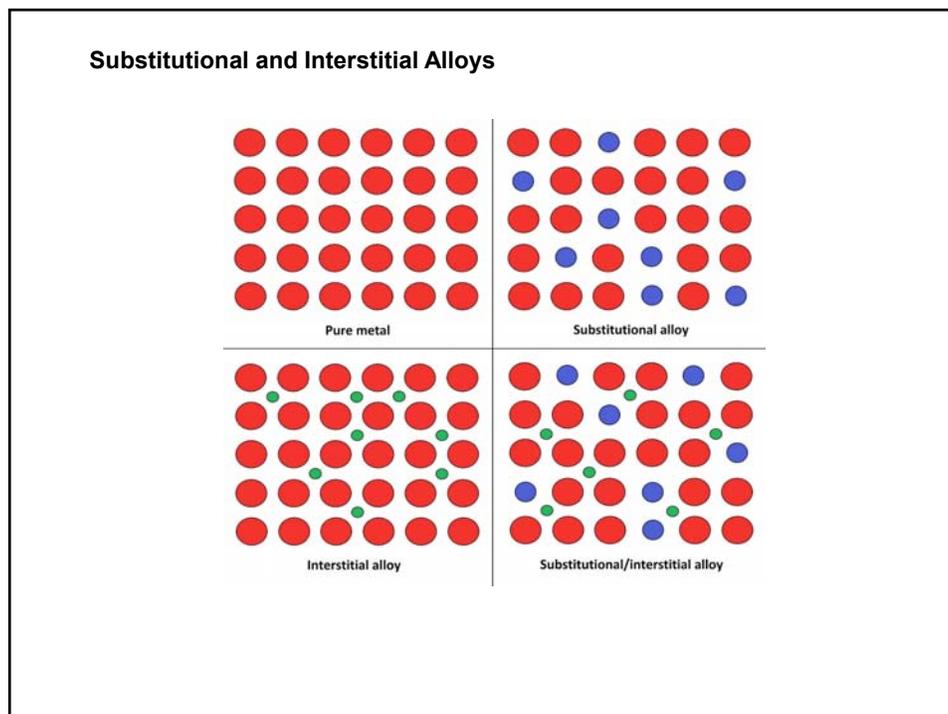
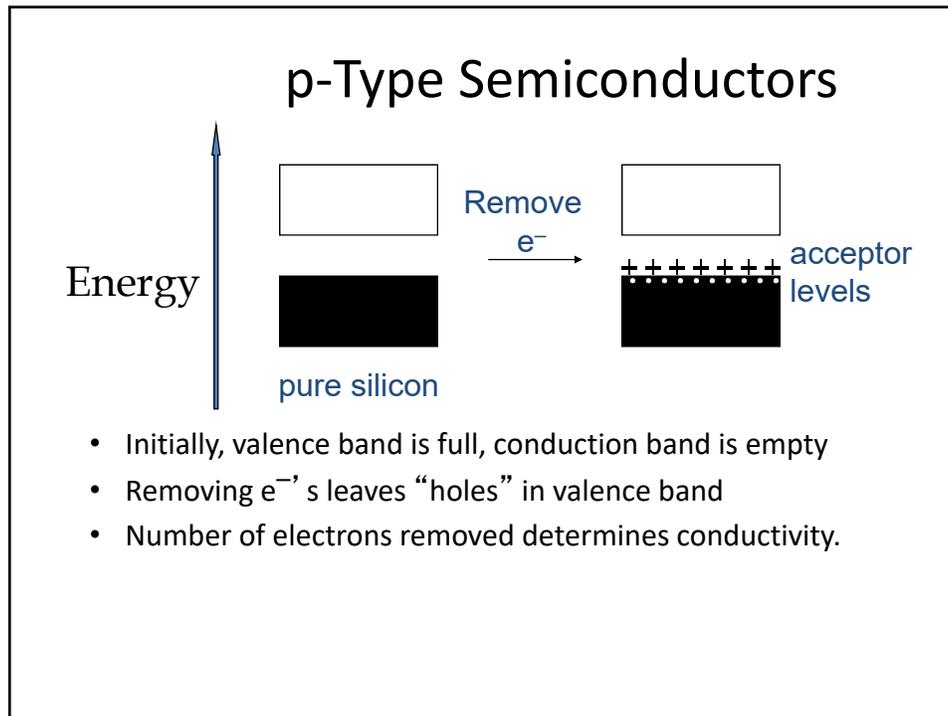
- Initially, valence band is full, conduction band is empty
- Added e^- 's must go in conduction band
- Extent of conductivity depends on # of electrons added.

p-Type Semiconductors

- ☒ “Dope” with aluminum. Formation of Al-Si bonds “steals” an electron from Si.
- The holes allow “places for electrons to move into” within the valence band, so they serve as charge carriers
- Shallow “impurity” levels, as for n-type - electrons easily promoted at normal temperatures.
- Properties of n & p type differ slightly. Most devices contain combinations of both.

Aluminum doped into Si



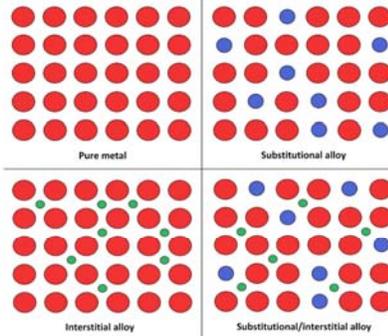


Types of Alloys

Substitutional and interstitial alloys

Examples of substitutional alloys include bronze and brass, in which some of the copper atoms are substituted with either tin or zinc atoms respectively. In the case of the interstitial mechanism, one atom is usually much smaller than the other and can not successfully substitute for the other type of atom in the crystals of the base metal. Instead, the smaller atoms become trapped in the spaces between the atoms of the crystal matrix, called the interstices. This is referred to as an interstitial alloy. Steel is an example of an

interstitial alloy, because the very small carbon atoms fit into interstices of the iron matrix. Stainless steel is an example of a combination of interstitial and substitutional alloys, because the carbon atoms fit into the interstices, but some of the iron atoms are substituted by nickel and chromium atoms.[8]



Alloys—Stainless Steel



Alloys—Brass



Copper with some zinc

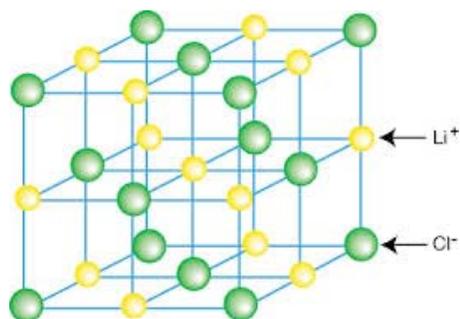
Bronze



Copper with some Tin

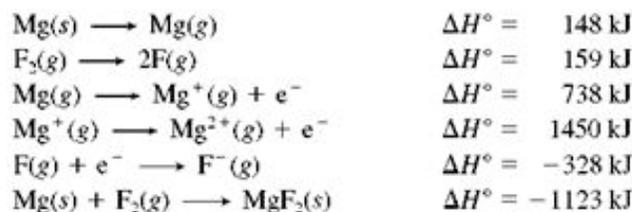
Composition of Alloys

- Bronze - probably the first intentionally created alloy - consists primarily of copper, usually with tin as the main additive: Musical instruments (cymbals), medals
 - Steel consists mostly of iron and has a carbon content between 0.2% and 2.1% by weight: Building, cutlery, surgical equipment
 - Brass consists of copper and zinc, the proportions of which can be varied to create a range of brasses with varying properties: Musical instruments, springs, screws, and rivets
 - Sterling silver (92.5% silver, the rest usually copper): Musical instruments (flute and saxophone), cutlery
 - 10K (or 12K, or 14K, or anything under 24K) gold: Jewelry, police badges
 - Cupronickel nickels are made of nickel and copper, typically 75% copper, 25% nickel: Coinage, e.g. the US five-cent coin
 - Pewter (traditionally 85–99% tin, with the remainder consisting of copper, antimony, bismuth and lead): Tankards, spoons
 - Solder consists of lead and tin, the proportions of which can be varied to create a range of solders. The two most common alloys are 60/40 Sn/Pb and 63/37 Sn/Pb: Used to join together metal pieces in plumbing and electronic/electrical work
 - "Type" metal is an alloy of lead, tin and antimony in different proportions depending on the application. The proportions used are in the range: lead 50–86%, antimony 11–30% and tin 3–20%: Typesetting (part of the printing process) where the molten type metal is injected into a mold that has the shape of one or more letters or characters, these are then used to press ink onto paper
 - Wood's metal is composed of 50% bismuth, 26.7% lead, 13.3% tin, and 10% cadmium: Used by gunsmiths for making castings of firearm chambers



Comparison of Lattice Energies (U in kJ/mol) of Some Salts

Solid	U	Solid	U	Solid	U	Solid	U
LiF	1036	LiCl	853	LiBr	807	LiI	757
NaF	923	NaCl	786	NaBr	747	NaI	704
KF	821	KCl	715	KBr	682	KI	649
MgF ₂	2957	MgCl ₂	2526	MgBr ₂	2440	MgI ₂	2327



ELEMENTS OF A SMARTPHONE

ELEMENTS COLOUR KEY: ● ALKALI METAL ● ALKALINE EARTH METAL ● TRANSITION METAL ● GROUP 13 ● GROUP 14 ● GROUP 15 ● GROUP 16 ● HALOGEN ● LANTHANIDE

SCREEN

In Indium
Sn Tin
O Oxygen

Indium tin oxide is a mixture of indium oxide and tin oxide, used in a transparent film in the screen that conducts electricity. This allows the screen to function as a touch screen.

Al Aluminium
Si Silicon
O Oxygen
K Potassium

The glass used on the majority of smartphones is an aluminosilicate glass, composed of a mix of alumina (Al₂O₃) and silica (SiO₂). This glass also contains potassium ions, which help to strengthen it.

Y Yttrium
La Lanthanum
Tb Terbium
Pr Praseodymium
Eu Europium
Dy Dysprosium
Gd Gadolinium

A variety of Rare Earth Element compounds are used in small quantities to produce the colours in the smartphone's screen. Some compounds are also used to reduce UV light penetration into the phone.

ELECTRONICS

Cu Copper
Ag Silver
Au Gold
Ta Tantalum

Copper is used for wiring in the phone, whilst copper, gold and silver are the major metals from which microelectrical components are fashioned. Tantalum is the major component of micro-capacitors.

Ni Nickel
Dy Dysprosium
Pr Praseodymium
Tb Terbium
Nd Neodymium
Gd Gadolinium

Nickel is used in the microphone as well as for other electrical connections. Alloys including the elements praseodymium, gadolinium and neodymium are used in the magnets in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.

Si Silicon
O Oxygen
Sb Antimony
As Arsenic
P Phosphorus
Ga Gallium

Pure silicon is used to manufacture the chip in the phone. It is oxidised to produce non-conducting regions, then other elements are added in order to allow the chip to conduct electricity.

Sn Tin
Pb Lead

Tin & lead are used to solder electronics in the phone. Newer lead-free solders use a mix of tin, copper and silver.

BATTERY

Li Lithium
Co Cobalt
C Carbon
Al Aluminium
O Oxygen

The majority of phones use lithium ion batteries, which are composed of lithium cobalt oxide as the positive electrode and graphite (carbon) as the negative electrode. Some batteries use other metals, such as manganese, in place of cobalt. The battery's casing is made of aluminium.

CASING

C Carbon
Mg Magnesium
Br Bromine
Ni Nickel

Magnesium compounds are alloyed to make some phone cases, whilst many are made of plastics. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

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