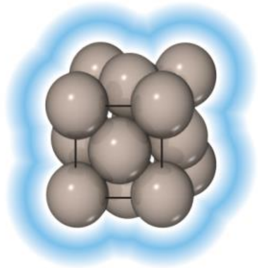
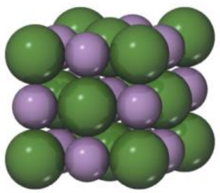
Classifying Solids Based on Bonds

- **Metallic solids** are held together by a “sea” of collectively shared electrons.
- **Ionic solids** are sets of cations and anions mutually attracted to one another.
- **Covalent-network solids** are joined by an extensive network of covalent bonds.
- **Molecular solids** are discrete molecules held together by weak forces.



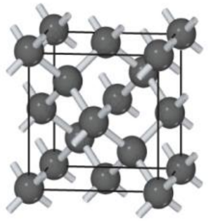
Metallic solids

Extended networks of atoms held together by metallic bonding (Cu, Fe)



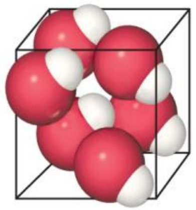
Ionic solids

Extended networks of ions held together by ion–ion interactions (NaCl, MgO)



Covalent-network solids

Extended networks of atoms held together by covalent bonds (C, Si)

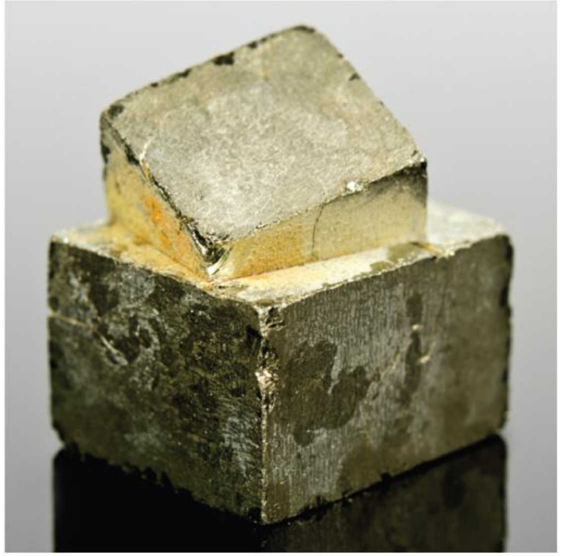


Molecular solids

Discrete molecules held together by intermolecular forces (HBr, H_2O)

One Organization of Solids

- Solids with a regular repeating pattern of atoms are **crystalline**.
- **Amorphous** solids are characterized by a distinct lack of order in the arrangement of atoms.
- Since crystalline solids have a regular pattern, they are of more interest to most chemists.



Iron pyrite (FeS_2), a crystaline solid

Obsidian (typically $KAlSi_3O_8$), an amorphous solid

Two Other Types of Solids

- **Polymers** contain long chains of atoms connected by covalent bonds; the chains can be connected to other chains by weak forces. These molecules have different properties than small molecules or metallic or ionic compounds.
- **Nanomaterials** are crystalline compounds with the crystals on the order of 1–100 nm; this gives them very different properties than larger crystalline materials.

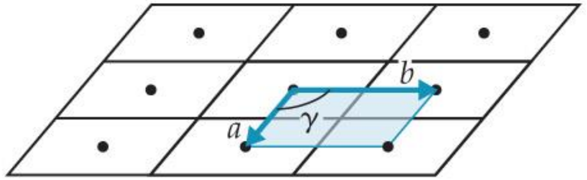
Unit Cell

- The basis of a repeating pattern is the unit cell.
- The structure of a crystalline solid is defined by
  - the size and shape of the unit cell.
  - the locations of atoms within the unit cell.

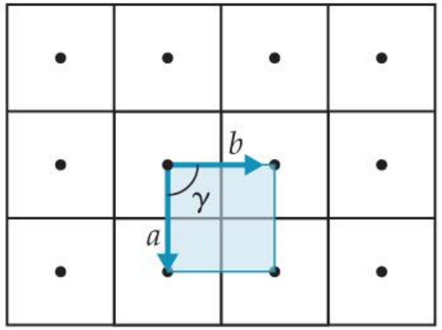
Lattice Points

- Positions that define the overall structure of the crystalline compound are called **lattice points**.
- Each lattice point has an identical environment.
- **Lattice vectors** connect the points and define the unit cell.
- The next slide shows how this works for five different two-dimensional lattices.

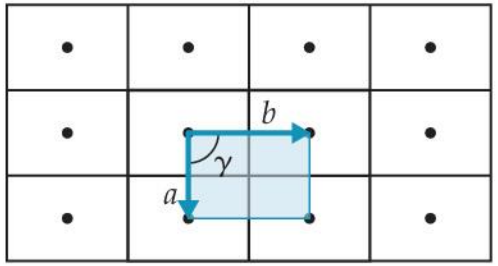
2-D Lattices



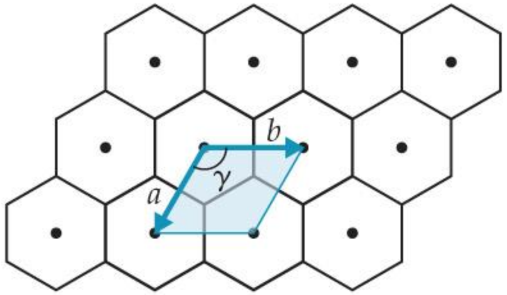
Oblique lattice ($a \neq b$, γ = arbitrary)



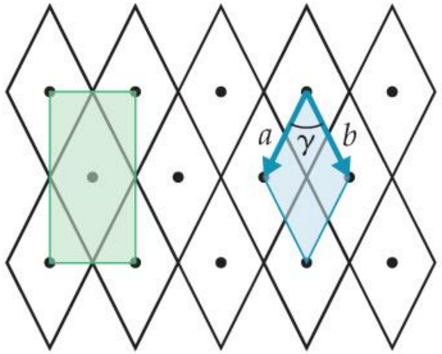
Square lattice ($a = b$, $\gamma = 90°$)



Rectangular lattice ($a \neq b$, $\gamma = 90°$)



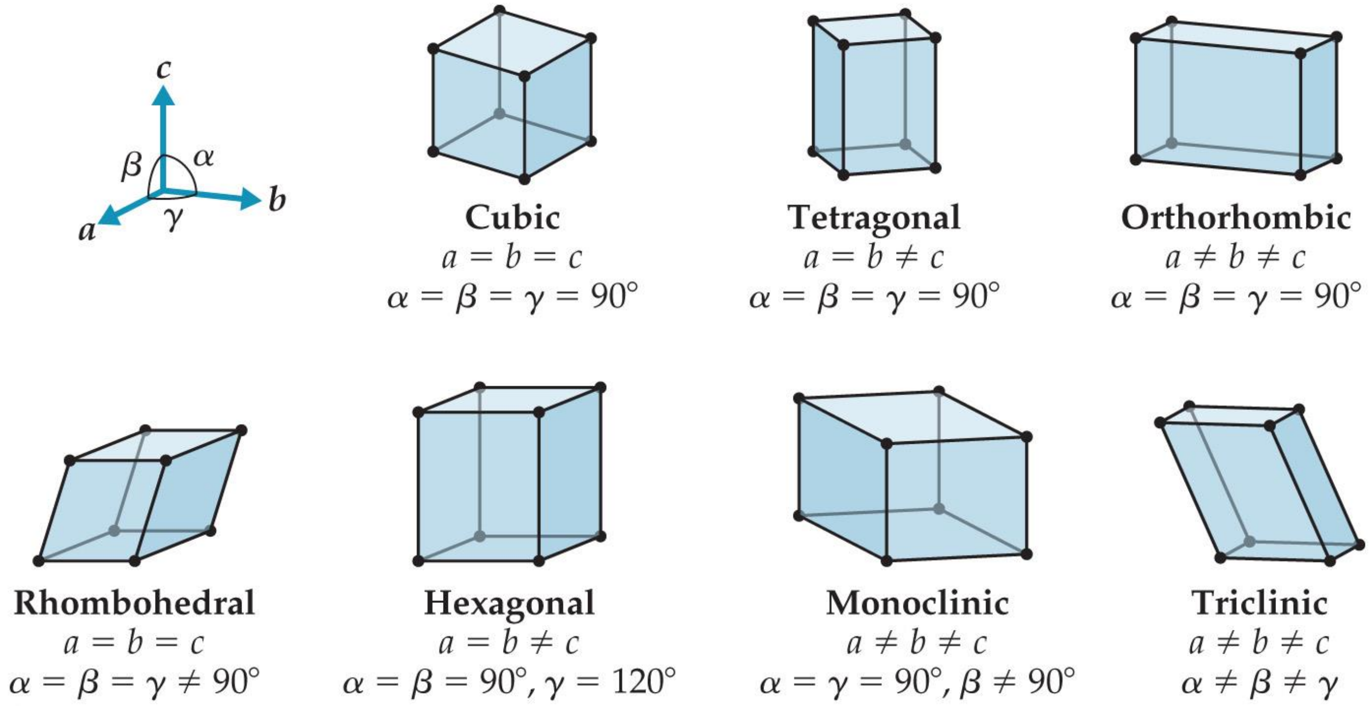
Hexagonal lattice ($a = b$, $\gamma = 120°$)



Rhombic lattice ($a = b$, γ = arbitrary)
Centered rectangular lattice

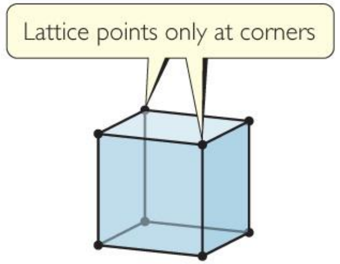
3-D Crystal Lattices

- There are seven basic three-dimensional lattices: cubic, tetragonal, orthorhombic, rhombohedral, hexagonal, monoclinic, and triclinic.

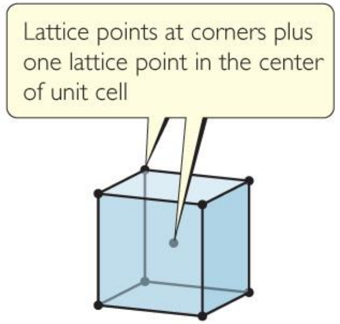


Primitive vs. Centered Lattices

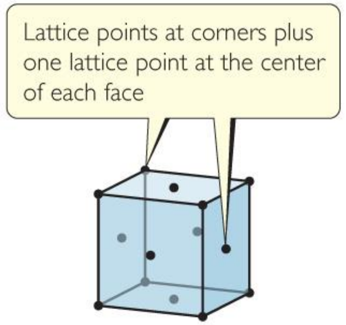
- **Primitive lattices** have atoms *only* in the lattice points.
- **Centered lattices** have atoms in another regular location, most commonly the **body-center** or the **face-center**.



Primitive cubic lattice



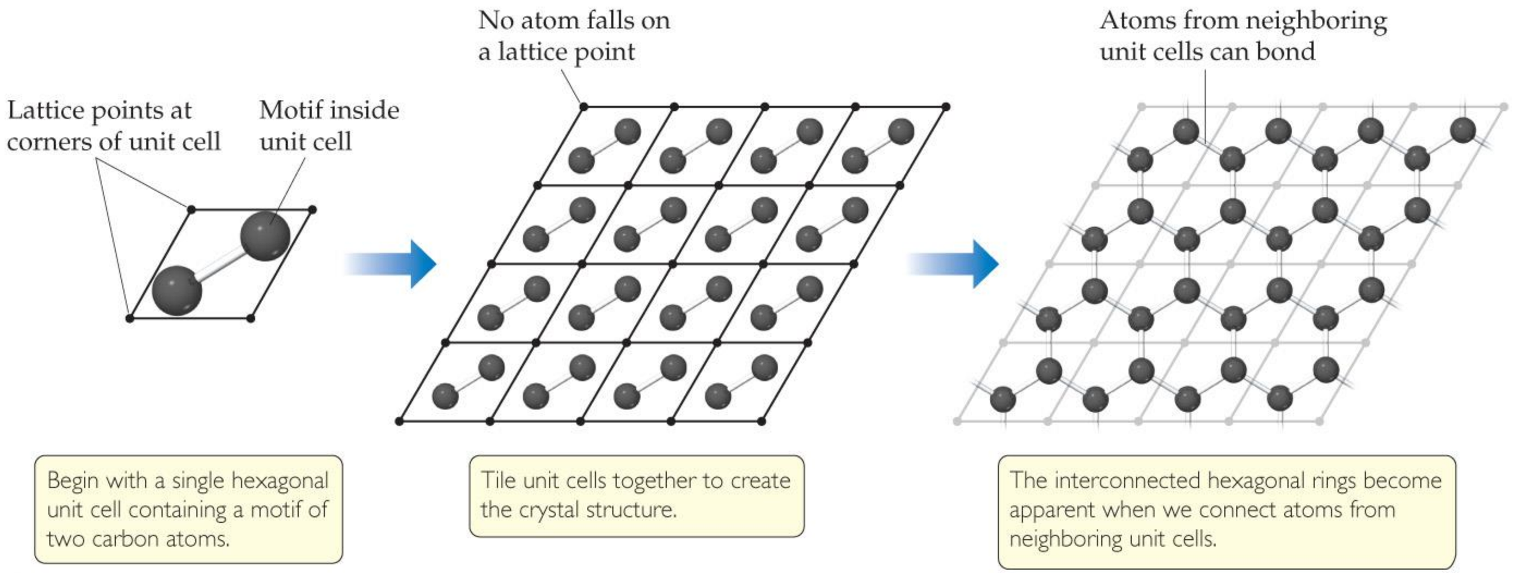
Body-centered cubic lattice



Face-centered cubic lattice

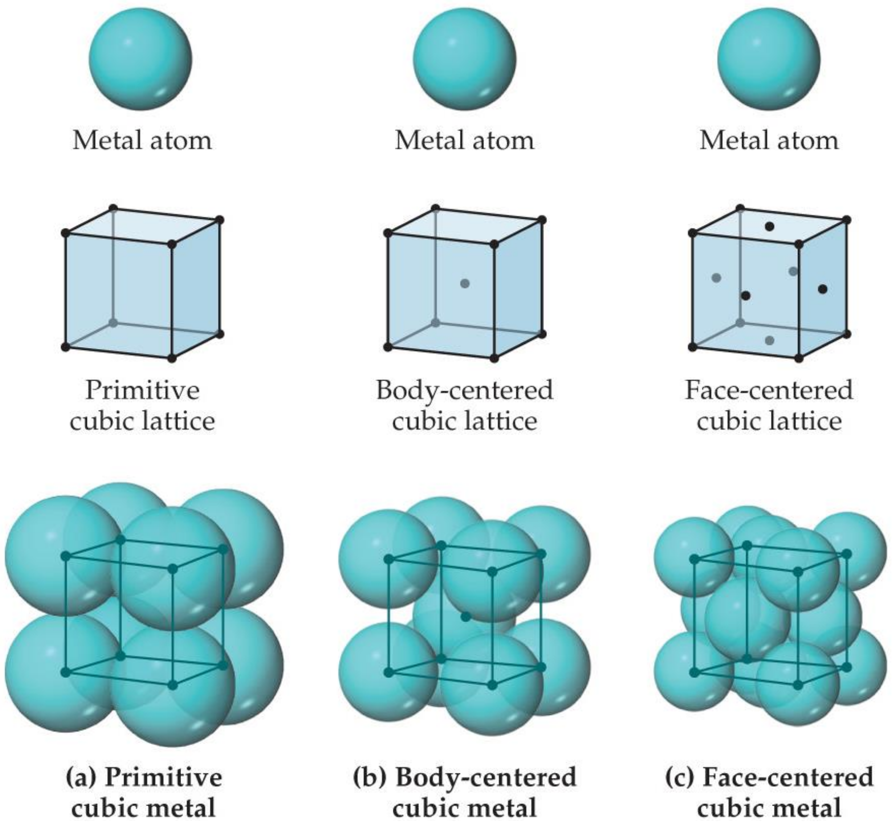
Motifs

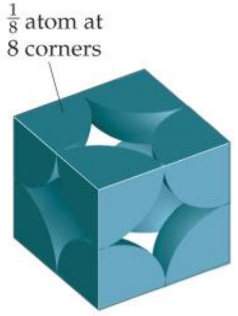
Sometimes, the atoms are *not* on the lattice points, but the overall structure follows a particular unit cell. The groups of atoms that define the overall structure is called a **motif**.



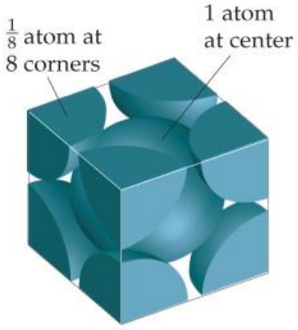
Metallic Structure

- The structures of many metals conform to one of the cubic unit cells: simple cubic, body-centered cubic, or face-centered cubic.

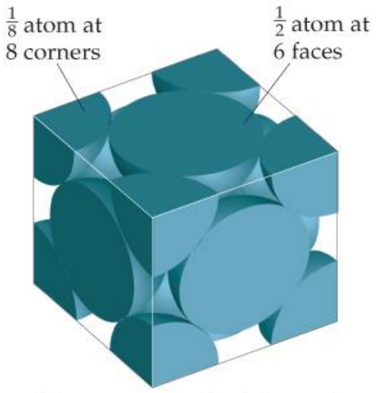




(a) Primitive cubic metal
1 atom per unit cell



(b) Body-centered cubic metal
2 atoms per unit cell

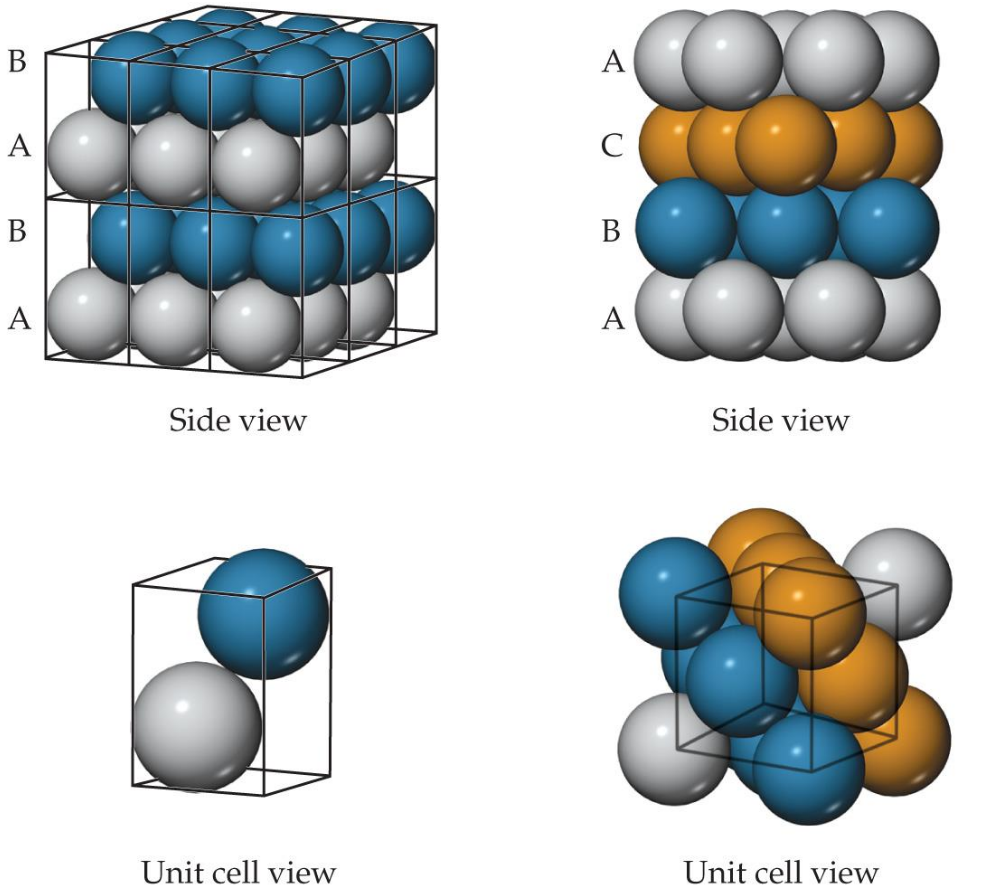


(c) Face-centered cubic metal
4 atoms per unit cell

Cubic Structures

- Not every part of an atom on a lattice point is completely within that unit cell. One can determine how many atoms are within each unit cell.
- Eight cubes meet at a corner, therefore only 1/8 of that corner atom is within any one unit cell meeting there.
- Two cubes meet at a face, therefore only 1/2 of that face atom is within any one unit cell meeting there.
- A body-centered atom is entirely within the unit cell.

Close Packing



(a) Hexagonal close-packed metal (b) Cubic close-packed metal

- Nature does not like empty space!
- The atoms in a crystal pack as close together as they can.
- The two common types of packing seen are
  - cubic close-packed.
  - hexagonal close-packed.

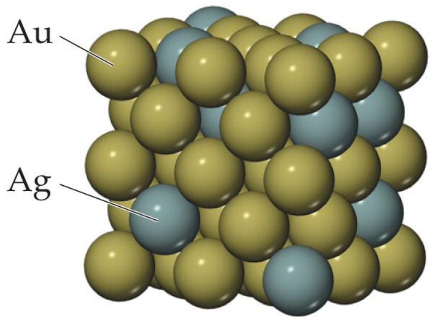
Alloys

- **Alloys** are materials that contain more than one element and have the characteristic properties of metals.
- It is an important means employed to change the properties of certain metals.

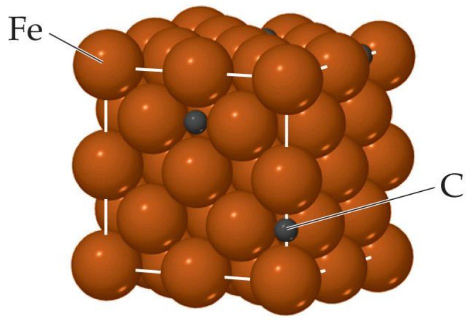
Table 12.2 Some Common Alloys

Name	Primary Element	Typical Composition (by Mass)	Properties	Uses
Wood's metal	Bismuth	50% Bi, 25% Pb, 12.5% Sn, 12.5% Cd	Low melting point (70 °C)	Fuse plugs, automatic sprinklers
Yellow brass	Copper	67% Cu, 33% Zn	Ductile, takes polish	Hardware items
Bronze	Copper	88% Cu, 12% Sn	Tough and chemically stable in dry air	Important alloy for early civilizations
Stainless steel	Iron	80.6% Fe, 0.4% C, 18% Cr, 1% Ni	Resists corrosion	Cookware, surgical instruments
Plumber's solder	Lead	67% Pb, 33% Sn	Low melting point (275 °C)	Soldering joints
Sterling silver	Silver	92.5% Ag, 7.5% Cu	Bright surface	Tableware
Dental amalgam	Silver	70% Ag, 18% Sn, 10% Cu, 2% Hg	Easily worked	Dental fillings
Pewter	Tin	92% Sn, 6% Sb, 2% Cu	Low melting point (230 °C)	Dishes, jewelry

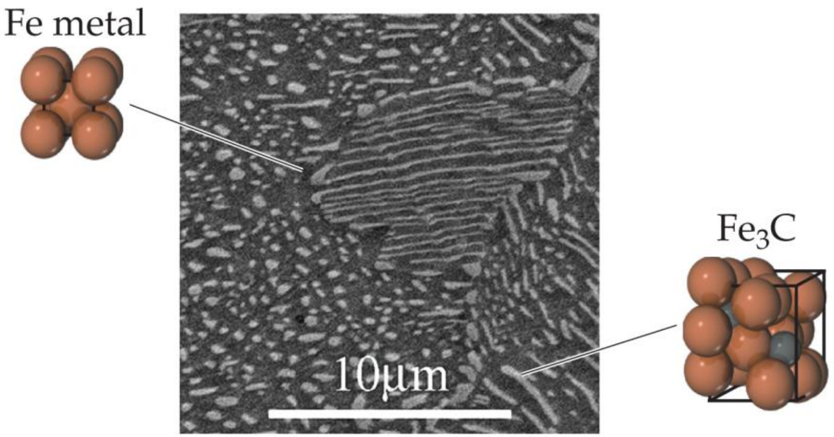
Types of Alloys



Substitutional alloy
14-karat gold



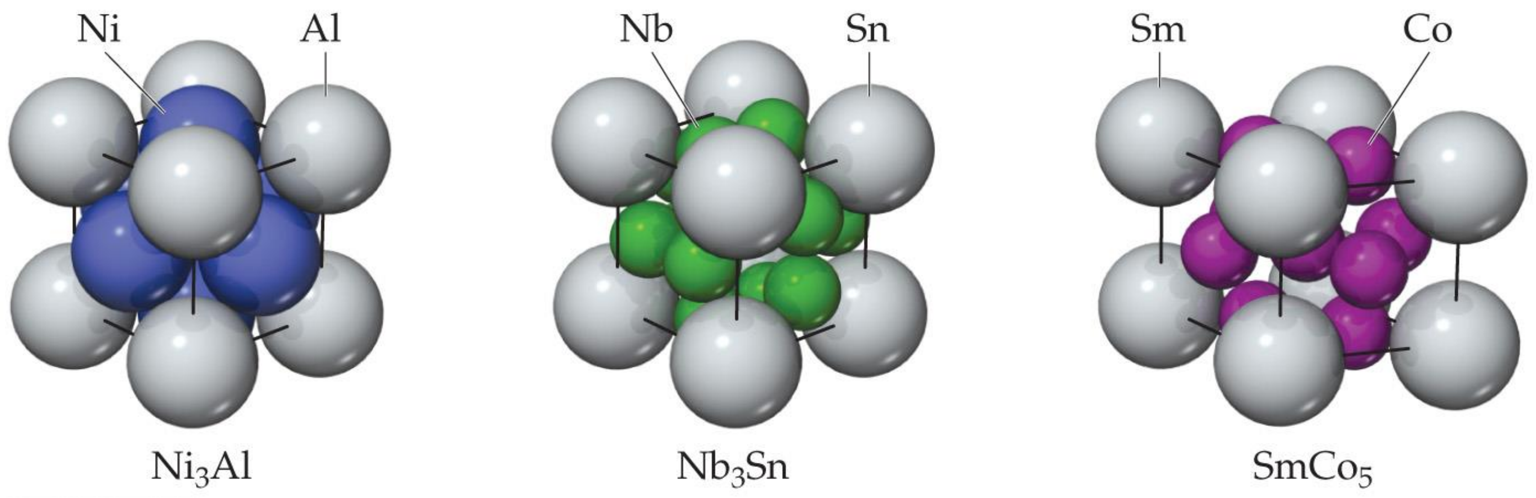
Interstitial alloy
Steel



- **Substitutional alloys**: A second element takes the place of a metal atom.
- **Interstitial alloys**: A second element fills a space in the lattice of metal atoms.
- **Heterogeneous alloys**: components not dispersed uniformly

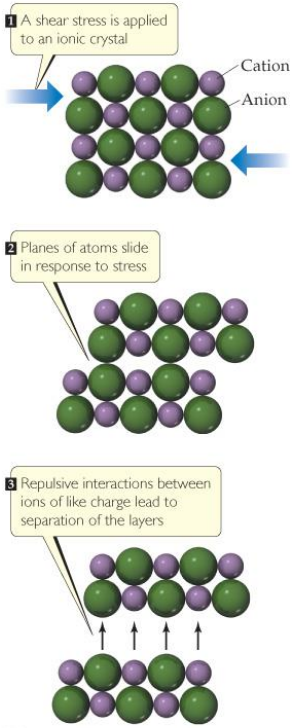
Intermetallic Compounds

- compounds, *not* mixtures
- distinct properties, definite composition (since they are compounds)
- ordered, rather than randomly distributed



Ionic Solids

- In ionic solids, the lattice comprises alternately charged ions.
- Ionic solids have very high melting and boiling points and are quintessential crystals.

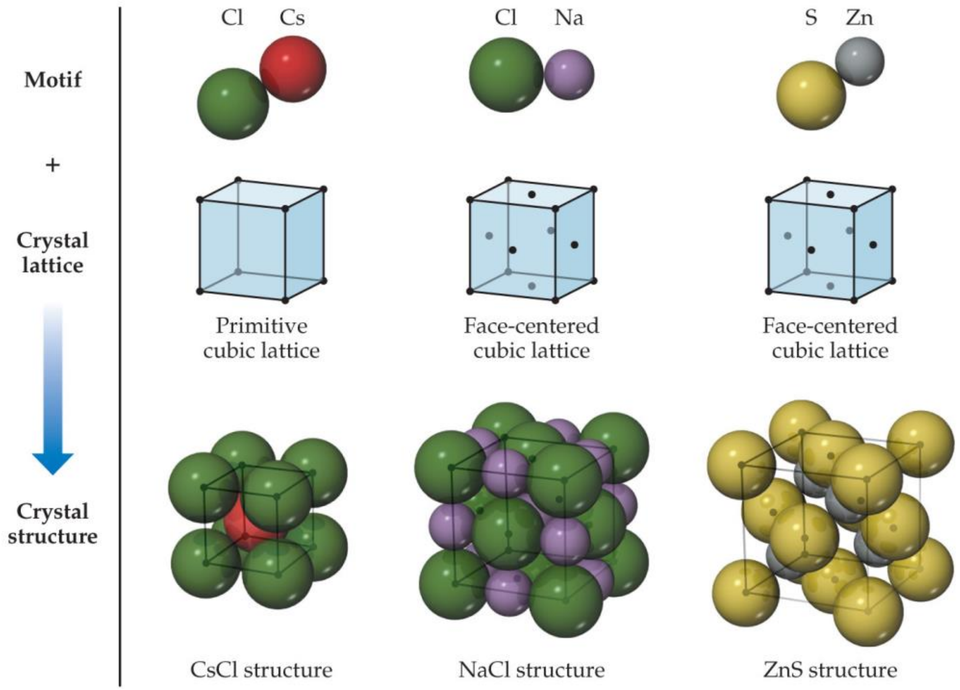


(a)

(b)

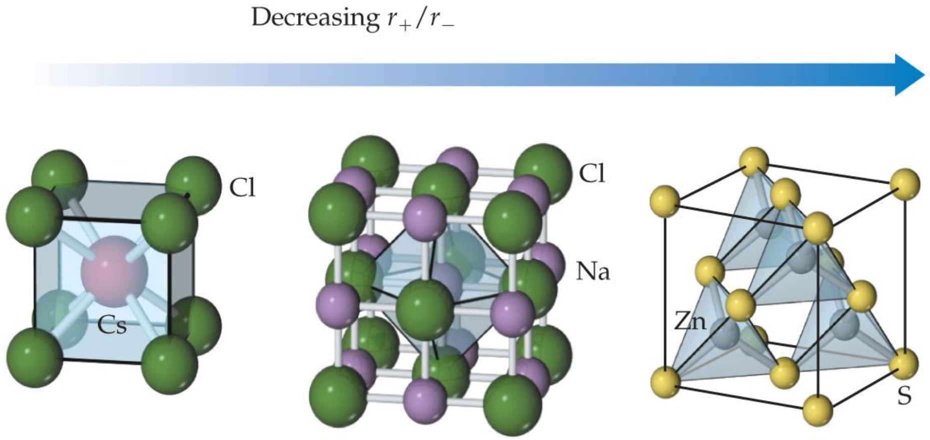
Ionic Solids

- Most favorable structures have cation–anion distances as close as possible, but the anion–anion and cation–cation distances are maximized.
- Three common structures for 1:1 salts:
  - CsCl structure
  - NaCl (rock salt) structure
  - zinc blende (ZnS) structure



Effect of Ion Size on Structure

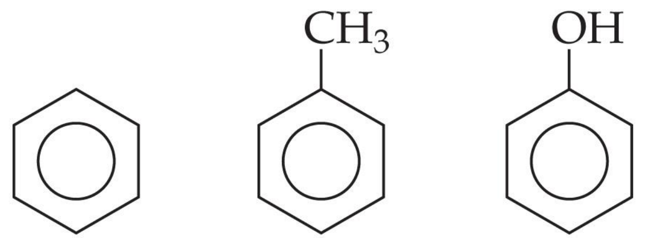
- The size of the cation compared to the anion (radius ratio) is the major factor in which structure is seen for ionic compounds.



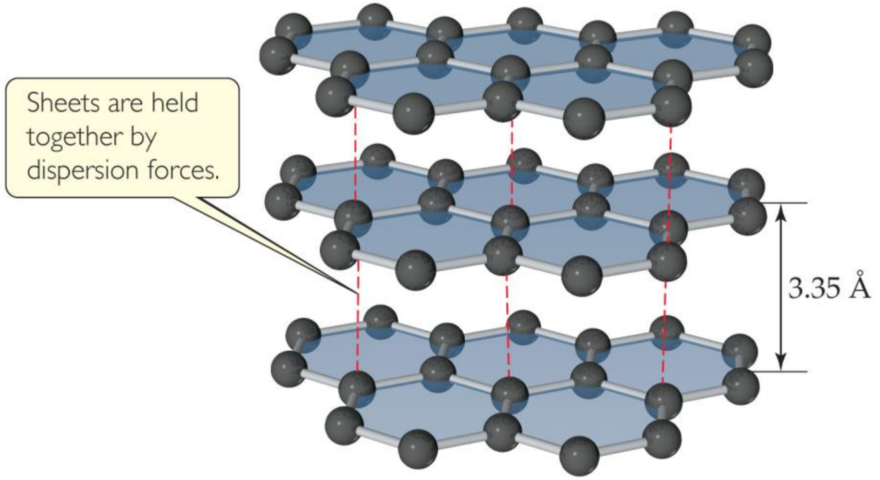
	CsCl	NaCl	ZnS
Cation radius, r_+ (Å)	1.81	1.16	0.88
Anion radius, r_- (Å)	1.67	1.67	1.70
r_+/r_-	1.08	0.69	0.52
Cation coordination number	8	6	4
Anion coordination number	8	6	4

Molecular Solids

- Consist of atoms or molecules held together by weaker forces (dispersion, dipole–dipole, or hydrogen bonds).
- Shape (ability to stack) matters for some physical properties, like boiling point.
- Graphite is an example.



	Benzene	Toluene	Phenol
Melting point (°C)	5	–95	43
Boiling point (°C)	80	111	182



(b) Graphite