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Intermolecular Forces

intermolecular force- forces *between* molecules.

intramolecular force- forces within a molecule, i.e. covalent bond

There are three *pure* intermolecular forces:

London forces: AKA van der Waals dispersion forces, AKA induced dipole

dipole-dipole attraction

hydrogen bonds

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Forces between Molecules I. London Forces

- all particles have London forces



- larger particles have larger London forces

- only force between noble gases and nonpolar compounds



- about 1/1000 as strong as a covalent bond

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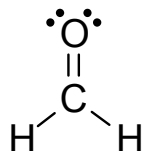
London Dispersion Forces

- relatively weak forces that exist among noble gas atoms and nonpolar molecules. (Ar, C₈H₁₈)
- caused by instantaneous dipole, in which electron distribution becomes asymmetrical.
- the ease with which electron "cloud" of an atom can be distorted is called polarizability.

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Forces between Molecules II. Dipole-Dipole Interactions

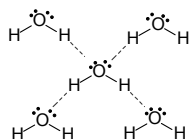
- different from London forces only in permanence
- somewhat stronger than London forces because permanent
- (~ 1/100 as strong as a covalent bond)
- occurs in all *polar* molecules
- weaker than ionic bond because only δ^+ or δ^-



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Forces between Molecules III. Hydrogen Bonds

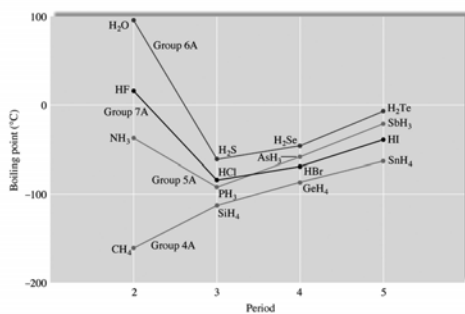
- relatively few molecules exhibit h-bonds
- occur between one H which is covalently bonded to an N, O, or F atom and a second N, O, or F atom
- strongest of three intermolecular forces



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Significance of h-bond

Fig. 11.6 Zumdahl and Zumdahl, 6th Ed.



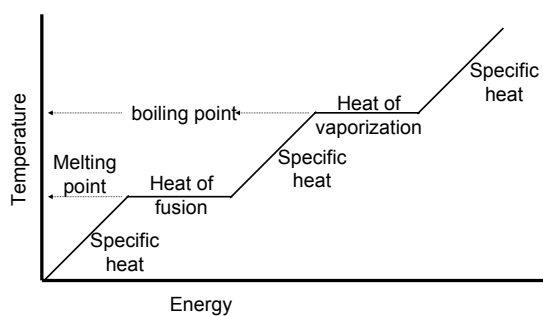
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“Impure” Intermolecular Forces

- Ion-dipole most important (dissolving salt in water, e.g.)
- Others exist

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The Temperature-Energy Diagram and Changes in Physical State



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Melting Point

Melting point- the *temperature* at which a solid is converted to a liquid

Molecules break loose from lattice points and solid changes to liquid. (Temperature is constant as melting occurs.)

Melting point- the temperature at which the vapor pressure of solid is equal to the *vapor pressure* of liquid

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Vapor Pressure

Vapor Pressure- the pressure that develops in a closed container when the (l) ↔ (g) are in equilibrium.

- . . . is determined principally by the size of the intermolecular forces in the liquid.
- . . . increases significantly with temperature.
- Volatile liquids have high vapor pressures.

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Boiling Point

- Constant temperature when added energy is used to vaporize the liquid.
- normal boiling point- temperature at which liquid is converted to gas, when 1 atm pressure exerted on it
- vapor pressure of liquid = pressure of surrounding atmosphere

11-7STQ

The Temperature-Energy Diagram and Changes in Physical State

- 50.0 g of ice is removed from a freezer at -20°C and allowed to absorb 5,400 J of energy. What is the state of the H_2O molecules? The specific heat of water is $4.18 \text{ J/g}^{\circ}\text{C}$, the HoF is 332.7 J/g , and the HoV is 2257 J/g .
- How much energy (in kJ) required to convert 74.6 g of water to steam at 100°C ?

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Phase Diagram

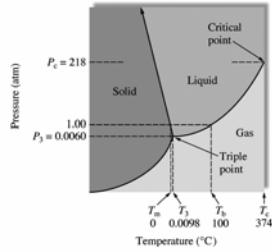
Fig. 11.40 Chang, 9th Ed.

Represents phases as a function of temperature and pressure.

critical temperature (T_c): temperature above which the vapor can not be liquefied.

critical pressure (P_c): pressure required to liquefy AT the critical temperature.

critical point: critical temperature and pressure (for water, $T_c = 374\text{ }^\circ\text{C}$ and 218 atm).



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Some Properties of a Liquid

- Surface Tension: The resistance to an increase in its surface area (polar molecules).
 - Capillary Action: Spontaneous rising of a liquid in a narrow tube.
 - Viscosity: Resistance to flow (molecules with large intermolecular forces).
- These are due to adhesive vs. cohesive forces**
- Remember that earlier this semester we had other properties such as indefinite shape and volume, not compressible, and fluid.

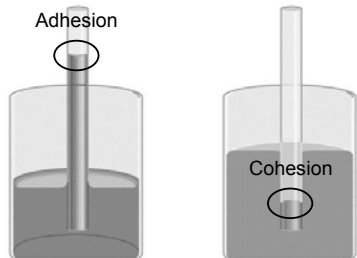
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Properties of Liquids

Fig. 11.10 Chang, 9th Ed.

Cohesion- is the intermolecular attraction between like molecules

Adhesion- is an attraction between unlike molecules



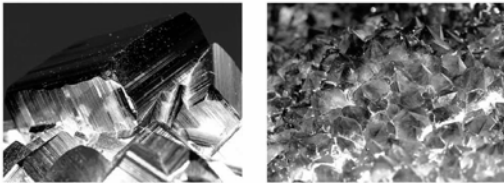
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Types of Solids

Fig. 10.8 Zumdahl and Zumdahl, 6th Ed.

Crystalline Solids: highly regular arrangement of their components [table salt (NaCl), pyrite (FeS₂)].

Amorphous solids: considerable disorder in their structures (glass).



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Representation of Components in a Crystalline Solid

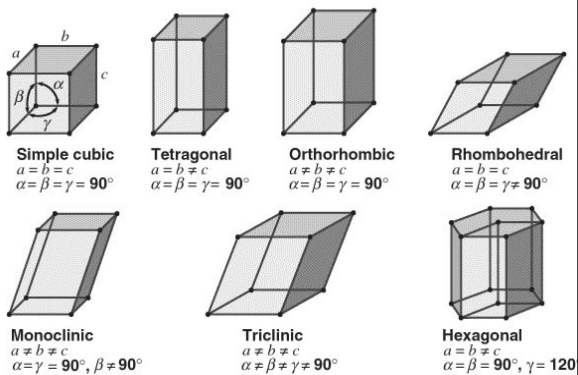
Lattice: A 3-dimensional system of points designating the centers of components (atoms, ions, or molecules) that make up the substance.

Unit Cell: The smallest repeating unit of the lattice.

- simple cubic
- body-centered cubic
- face-centered cubic

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Seven Types of Unit Cells



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Types of Crystalline Solids

Ionic Solid: contains ions at the points of the lattice that describe the structure of the solid (NaCl, e.g.).

Molecular Solid: discrete covalently bonded molecules at each of its lattice points (sucrose, ice, e.g.).

Atomic solid: as name implies, atoms not compounds (diamond, copper metal, e.g.)

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The Bragg Equation is Used for Analysis of Crystal Structures

$$n\lambda = 2d \sin \theta$$

where

d = distance between atoms

n = an integer

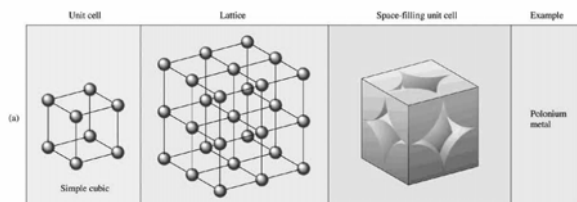
λ = wavelength of the x-rays

Recall the Crystal movie shown 10-25-05
We don't have time to do anything with this; suffice to say that this is the technique which is used to determine where atoms are located.

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Simple Cubic

Fig. 10.9(a) Zumdahl and Zumdahl, 6th Ed.
See Fig. 11.16 Chang, 9th Ed.

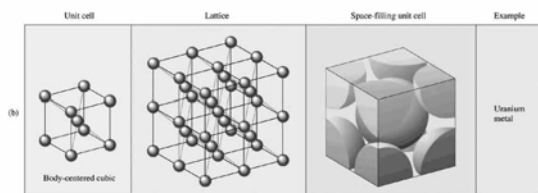


- There is one atom per unit cell

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Body-Centered Cubic

Fig. 10.9(b) Zumdahl and Zumdahl, 6th Ed.
See Fig. 11.18 Chang, 9th Ed.

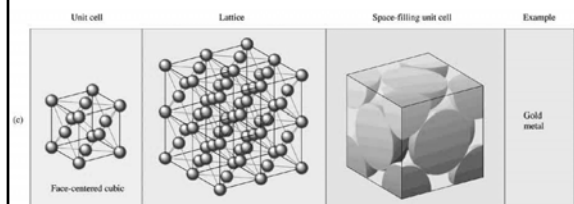


- There are two atoms per unit cell

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Face-Centered Cubic

Fig. 10.9(c) Zumdahl and Zumdahl, 6th Ed.
See Fig. 11.17 Chang, 9th Ed.



- How many atoms per unit cell?

STQ

- Iridium (Ir) has a face-centered cubic (fcc) unit cell with an edge length of 383.3 pm. Calculate the density of iridium.

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Packing in Metals

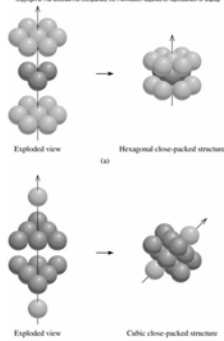
Fig. 11.21 Chang, 9th Ed.

Model: Packing uniform, hard spheres to best use available space. This is called closest packing. Each atom has 12 nearest neighbors.

- hexagonal closest packed (“aba”)

- cubic closest packed (“abc”)

- Why a particular metal adopts the structure it does is not completely understood. Certainly it depends on the most stable attractions.



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Crystal Structures of Metals

Fig. 11.29 Chang, 9th Ed.

| 1 1A | | 2 2A | | Hexagonal close-packed Face-centered cubic | | | | | | | | | | Body-centered cubic Other structures (see caption) | | | | | | 13 3A | 14 4A | 15 5A | 16 6A | 17 7A | 18 8A |
|---------|----|---------|----|---|---------|---------|---------|---------|----|----|----|----------|----------|---|----|--|--|--|--|----------|----------|----------|----------|----------|----------|
| Li | Be | Na | Mg | 3 3B | 4 4B | 5 5B | 6 6B | 7 7B | 8 | 9 | 10 | 11 1B | 12 2B | Al | | | | | | | | | | | |
| | | K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | | | | | | | | | | | |
| | | Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | | | | | | | | | | |
| | | Cs | Ba | La | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | | | | | | | | | | |

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Bonding Models for Metals

- Electron Sea Model: A regular array of metals in a “sea” of electrons.
- Band (Molecular Orbital) Model: Electrons assumed to travel around metal crystal in MOs formed from valence atomic orbitals of metal atoms.

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Metal Alloys

- Substances that have a mixture of elements and metallic properties.
- 1. Substitutional Alloy: some metal atoms replaced by others of similar size.
 - brass = Cu/Zn
 - Pewter, etc.
- 2. Interstitial Alloy: Interstices (holes) in closest packed metal structure are occupied by small atoms.
 - steel = iron + carbon
- 3. Both types: Alloy steels contain a mix of substitutional (carbon) and interstitial (Cr, Mo) alloys.

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Network Solids

- Composed of strong directional covalent bonds that are best viewed as a “giant molecule”.
 - Brittle
 - do not conduct heat or electricity
 - carbon, silicon-based
- Examples are graphite, diamond, ceramics, glass
