Liquids and Solids
Relative Magnitudes of Forces

The types of bonding forces vary in their strength as measured by average bond energy.

- Covalent bonds (400 kcal/mol)
- Hydrogen bonding (12-16 kcal/mol)
- Dipole-dipole interactions (2-0.5 kcal/mol)
- London forces (less than 1 kcal/mol)
Dipole-Dipole Forces

Attraction between the positive end of one molecule and the negative end of another. Strong attractions, but not as strong as hydrogen bonding. These are only found in polar molecules.
Hydrogen Bonding

Bonding between hydrogen and more electronegative neighboring atoms such as oxygen and nitrogen.

Hydrogen bonding between ammonia and water.
Boiling point as a measure of intermolecular attractive forces
Hydrogen Bonding in DNA

Thymine hydrogen bonds to Adenine
Hydrogen Bonding in DNA

Cytosine hydrogen bonds to Guanine
Factors making Hydrogen Bonding

Special strong dipole-dipole attraction

1. The small size of the elements F, N, O
2. The relatively high electronegativity of them.

- This allows for the creation of strong dipole forces of attraction between the molecules. The effect of which can be seen on the boiling point of substances that contain hydrogen bonding.
London Dispersion Forces

The temporary separations of charge that lead to the London force attractions are what attract one nonpolar molecule to its neighbors.

London forces increase with the size of the molecules.

Fritz London 1900–1954
London Dispersion Forces

Atom A  Atom B
No polarization

δ⁻  δ⁺
Instantaneous dipole on atom A induces a dipole on atom B

δ⁻  δ⁺

Atom A  Atom B

Molecule A  Molecule B
No polarization

δ⁻  δ⁺
Instantaneous dipole on molecule A induces a dipole on molecule B

δ⁻  δ⁺
London Forces in Hydrocarbons

Boiling points of simple hydrocarbons in degrees Kelvin

Simple hydrocarbons have only London dispersion forces as intermolecular forces
# Summary of Intermolecular Forces

<table>
<thead>
<tr>
<th>Hydrogen Bonding</th>
<th>Dipole-dipole</th>
<th>LDF (London Dispersion Forces)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occurs between molecules that are <strong>polar</strong> and have H-F, H-O or H-N bonds.</td>
<td>Occurs in <strong>polar molecules that do not have hydrogen bonding</strong>. Weaker than H-bond</td>
<td>Occurs in <strong>non-polar molecules</strong>. The weakest interaction.</td>
</tr>
<tr>
<td>Caused by attraction of highly electronegative and small F, O, N with hydrogen.</td>
<td>Caused by attraction of oppositely charged poles of molecules</td>
<td>Caused by attraction of atoms when their electrons are unequally distributed around the molecule for an instant of time.</td>
</tr>
<tr>
<td><strong>Strongest</strong></td>
<td><strong>strong</strong></td>
<td><strong>Weak</strong> - gets stronger with more electrons. Ex. He-weak Ar-Stronger</td>
</tr>
</tbody>
</table>
Some Properties of a Liquid

- **Surface Tension**: The resistance to an increase in its surface area (polar molecules, liquid metals).

- **Capillary Action**: Spontaneous rising of a liquid in a narrow tube.
Some Properties of a Liquid

- **Viscosity**: Resistance to flow

- **High viscosity** is an indication of **strong intermolecular forces**

![Image of Karo corn syrup bottle]
Types of Solids

- **Crystalline Solids**: highly regular arrangement of their components
Types of Solids

- Amorphous solids: considerable disorder in their structures (glass).
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.
Bragg's Law

\[ xy + yz = n\lambda \quad \text{and} \quad xy + yz = 2d \sin \theta \]

\[ \therefore \quad n\lambda = 2d \sin \theta \]
Crystal Structures - **Cubic**

- **Simple**
- **Face-Centered**
- **Body-Centered**
Crystal Structures - **Monoclinic**

Simple

End Face-Centered
Crystal Structures - Tetragonal

Simple

Body-Centered
Crystal Structures - Orthorhombic

Simple
End Face-Centered
Body Centered
Face Centered
Crystal Structures - Other Shapes
Packing in Metals

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

(a) Trigonal hole

(b) Tetrahedral hole

(c) Octahedral hole
Metal Alloys

- **Substitutional Alloy:** some metal atoms replaced by others of similar size.
  - brass = Cu/Zn
Metal Alloys
(continued)

- **Interstitial Alloy:** Interstices (holes) in closest packed metal structure are occupied by small atoms.

  - steel = iron + carbon
Network Atomic Solids

Some covalently bonded substances DO NOT form discrete molecules.

Diamond, a network of covalently bonded carbon atoms

Graphite, a network of covalently bonded carbon atoms
Molecular Solids

Strong covalent forces within molecules

Weak covalent forces between molecules

Sulfur, $S_8$

Phosphorus, $P_4$
Equilibrium Vapor Pressure

- The pressure of the vapor present at equilibrium.
- Determined principally by the size of the intermolecular forces in the liquid.
- Increases significantly with temperature.
- **Volatile liquids** have high vapor pressures.
Temperature remains **constant** during a phase change.
Phase Diagram

- Represents phases as a function of temperature and pressure.
- Critical temperature: temperature above which the vapor can not be liquefied.
- Critical pressure: pressure required to liquefy AT the critical temperature.
- Critical point: critical temperature and pressure (for water, $T_c = 374°C$ and 218 atm).
Phase changes by Name

- **Solid**
- **Liquid**
- **Gas**

Key phases:
- Melting
- Freezing
- Sublimation
- Deposition
- Vaporization
- Condensation

Critical point and triple point markers.
Water

$P_c = 218$

$P_3 = 0.0060$

$T_m, T_3, T_b, T_c$

Temperature (°C)

0 0.0098 100 374
The diagram represents the phase diagram of carbon dioxide. It shows the relationship between pressure and temperature, with regions labeled forSolid, Liquid, and Gas phases. The critical point, triple point, and m melting point are indicated on the diagram.

- Critical point: $P_c = 72.8$ atm,
- Triple point: $P_3 = 5.1$ atm,
- Melting point: $T_m = -78^\circ C$,
- Tr Transition point: $T_3 = -56.6^\circ C$,
- Critical temperature: $T_c = 31^\circ C$. 

This diagram is used to understand the phase transitions and behavior of carbon dioxide under different conditions.