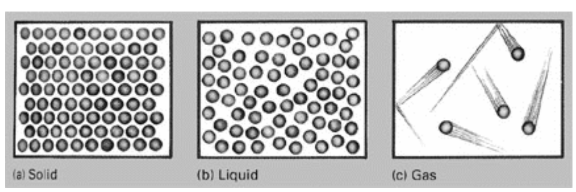
Chapter 5

Solids, Liquids, and Gases

Three States of Matter

Solid **Liquid** **Gas**



Kinetic molecular theory: all particles are in motion.

Table 6.1 Kinetic Molecular Theory and the Three Physical States

Physical State and Property	Kinetic Molecular Theory Explanation
Solid	
definite volume and shape; doesn't flow or mix readily	Attractive forces hold particles in place so they don't move freely.
most dense physical state; not very compressible	Attractive forces hold particles as close together as possible.
Liquid	
indefinite shape; flows and mixes readily; conforms to the shape of its container	Attractive forces allow particles to move about.
definite volume	Attractive forces are strong enough to keep particles from escaping.
more dense than gas; not very compressible	Attractive forces keep particles fairly close together.
Gas	
indefinite volume and shape; readily flows and mixes; conforms to the shape of its container	Attractive forces are so weak that particles move about freely.
least dense physical state; compressible	Particles move freely with much empty space between them.
exerts pressure equally in all directions on surfaces	Particles move rapidly and strike surfaces with equal force.

Forces Between Molecules

Opposites attract

Solids - Strong intermolecular attractive forces (ionic crystalline material, metals)

Liquids - Moderately strong intermolecular attractive forces (keep from escaping)

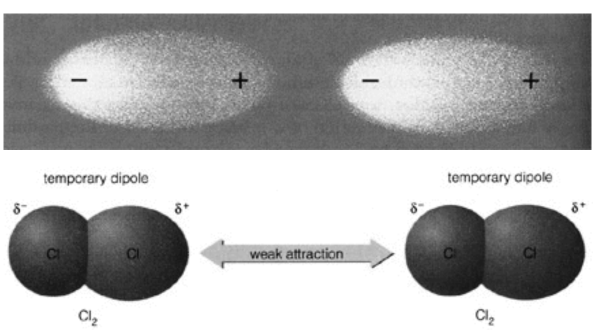
Gases - Weak intermolecular attractive forces

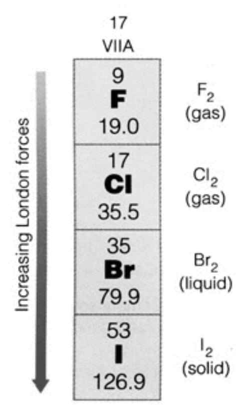
In covalent compounds, things are more complicated. Attractive forces typically weaker than in ionic compounds or metals, but stronger than in noble gases.

3 Attractive Forces -

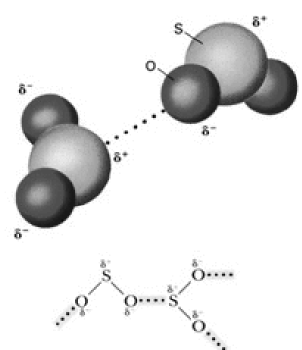
1.
2.
3.

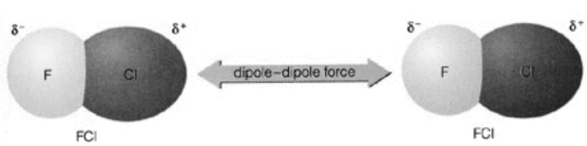
London Forces: Result from temporary shifts in electron distribution. Weakest of three.





Dipole - Dipole Interactions: Attractive forces between molecules having permanent dipoles. Weaker than ionic bonds, stronger than London forces.





Hydrogen Bonding: Special type of dipole - dipole interaction. Most important of the three. Occur between a very electronegative atom and a covalently bonded hydrogen on the same type or different nearby molecule. Strongest of the three but still much weaker than covalent, ionic, and metal bonds. Most important interactions occur in F–H, –O–H, and –N–H.

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δ-   δ+        δ-   δ+         δ-   δ+         |    δ+
O — H - - - - O — H        — N — H - - - - N — H
|              |            |              |δ-
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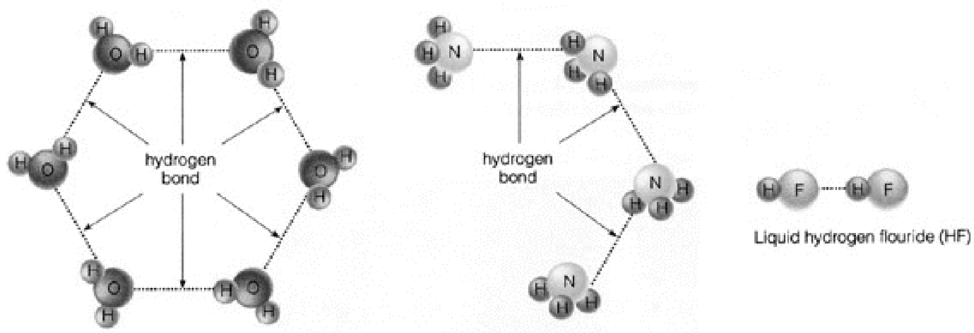
How strong are they? Consider H_2O (18 g mol^{-1}) and CO_2 (44 g mol^{-1}) at room temperature.



Solid water (ice)

Liquid ammonia (NH_3)

Liquid hydrogen flouride (HF)

Changing States

<u>S</u>outh Dakota to <u>L</u>ouisiana to <u>G</u>eorgia

Melting and Freezing:

Melting - A solid is heated (or absorbs heat) to a point where some molecules have enough kinetic energy to overcome strong attractive forces holding them in place.

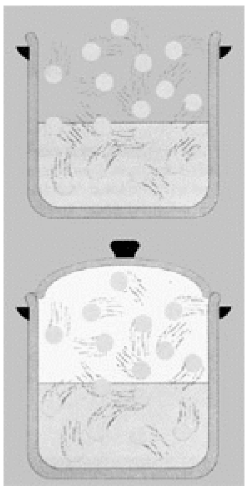
The opposite occurs on freezing (solidification). Enough kinetic energy is lost until attractive forces lock the molecules into place.

Some solids have such strong attraction between molecules that when they gain enough kinetic energy to break free, they go directly to the gas phase. This is called sublimation. Examples: iodine, solid CO_2.

Vaporization and Vapor Pressure:

Liquids (and some solids) can be heated to a point where molecules gain enough energy to break free from moderately strong attractive forces. The molecules then enter the gas state (phase). This is known as vaporization.

If vaporization takes place in a closed container (does not always have to be closed container), then eventually the molecules will lose enough energy so that they are again attracted into more ordered interaction and return to liquid state. This is called condensation.



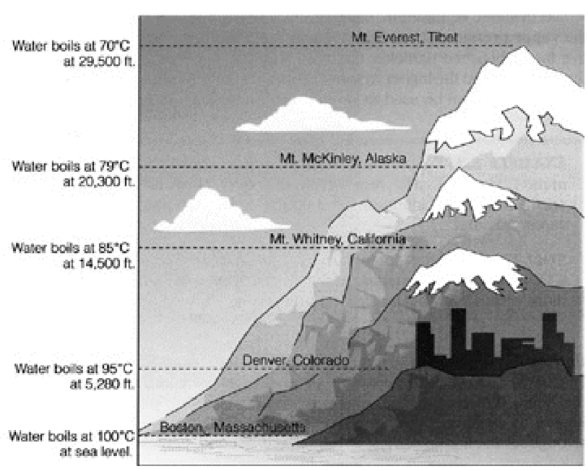
In closed container, both processes can take place at same time. They set-up a balance called a *dynamic equilibrium*. Dynamic implies motion or some change and equilibrium implies balance or consistency. Here, number of particles or molecules in each state remain constant.

When liquid is in dynamic equilibrium with its vapor, the gaseous pressure over liquid is called vapor pressure. Weak attractive forces increase likelihood that at a given temperature liquid will change into vapor, therefore increasing amount of vapor present and vapor pressure.

Boiling:

Boiling occurs when vapor pressure of a pure substance has increased enough so that bubbles of the substance form in the interior of the liquid so that they rise and escape out of an open container.

The boiling point is the temperature at which bubbles begin to form in a liquid and is related to the atmospheric pressure above the liquid. The higher the atmospheric pressure above the liquid, the higher the boiling point and vice versa.



Energy of State Change

Heats of vaporization, fusion, and specific heat

During phase (state) transitions, e.g., melting, vaporizing, etc., energy is either absorbed or given-off.

Example: Water boils at 100°C and stays at that temperature even though it is still being heated. Additional heat is being converted to kinetic energy causing molecules to enter gas phase.

Heat of vaporization: the extra energy required to convert (vaporize) a liquid at its boiling point to a gas phase. The same amount of energy is given-off when a gas condenses to a liquid.

Heat of fusion: the extra energy needed to convert (melt) a solid at its melting point to a liquid phase. The same amount of energy is given-off when a liquid solidifies to a solid.

Specific Heat: the energy required to raise the temperature of 1 gram of a substance 1 °C. (Water is the reference material = 1.00 cal/g °C)

Table 6.4 Heat of Fusion, Heat of Vaporization, and Specific Heat for Some Substances

Substance	Strongest Bonding Forces	Heat of Fusion (cal/g)	Heat of Vaporization (cal/g)	Specific Heat (cal/g °C)
Hydrogen chloride (HCl)	dipole–dipole	13.9	99	0.19
Chloroform ($CHCl_3$)	dipole–dipole	18	59	0.23
Ethanol (C_2H_6O)	hydrogen	24.9	204	0.58
Water (H_2O)	hydrogen	79.8	540	1.00
Aluminum (Al)	metallic	94.4	2500	0.22
Sodium chloride (NaCl)	ionic	124	3130	0.21

- **How much energy is required to vaporize 120 g of ethanol at its boiling point?**

✪ How many Joules of energy is required to raise the temperature of 50.0 grams of chloroform 25 °C?

✪ Calculate how many a) kcal and b) kJ are needed to convert 128.5 g of frozen CH_3CH_2OH at -114.4 °C into gaseous ethanol at 78.8 °C.

H_{fus} = 24.9 cal/g, H_{vap} = 204 cal/g,
Specific heat = 0.580 cal/g °C

1) Use heat of fusion to calculate energy needed to melt solid EtOH @ -114.4 °C.

2) Use specific heat to calculate energy needed to raise temperature to 78.8 °C.

3) Use heat of vaporization to find energy needed to convert to gas @ 78.8 °C.

4) Total energy needed (in kcal and kJ).