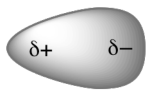
Handout: Effect of Intermolecular Forces on Boiling Point and Solubility

<u>Intermolecular Forces</u>

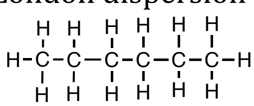
Intermolecular forces are attractive forces between molecules. They are largely responsible for the observed boiling points and solubility properties of molecules.

<u>Types of Intermolecular Forces</u> (All intermolecular forces are electrostatic in nature!)

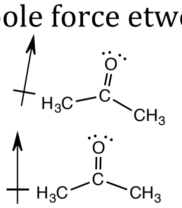
*Background:
Dipole: "two-pole"; a molecule that has a partial positive end and a partial negative end; a polar molecule. Arises from unequal distribution of shared electrons between two bonded atoms (polar covalent bonds) in the molecule, due to a significant electronegativity difference between the two atoms. [like C-N, C-O, C-X]



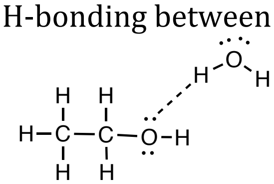
1. London Dispersion: Attraction between molecules that form due to a temporary dipole on one molecule inducing a temporary dipole in neighboring molecules. Temporary dipoles arise because of the momentary non-symmetrical distribution of electrons. London dispersion forces operate between <u>all</u> molecules! However, this force is particularly important in interactions of nonpolar molecules because it is the only attractive force available to them. Very weak!
   Eg. London dispersion force between two hexane molecules

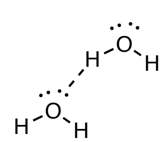


2. Dipole-Dipole: Attraction between two polar molecules (dipoles)
   Eg. Dipole-dipole force etween two acetone molecules

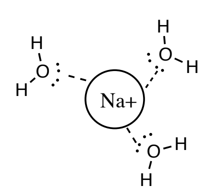


3. Hydrogen Bonding: Attraction between two polar molecules, specifically one molecule having a H bonded directly to an electronegative atom (eg. H-O-, H-N-, H-F), and the other having a nonbonding electron pair on an electronegative atom. A special type of dipole-dipole bond that is particularly strong.
   Eg. H-bonding between ethanol and water; H-bonding between two water molecules





4. Ion-Dipole: Attraction between an ion and a polar molecule.
   Eg. Ion-dipole force between sodium ion and water



Relatives Strengths of Intermolecular Forces

- London dispersion — Weakest
- Dipole-dipole ↓
- Hydrogen-bond
- Ion-dipole — Strongest

Intermolecular Forces: Effect on Boiling Point

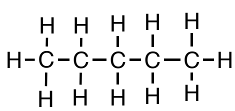
Main Idea: Intermolecular attractive forces hold molecules together in the liquid state. The stronger the intermolecular forces between the molecules of a liquid, the greater the energy required to separate the molecules and turn them into gas → higher boiling point

Trends:

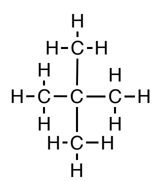
1. Between two molecules of similar mass, the one with the stronger type of intermolecular force has a higher boiling point (Look for functional groups that may indicate polar molecule).

$CH_3CH_2CH_3$	CH_3CH_2OH
bp = –42 °C	bp = 78 °C

2. Between two nonpolar molecules of similar mass, the more extended molecule will have the higher boiling point (more extended → more surface area for London dispersion interaction).



n-pentane, bp = 309.4 K



neopentane, bp = 282.7 K

3. Between two nonpolar molecules of different masses, the larger molecule will have the higher boiling point (larger molecule → more electrons → more polarizability → more London dispersion forces)

$CH_3(CH_2)_5CH_3$	$CH_3CH_2CH_3$
bp = 98 °C	bp = –42 °C

*When comparing molecules of both significantly different masses and polarity, it's more difficult to predict boiling point trend.

$CH_3(CH_2)_5CH_3$	CH_3CH_2OH
bp = 98 °C	bp = 78 °C

Intermolecular Forces: Effect on Solubility

Main Idea: "Like dissolves like." The stronger the intermolecular forces between solute molecule and solvent molecule, the greater the solubility of the solute in the solvent.

- Polar molecules are soluble in polar solvents (Predominant intermolecular force is dipole-dipole attraction between polar solute molecule and polar solvent molecule).
- Nonpolar molecules are soluble in nonpolar solvents (Predominant intermolecular force is London dispersion attraction between nonpolar solute molecule and nonpolar solvent molecule).
- Polar molecules and nonpolar molecules do not mix.

Trends

1. Between two polar molecules, the molecule with the smaller hydrocarbon portion (or the larger polar portion) is more soluble in water.

CH_3CH_2OH	Soluble in water
$CH_3CH_3CH_3CH_3CH_3CH_2OH$	Insoluble in water
$CH_2(OH)CH(OH)CH(OH)CH(OH)CH(OH)CH_2OH$	Soluble in water. Large but many OHs that can hydrogen bond with water.

2. If completely nonpolar, insoluble in water (and soluble in nonpolar solvents).

$CH_3CH_3CH_3CH_3CH_3CH_3$	Insoluble in water