

## LECTURE 16. INTRODUCTION TO INTERMOLECULAR FORCES

As we ended the lectures on gases, we were introduced to an idea that serves as foundation for the material in this lecture:

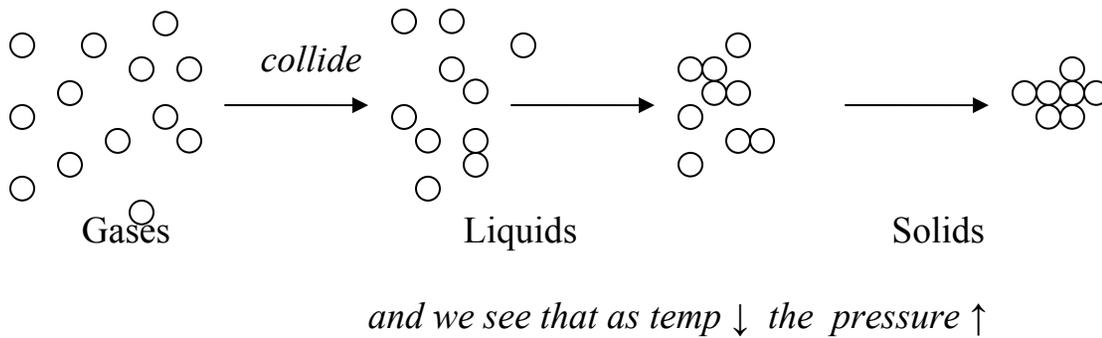
As we were introduced to ideal gases, we learned from kinetic molecular theory exhibit that no attractions occur between colliding molecules.

...BUT THIS IS NOT TRUE

So at the gas material we learned that non-ideality arises because of the attractive forces between colliding molecules and that consequently  $PV \neq nRT$ .

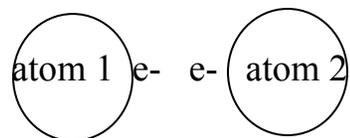
So can we explain the source of this non-ideality? It is important because

...NON-IDEALITY from attractive collisions explains how liquids and solids form.

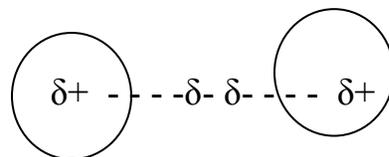


So the lectures on liquids and solids must begin with a better understanding of intermolecular attraction.

Let's get started by looking at attractive forces more generally:



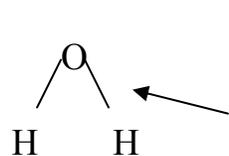
involves e<sup>-</sup>s from one atom attracted to nucleus of another



but this is just Coulombic forces opposite charges attract

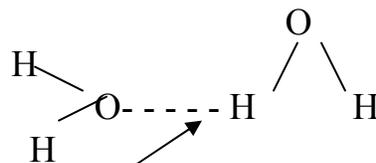
Two examples of Coulombic attraction can be distinguished in matter:

Bonding attraction inside a molecule



The covalent bond between sp<sup>3</sup> hybridized oxygen e<sup>-</sup> and 1s hydrogen electron

Bonding interaction outside a molecule



Hydrogen bonding between molecules

Two definitions for these kinds of attractions are:

- Intramolecular forces- bonds inside molecules, either covalent or ionic
- Intermolecular forces- bonds between molecules

## Intermolecular Bond Strengths

So now let's get quantitative with bonding.

**TABLE 5.1** Interionic and Intermolecular Interactions\*

Type of interaction	Typical energy (kJ·mol <sup>-1</sup> )	Interacting species
ion-ion	250	ions only
ion-dipole	15	ions and polar molecules
dipole-dipole	2	stationary polar molecules
	0.3	rotating polar molecules
dipole-induced dipole	2	at least one molecule must be polar
London (dispersion) <sup>†</sup>	2	all types of molecules
hydrogen bonding	20	molecules containing N, O, F; the link is a shared H atom

\*The total interaction experienced by a species is the sum of all the interactions in which it can participate.

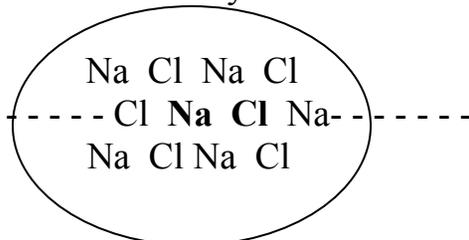
<sup>†</sup>Also known as the induced-dipole-induced-dipole interaction.

Note, intramolecular bonds are 1 to 2 orders of magnitude stronger (But it is weak intermolecular attractions intermolecular forces) that allow liquids and solids to form.)

- intermolecular forces are responsible for solution properties like boiling point and viscosity
- the relative magnitude of intermolecular forces is determined for existence of dipoles in molecules which comes from  $\Delta EN$
- you can rank solution properties based on  $\Delta EN$  results

An interesting side note about ionic bonds: they are both inter and intramolecular. Why?

The bonds in a crystal are not distinct as a molecule. So the ambiguity in inter and intramolecular exists

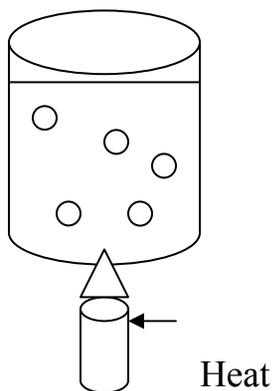


Look at this salt crystal  
Notice that a single **Na-Cl** unit does not actually exist.

Now the rest of the lecture. What are the solution properties? (You need only to know their definitions and a brief theoretical explanation for relationship to intermolecular forces.)

## Boiling Point

This is a process that happens in solution when energy in system from an increase in temperature causes IMF (intermolecular forces) to break, creating a vaporized (gas) molecule. However for a molecule to escape liquid, a sufficient number need to create a vapor pressure exceeding atmospheric pressure. This is the definition of boiling.

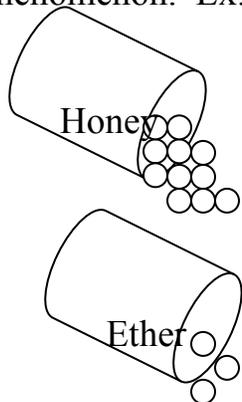


Bubbles of vapor that exit solution when  
vapor pressure  $>$  atmospheric pressure

Note: The stronger the IMF, the higher the boiling point. Ex:  $\text{H}_2\text{O}$  b.p. =  $100^\circ\text{C}$ ,  $\text{N}_2$  b.p. =  $196^\circ\text{C}$

## Viscosity

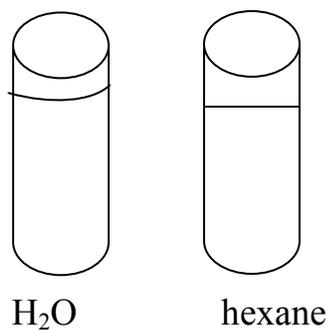
: stickiness when pouring; consequences of IMF attraction between molecules. This “resistance to flow” is a surface phenomenon. Ex. honey vs ether



Note: The stronger the IMF, the more viscous the solution

## Capillary Action

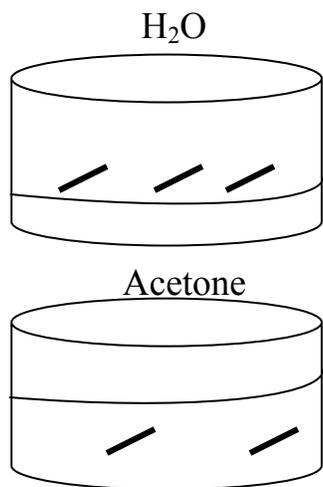
this is the tendency to climb the walls of a capillary. It is what created the meniscus you see in burettes and straws filled with water



Note: The stronger the IMF, the greater the capillary action so water is observed to crawl up the walls.

## Surface Tension

The phenomenon that maintains the surface interface between liquid and gas. It allows you to place needles and insects on surfaces despite being denser.

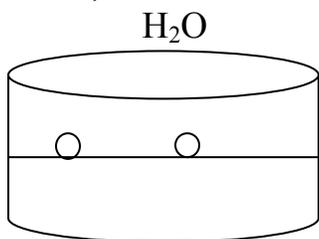


Note: The greater the IMF, the greater the surface tension. Here, water is has a much greater surface tension than acetone.

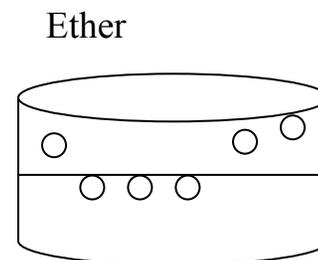
The demo in class with the ants is recreated here with the ants floating of the surface of water because of the larger surface tension of water and sinking because in acetone because of the smaller surface tension.

### Evaporation

Surface phenomenon that explains why solution molecules enter gas phase. This is different from boiling in that it occurs at surface, but it is also temperature dependent.



Note: The greater the IMF, the less the evaporation rate.



### $\Delta H_{\text{vap}}$

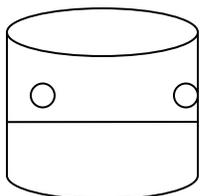
Thermodynamic term for which is the energy for a liquid to become a gas. It is found in boiling and evaporation equations.

Note: The larger the IMF, the greater the  $\Delta H_{\text{vap}}$ .

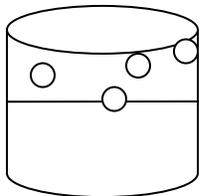
### Vapor Pressure

The flip side of evaporation. It is the pressure that builds in a closed system about the liquid. Obviously if  $\Delta H_{\text{vap}}$  is small, vapor pressure is large.

$P_v$  of H<sub>2</sub>O



$P_v$  of ether



Note: The greater the IMF, the lower the vapor pressure.

## Predicting the Ranking of Solution Properties

Now that we have seen the various solution properties and how they relate to IMF, let's see whether we can predict the ranking of various molecules.

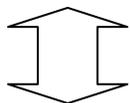
Can I rank the the solution properties of compounds? It's easy. Example: Rank H<sub>2</sub>O, CH<sub>3</sub>Cl, and N<sub>2</sub> in terms of increasing  $\Delta H_{\text{vap}}$

Answer: N<sub>2</sub> < CH<sub>3</sub>Cl < H<sub>2</sub>O .... How'd I do that?

### We get help from our friend Electronegativity

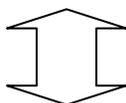
In a nutshell, you can relate the three kinds of intermolecular forces directly to the magnitude of solutions properties.

Instantaneous Dipoles  
(< 1 kJ/mole)



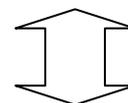
Occurs for symmetrical  
(nonpolar) molecules  
Examples: N<sub>2</sub>, CH<sub>4</sub>, BF<sub>3</sub>

Dipole-Dipole  
(5 kJ/mole)



Occurs for asymmetrical  
(polar) molecules like  
Examples: CH<sub>3</sub>Cl, H<sub>2</sub>O, NH<sub>3</sub>

H-bond  
(10-20 kJ/mole)



Occurs when polar  
molecules have a H and it is  
next to EN atom like N or O  
Examples: NH<sub>3</sub> and H<sub>2</sub>O

And the general rule:

- As IMF magnitude increases, the magnitude of solution properties like boiling point increases
- As the IMF magnitude increases, the magnitude of solution properties like evaporation decreases.

So you need to be able to create 3D Lewis structure for molecules, assign EN, create dipoles, cancel them out and see if a net dipole exists. This is something you learned to do when drawing the 3-D structures of molecules.

### Example: Predict the Ranking of Solution Properties for N<sub>2</sub>, CH<sub>3</sub>Cl, and H<sub>2</sub>O

1. Create 3D Lewis structure
2. Assign EN and form dipoles
3. Determine if net dipole ( $\Sigma \Delta EN \neq 0$ )

N<sub>2</sub> has no net dipole so nonpolar    CH<sub>3</sub>Cl has a net dipole so polar    H<sub>2</sub>O has a net dipole so polar

So what does this information tell us about the solution properties of these molecules?

N<sub>2</sub> →  $\Sigma \Delta EN = 0$ , nonpolar so it only forms instantaneous dipoles

CH<sub>3</sub>Cl →  $\Sigma \Delta EN \neq 0$ , polar, net dipole so it also forms dipole-dipole

H<sub>2</sub>O →  $\Sigma \Delta EN \neq 0$ , polar, so it also forms dipole-dipole, but has H next to EN atom so also H-bonding

In terms of solutions properties, we can say generally that

N<sub>2</sub> < CH<sub>3</sub>Cl < H<sub>2</sub>O                      for boiling point, melting point,  $\Delta H_{\text{vap}}$ , capillary action, surface tension, viscosity, cohesion because these properties increase as IMF increases

...And reverse

N<sub>2</sub> > CH<sub>3</sub>Cl > H<sub>2</sub>O                      for evaporation and vapor pressure because these properties decrease as IMF increases

So the order is the same, just one direction or the other, for every solution property, and in every case is related to magnitude of IMF. Get really good at creating 3-D structures and assigning polarity. It is the essential step in explaining IMF in solution properties.