Intermolecular Forces (IMF)

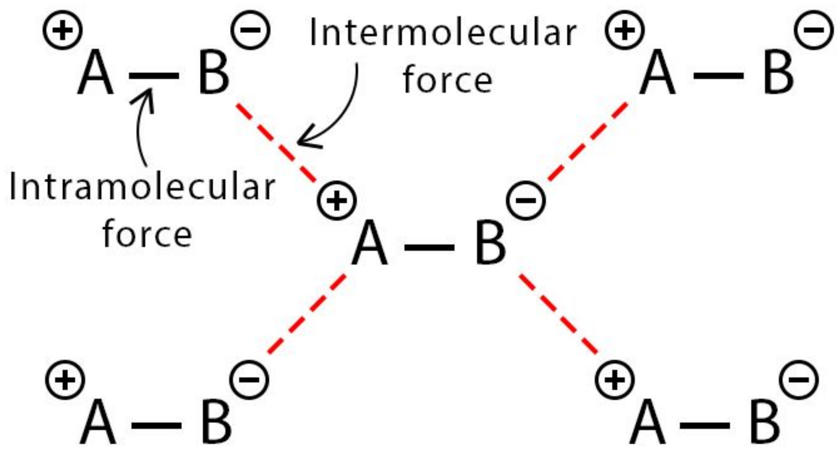
Forces and bonding with molecules is either...

INTRAmolecular

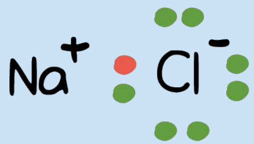
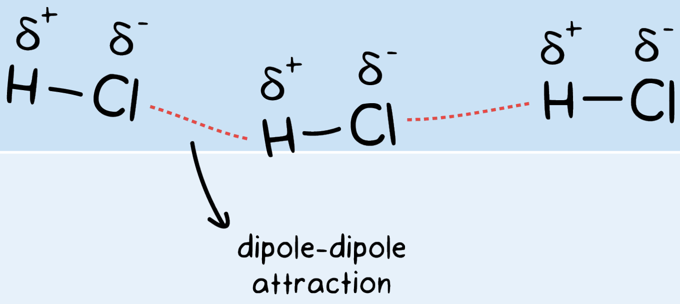
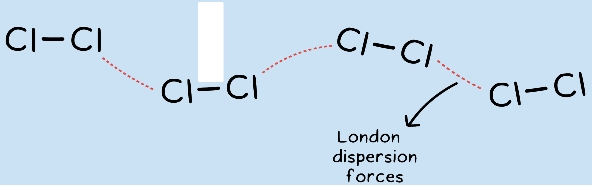
- Attraction WITHIN a molecule
- Types: Ionic, covalent

INTERmolecular

- Attraction BETWEEN molecules
- Weaker than intramolecular forces
- Types: Ion-Ion, Ion-Dipole, Dipole-Dipole, Hydrogen-Bonding, London Forces



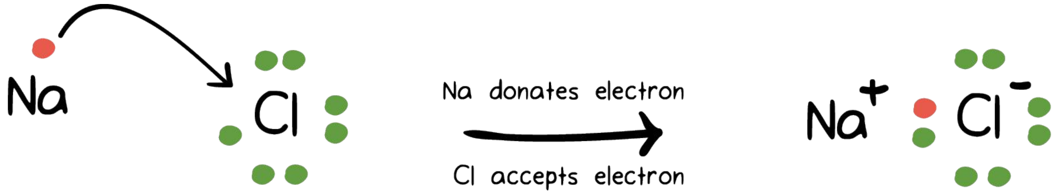
INTERmolecular Forces

Five Major Types		
Ion-Ion	(Ionic Compounds)	
Ion-Dipole	(Mix of Ionic and Polar)	
Dipole-Dipole	(Polar Compounds)	
Hydrogen Bonding	(special Dipole-Dipole)	
London Forces	(All Compounds)	

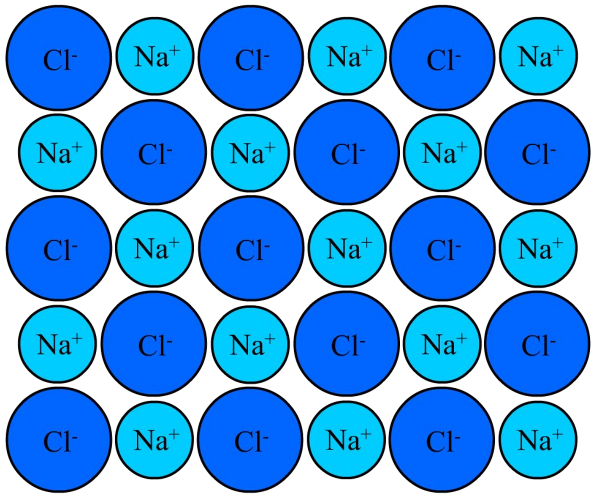
INTERmolecular Forces

Ion-Ion Interactions (Strongest Intermolecular Force)

These are the Ionic Bonds found in ionic crystals



- Forces very hard to break, very strong
  - The strength of an ionic bond is referred to as lattice energy.
  - Takes a lot of energy (high temperatures) to cause them to split from one another and change states
- Strength of the interaction is proportional to the magnitude of the charges and decreases as the distance between the particles increases.
  - These two factors combined is referred to as charge density



INTERmolecular Forces

Ion-Ion Interactions (Strongest Intermolecular Force)

Consider the following ionic solids:

Substance	MP (^oC)	Solubility (g/100g H_2O)
CsCl	646	High
NaCl	800	Medium
MgO	2800	Low (very little)

Can you account for the differences in properties of these 3 ionic solids?

Both NaCl and CsCl have the same magnitude of charges on their ions.

- However, Cs is much larger than Na, making the ionic radius much larger
- MgO not only consists of smaller ions, but its ions also have higher charge magnitudes

INTERmolecular Forces

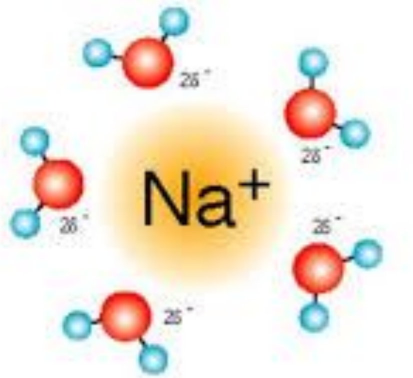
Ion-Dipole Interactions (2nd Strongest Intermolecular Force)

Occurs when a fully charged ion interacts with polar molecules (molecules that have a dipole)

- Negative end of dipole on polar molecule attracted to a positive ion
- Positive end of dipole on polar molecule attracted to a negative ion

- Since a dipole is not a FULL charge, this attraction is not as strong as ion-ion

Slightly positive hydrogen are attracted to chlorine anions



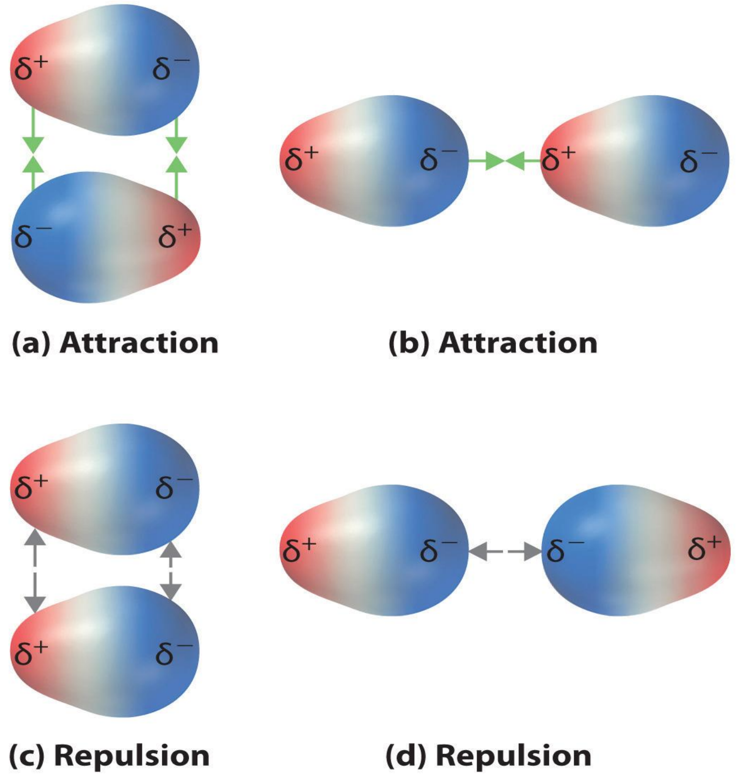
Slightly negative oxygen are attracted to sodium cations

INTERmolecular Forces

Dipole-Dipole Interactions (3rd Strongest IMF)

When molecules have dipoles negative end on one molecule attracted to the positive end of another

- This attraction will hold the molecules together, and keep them from separating
- There will also be a repulsive force between likely charged sides



INTERmolecular Forces

Dipole-Dipole Interactions (3rd Strongest IMF)

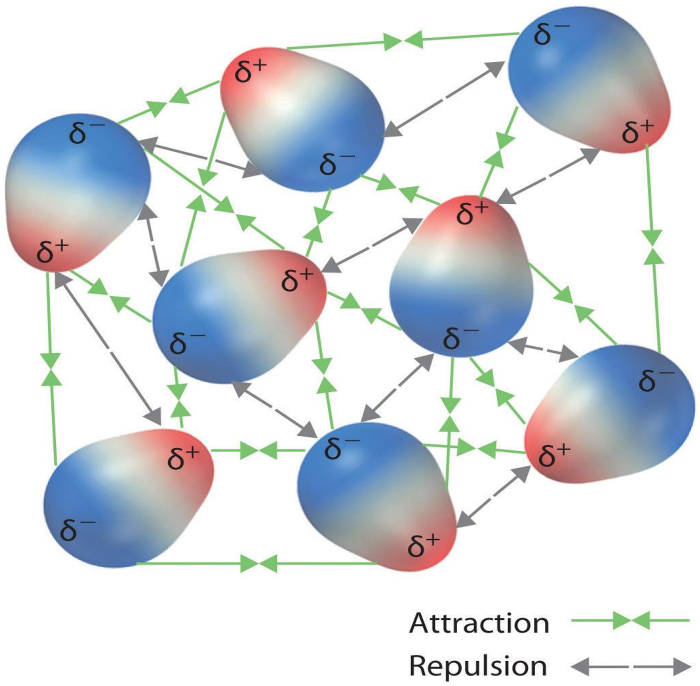
As they are an electrostatic attraction, the strength of DP-DP interactions are affected by:

1) The distance between both molecules

- Molecules that are further apart will experience a weaker attraction to one another

2)The degree of charge separation (ie. how polar are they?)

- Molecules with a smaller charge separation will experience a weaker attraction

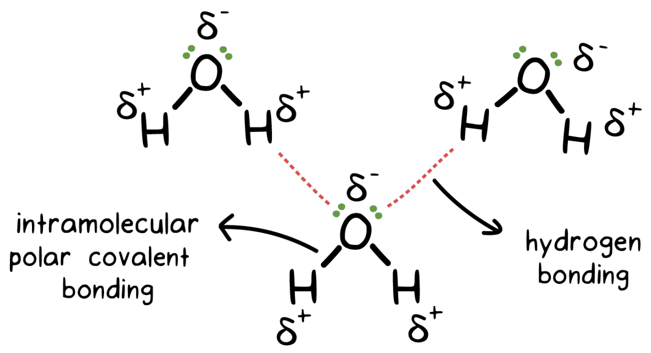


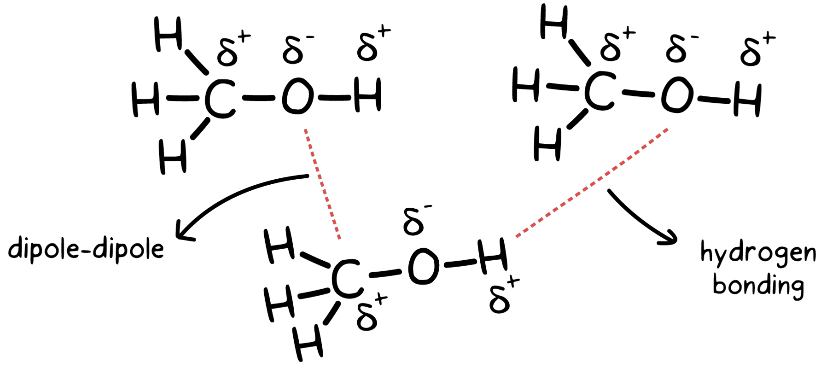
INTERmolecular Forces

Hydrogen Bonding (Strong version of Dipole-Dipole)

When Hydrogen is a part of a dipole with O, F or N, it is a special case of Dipole-Dipole Interaction

- Dipole-Dipole but STRONGER than other forms of Dipole-Dipole due to large ΔEN between H and the atom (N,O, or F)
- Hydrogen gets a partial positive charge
  - Hydrogen is small and has no shielding electrons
  - It will attract to the lone pair of electrons on the electronegative atom of neighboring molecules
- This attraction is very strong, and gives these molecules high melting/boiling points



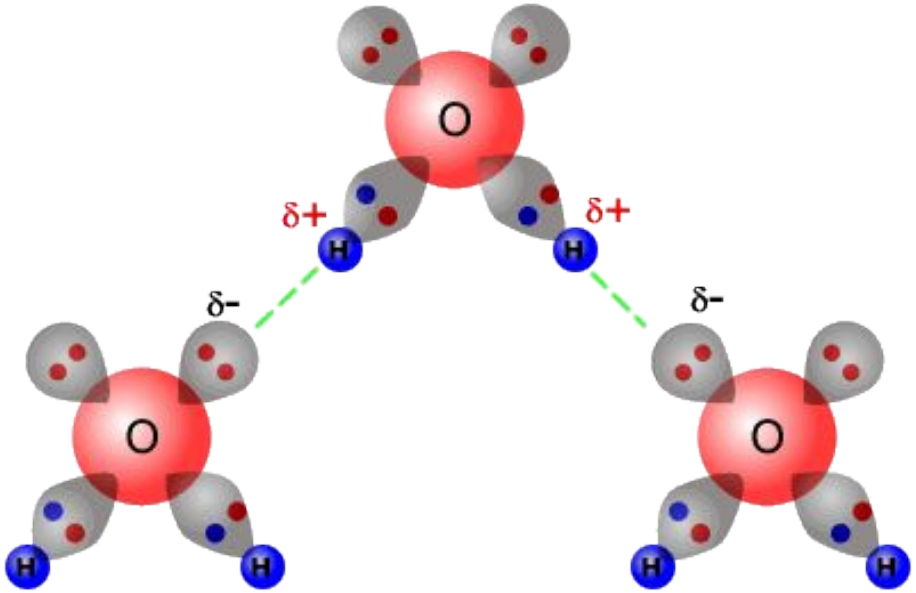


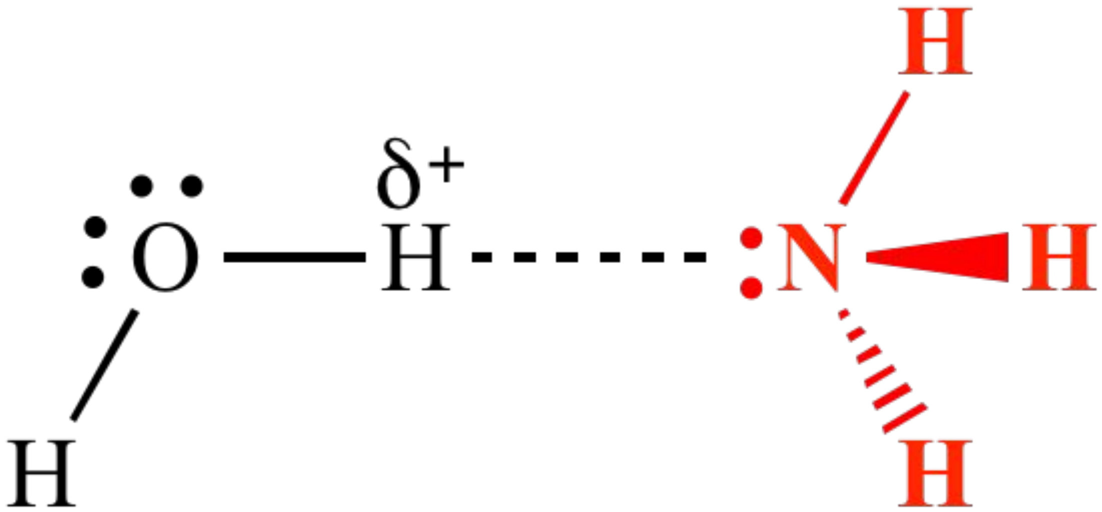
Careful! This only works when Hydrogen is bonded to N, O or F, not every single Hydrogen bond

INTERmolecular Forces

Hydrogen Bonding (Strong version of Dipole-Dipole)

Hydrogen bonding is the attraction between a **Hydrogen atom** (bonded to Oxygen, Nitrogen, Fluorine) and the **lone pair** on a neighboring atom

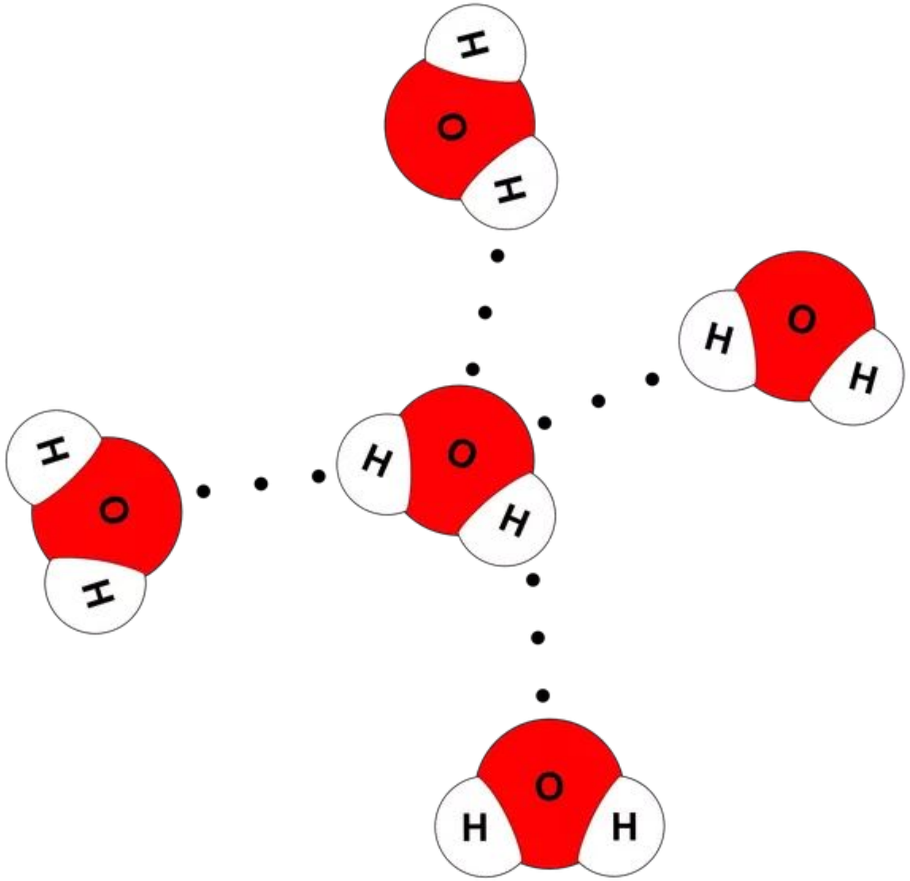




INTERmolecular Forces

Hydrogen Bonding (Strong version of Dipole-Dipole)

- Hydrogen Bonding is why water is a liquid at room temperature, not a gas.
- Each water molecule can make 4 hydrogen bonds to neighboring water molecules
  - This arrangement is one reason why ice is less dense than liquid water

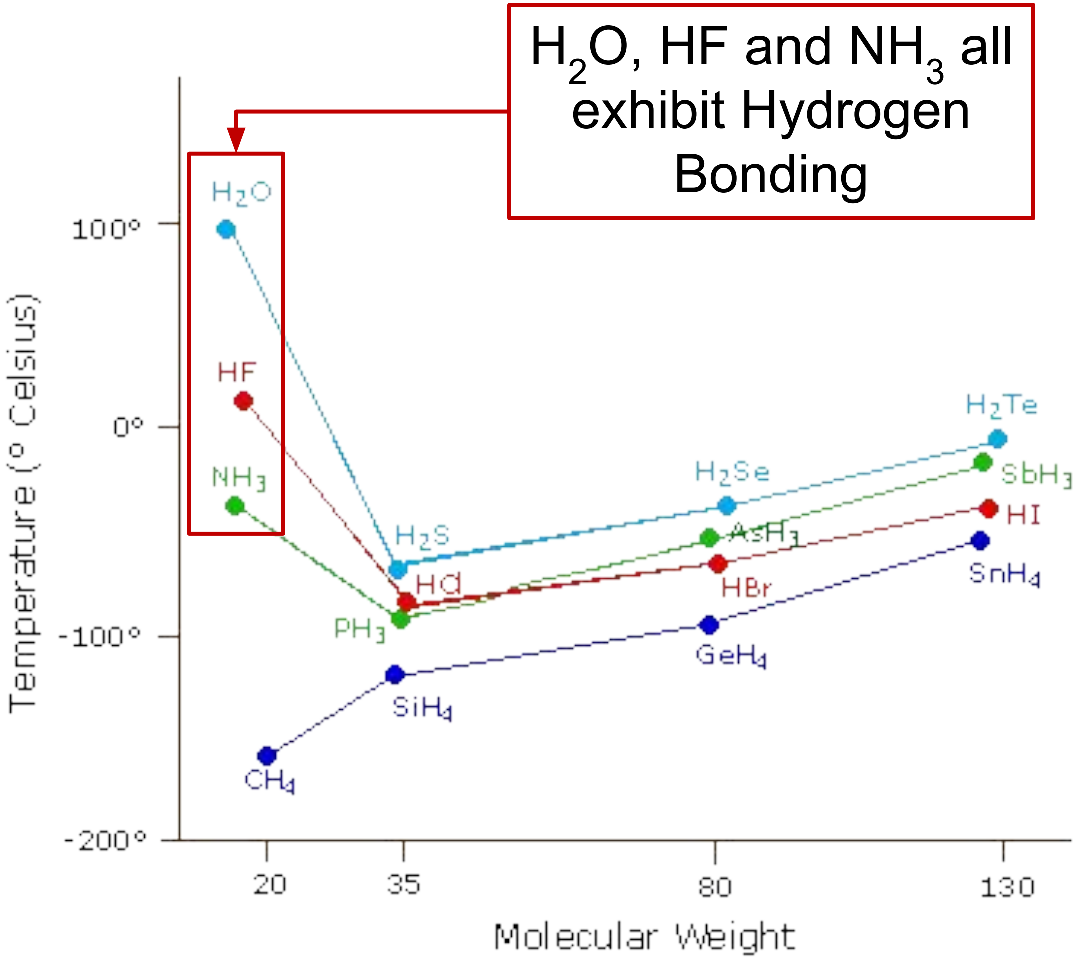


Substance	Molar Mass ($gmol^{-1}$)	Melting Point (°C)
H_2O	18.02	0
H_2S	34.1	-60.1

INTERmolecular Forces

Hydrogen Bonding (Strong version of Dipole-Dipole)

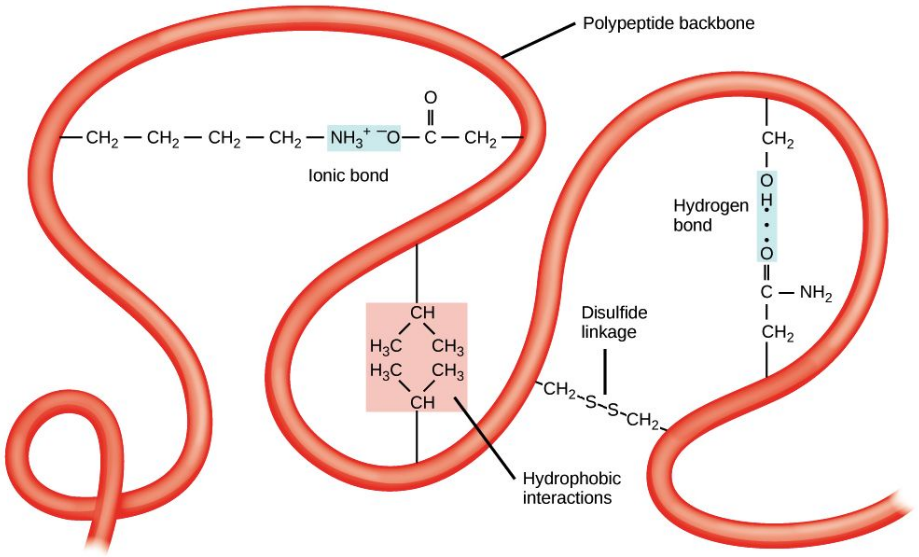
- The hydrogen bond causes the boiling points of molecules with Hydrogen Bonding to be higher than predicted (due to LDF and DP-DP)

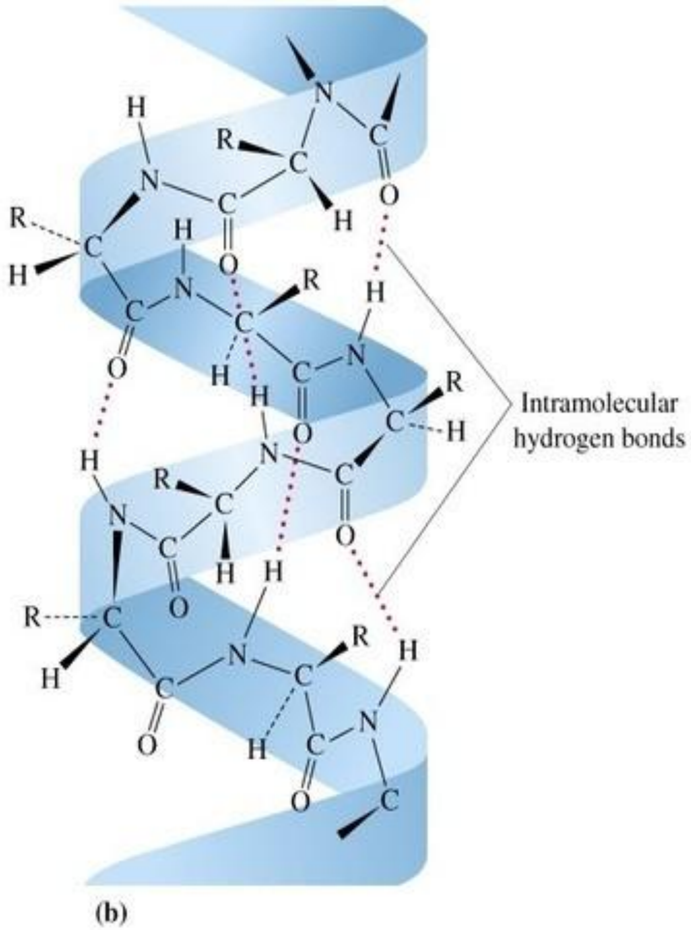


INTERmolecular Forces

Hydrogen Bonding (Strong version of Dipole-Dipole)

- This is specifically important for proteins, whose shape is held together by specific angular bonding, which includes hydrogen bonding
- This is one of the reasons why DNA spirals!



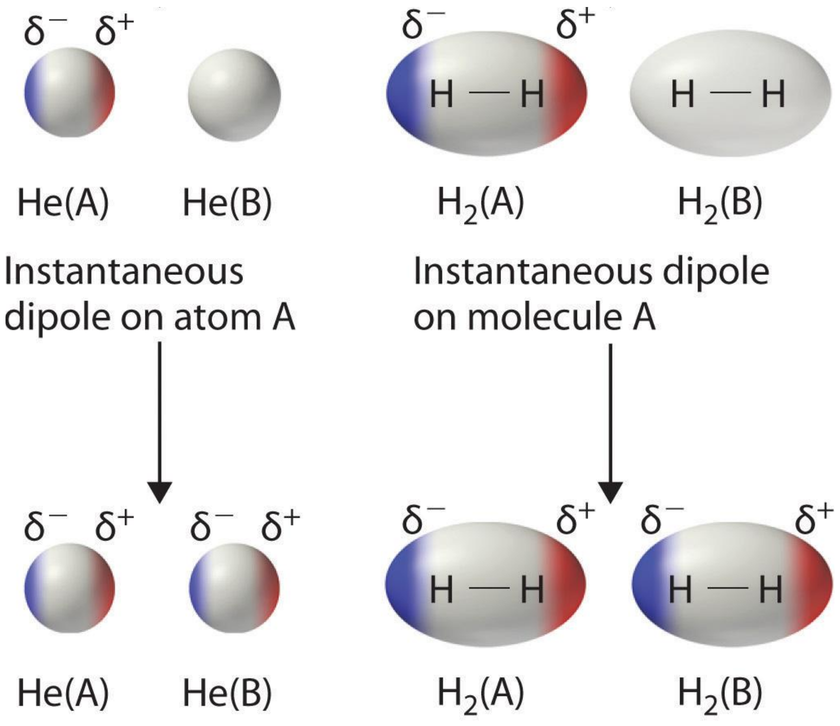


INTERmolecular Forces

London Forces (Weakest Intermolecular Force)

Occur in ALL molecules

- Attraction of proton from one molecule to electrons of another molecule due to temporary fluctuations in the electron cloud shifting randomly within atoms and nonpolar molecules result in the formation of short-lived instantaneous dipole moments

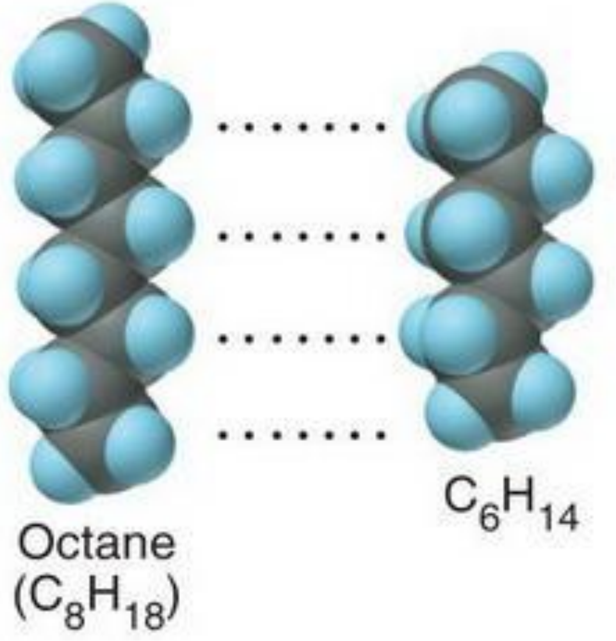


- Once an instantaneous dipole is formed on a molecule or atom, the partial charges can induce a dipole on neighboring atom or molecules
    - This induced dipole will be complimentary to the instantaneous dipole, causing an electrostatic attraction to form between both molecules

INTERmolecular Forces

London Forces (Weakest Intermolecular Force)

- These interactions are SO much weaker than the others, that we only study them in terms of non-polar (pure) covalent molecules
  - They are overpowered by the other forces
- They are dependent on size □ the larger the molecule, the stronger their London Forces, because as they increase in mass, they also increase in number of electrons.
  - This increases the number that can be temporarily unbalanced to one side, therefore increasing the strength of LDF.
- Examples of molecules that only have LDF forces:
  - Noble Gases (eg. He or Ar) Diatomic elements (eg. H_2 or F_2)
  - Non-Polar molecules (eg. CO_2 or CH_4)



INTERmolecular Forces

London Forces (Weakest Intermolecular Force)

Substance	# of electrons	Melting Point (°C)	Boiling Point (°C)
F_2	18	−219.6	−188.1
Cl_2	34	−101	−34
Br_2	70	-7.2	58.8
I_2	106	113.7	184

Compare these two data sets for the same group of elements. Where are they on the periodic table? What explains the trend in M.P. & B.P. ?

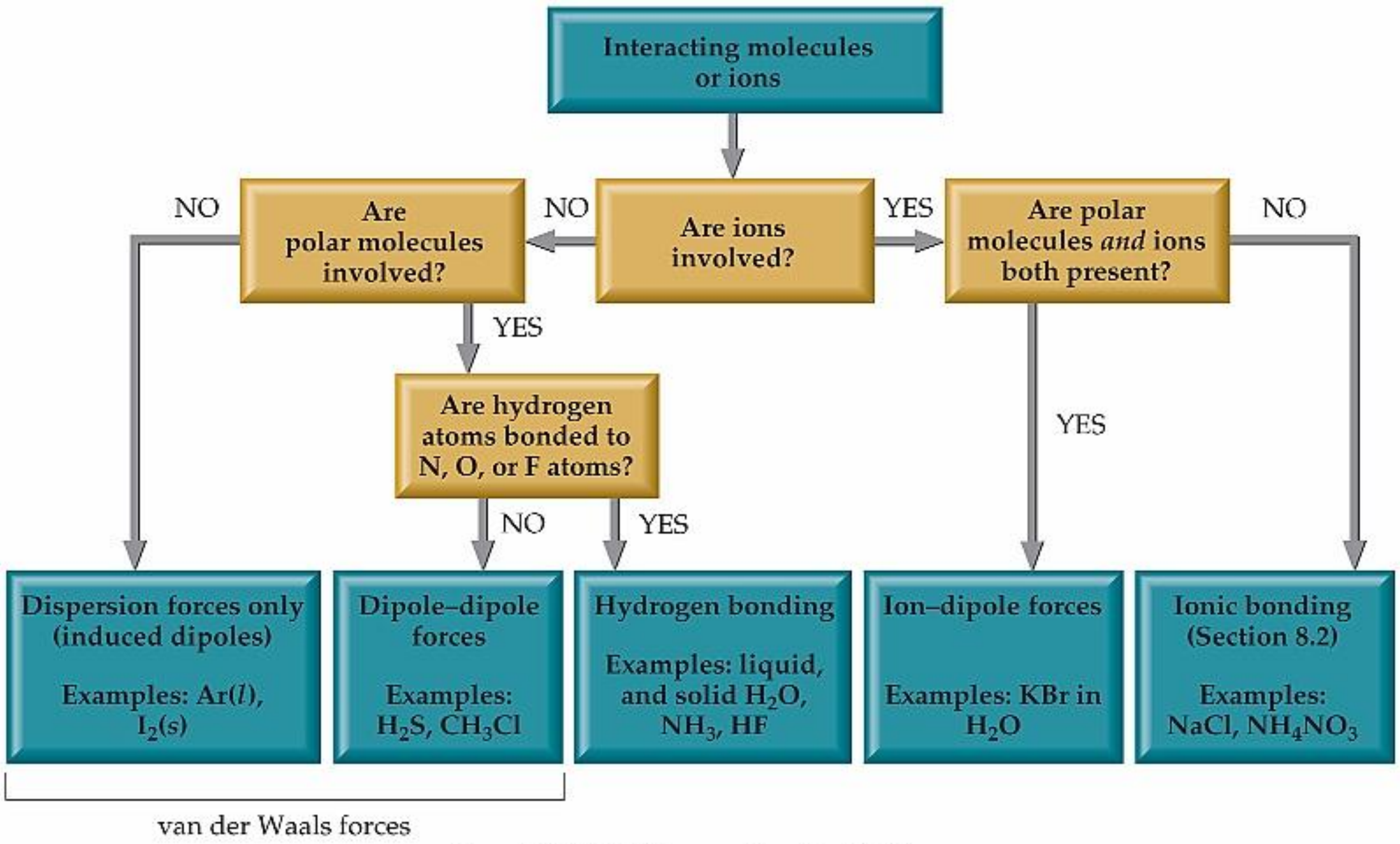
Note: Surface Area of the molecule/atom also impacts LDF

- A larger surface area increases the overlap area for the dipoles
- Therefore, a particle with a larger SA will have a higher LDF

- As atoms get bigger, more London Dispersion Forces so more attraction between molecules (not atoms within molecule) and therefore higher B.P & M.P.
- Substances that only have LDF will generally have very low melting and boiling points
  - The presence of any other IMF will greatly increase BP

Force	Type of Compound	Example	Rel. Strength
Ion-Ion (Electrostatic)	Ionic	NaCl	Strongest
Ion-Dipole	Ionic and Polar	Salted Water	2nd Strongest
Hydrogen Bonding	Polar (with H)	NH_3	Middle (stronger than other Dipole-Dipole)
Dipole-Dipole	Polar Covalent	HCl	Middle
London Forces	All (Non-Polar too)	Cl_2	Weakest

Decision Flow Chart

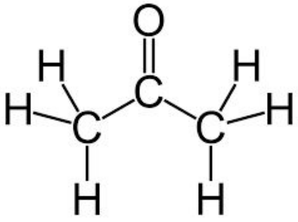


-----> Increasing Strength of attractions --->

**London dispersion force is a sub-type of the Van der Waals force that is predominant in non-polar molecules.

Determine what kind of intermolecular forces exist in the substances below.

a) Acetone



C=O is polar bond, rest are non-polar so overall molecule is polar

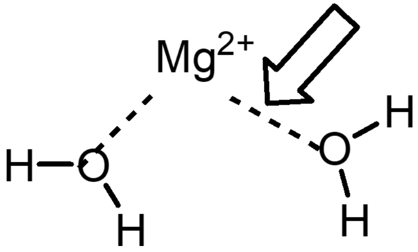
IMF: Dipole-Dipole, London Forces

b) Nitrogen Gas

N=N is non-polar bond so overall molecule is non-polar

IMF: London Forces

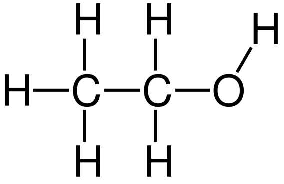
c) Dissolved Mg ion



O-H is a polar bond, Mg^{2+} is ionic

IMF: Ion-Dipole, London Forces

d) Ethanol



C-H, and C-C are non-polar & O-H is polar

IMF: Hydrogen Bonding, (Dipole-dipole) London Forces

e) Carbon Dioxide

C-O is a polar bond, but the dipoles cancel out

IMF: London Forces

Note!

If you are asked to rank molecules in order of melting point, boiling point, viscosity, surface tension or other affected property, what they are actually asking is for you to rank them by strength of <u>intermolecular forces</u> (either increasing or decreasing)

Thinking Process for answering these:

i. Look for molecules with hydrogen bonding. They will have the strongest intermolecular forces.
ii. Look for molecules with dipoles. These will have the next strongest intermolecular forces.
iii. Larger molecules will have stronger London dispersion forces. These are the weakest intermolecular forces BUT will often be the deciding factor in multiple choice questions.

Apply the strategy from the yellow slide to the following questions. Write out your thinking!

1. List the following molecules in order of increasing surface tension: C_3H_8, CH_4, CH_3COOH, C_2H_6.

Higher surface tension corresponds to stronger intermolecular forces.

1. One of these (CH_3COOH) has the ability to hydrogen-bond. It will probably have the strongest intermolecular forces.
2. CH_3COOH is the only one of these molecules to have a dipole, and we already decided it has the strongest intermolecular forces.
3. Of the molecules that are left, the largest one (C_3H_8) likely has the strongest London dispersion forces. The smallest (CH_4) likely has the weakest intermolecular forces.

The answer is: CH_4, C_2H_6, C_3H_8, CH_3COOH

Apply the strategy from the yellow slide to the following questions. Write out your thinking!

2. List the following molecules in order of increasing boiling point: Br_2, F_2, I_2, Cl_2.

Higher boiling points will correspond to stronger intermolecular forces.

1. None of these have hydrogen bonding.
2. None of these have dipoles.
3. Bigger molecules will have stronger London dispersion forces. So I_2 has the strongest forces, and F_2 will have the weakest. Correspondingly, I_2 will have the highest boiling point and F_2 will have the lowest boiling point.

Answer: F_2, Cl_2, Br_2, I_2