Intramolecular Forces vs. Intermolecular Forces

- We already talked about the ionic bonds that exist in ionic compounds
  - ✳ Recall that an ionic bond is due to the electrostatic attraction between the cations and anions that make up the ionic compound

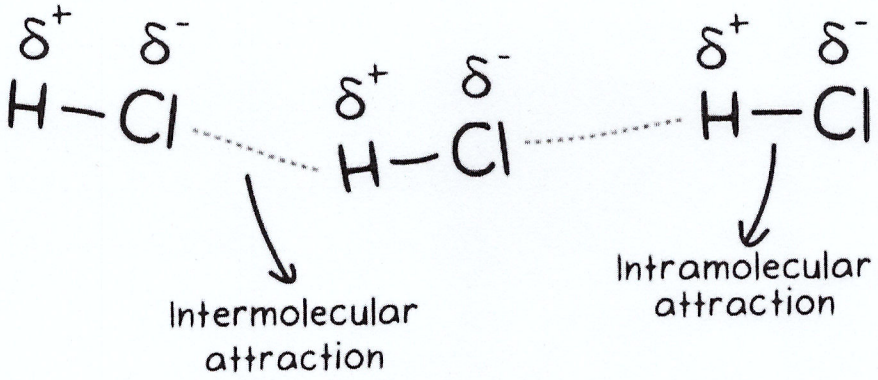
- ✳ In contrast, we have already discussed how covalent bonds (both polar and nonpolar) exist in molecular compounds due to a sharing of electrons between atoms

- Ionic bonds and covalent bonds are both examples of *intramolecular forces*
  - **Intramolecular forces** are the that hold atoms together *within a molecule*

know the difference

- **Intermolecular forces** are the forces that exist *between molecules*

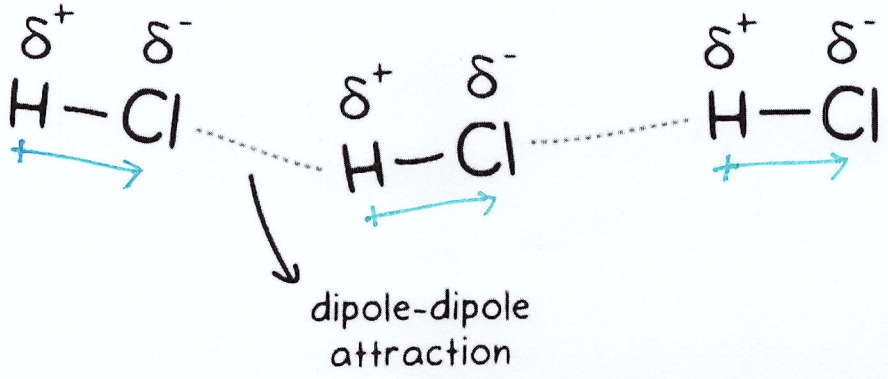
- Tip: to help remember the difference between the two
  - the "a" in intramolecular stands for **a**toms (the forces between atoms)
  - the "e" in intermolecular stands for **e**ntire molecule (forces between entire molecules)



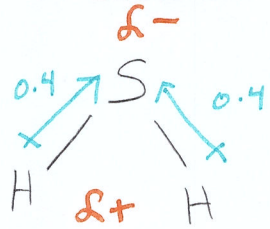
- There are three types of intermolecular forces

1. Dipole-Dipole Forces

- ✳ The electrostatic attraction between the negative poles and positive poles of polar molecules create **dipole-dipole forces**.
  - Dipole-dipole forces only exist in polar molecules! Remember that polar molecules are molecular and not ionic!



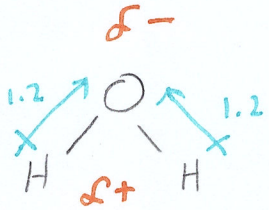
- The strength of the dipole-dipole forces increases as the polarity of the molecule increases
  - The polarity of the molecule increases as the electronegativity difference (ΔEN) between the atoms increases
  - EXAMPLE:



ΔEN = 2.6 − 2.2

ΔEN = 0.4

vs



ΔEN = 3.4 − 2.2

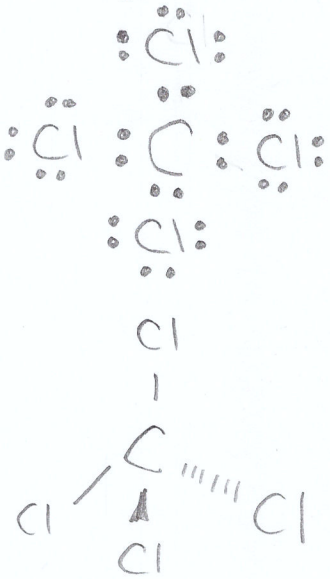
ΔEN = 1.2

∴ has stronger dipole–dipole forces b/w molecules than H_2S

- EXAMPLE: When comparing $CCl_{4(l)}$, $CH_3Cl_{(l)}$, and $CHCl_{3(l)}$, which would have dipole-dipole forces between molecules?

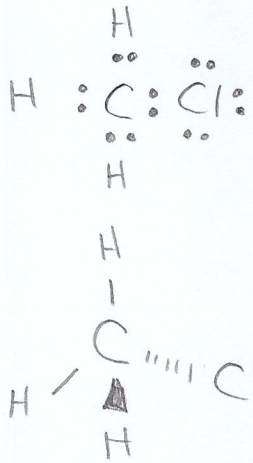
Only occurs in polar molecules!

C = 4 ve⁻
Cl = 7 ve⁻ (×4)
= 32 ve⁻



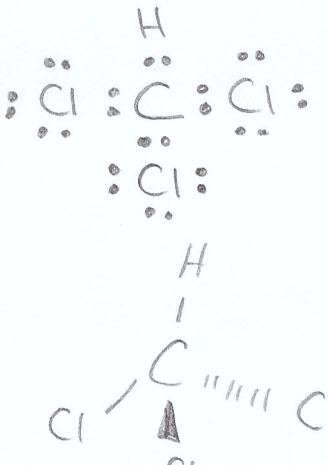
symmetrical
= not polar
∴ no dipole-dipole forces

C = 4 ve⁻
H = 1 ve⁻ (×3)
Cl = 7 ve⁻
= 14 ve⁻



not symmetrical
= polar
∴ has dipole-dipole forces

C = 4 ve⁻
H = 1 ve⁻
Cl = 7 ve⁻ (×3)
= 26 ve⁻

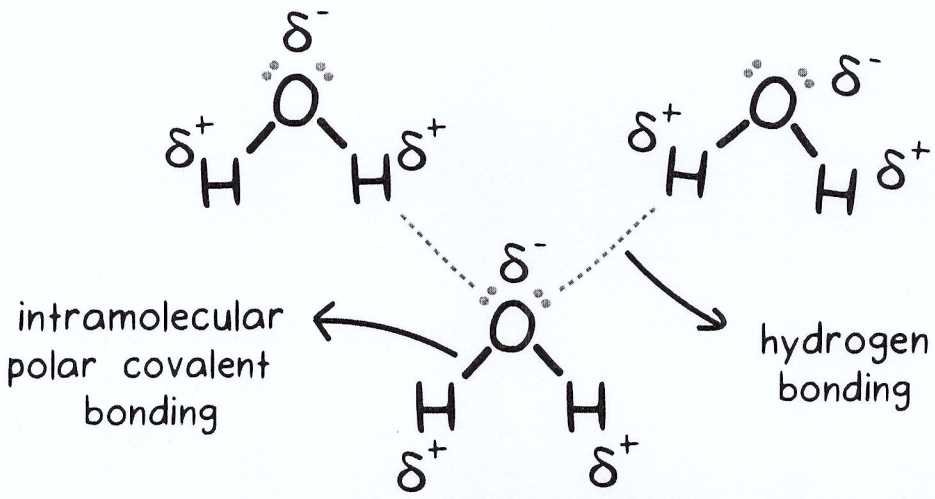


not symmetrical
= polar
∴ has dipole-dipole forces

*****Now try Practice Problem #1, 2*****

2. Hydrogen Bonding

- Hydrogen bonding is a special type of dipole-dipole interaction that is very strong
- When a hydrogen atom is covalently bonded to a highly electronegative atom (oxygen, nitrogen or fluorine), the electronegative atom pulls the electrons away from the hydrogen
  - Therefore, hydrogen bonding can only exist in molecules that have O---H, N---H, or F---H bonds
- Since hydrogen has no other electrons than the one bonding electron, the positive proton in the nucleus is mostly exposed
- The electrostatic attraction between the exposed proton (or nucleus) of the hydrogen atom and the partial negative charge of the highly electronegative atom on the adjacent molecule creates a strong **hydrogen bond**



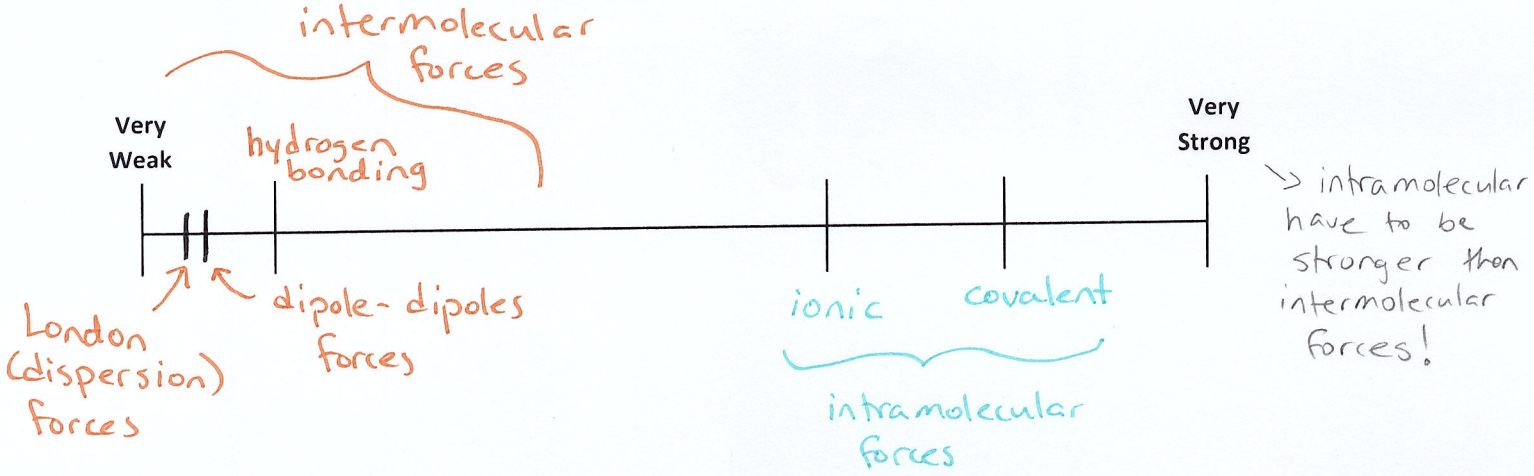
3. London (Dispersion) Forces

- London (dispersion) forces are the attractive forces that act between *all molecules*
- London (dispersion) forces are the only forces that exist between nonpolar molecules and are very weak
- Non-polar molecules can spontaneously form temporary dipoles due to the fact electrons in atoms and molecules are in constant rapid motion
  - For a brief instant, the distribution of electrons can become distorted so that one point in a molecule is slightly positive and another point is slightly negative.
  - This temporary dipole (ie. charge separation) induces/creates a temporary dipole in the molecules beside it
  - This process spreads/ "disperses" through the substance so the molecules are attracted together by this weak force

FYI only!

- The strength of London (dispersion) forces depends on the size of the molecule
  - The London (dispersion) forces will be stronger with larger molecules because larger molecules have more electrons to increase the probability of a temporary dipole forming

- Comparing the relative strengths of intramolecular and intermolecular forces



EXAMPLES:

1. In which compound, $H_2O_{(l)}$ or $NH_{3(g)}$, will the hydrogen bonding be stronger?

greater ΔEN = stronger bond

O—H
$\Delta EN = 3.4 - 2.2$
$\Delta EN = 1.2$

N-H
$\Delta EN = 3.0 - 2.2$
$\Delta EN = 0.8$

∴ H_2O will have stronger hydrogen bonding than NH_3

2. Distinguish what intermolecular bonds exist between CS molecules and CO_2 molecules.

* definitely no hydrogen bonding b/c H-O, H-N, or H-F bonds are not present!

C = 4 ve⁻
S = 6 ve⁻
= 10 ve⁻

C≡S

$\Delta EN = 2.6 - 2.6$
$\Delta EN = 0$

∴ nonpolar covalent bond, making the molecule non-polar

∴ only has (dispersion) forces

C = 4 ve⁻
O = 6 ve⁻ (x2)
= 16 ve⁻

0.8 0.8
O—C=O

$\Delta EN = 3.4 - 2.6$
$\Delta EN = 0.8$

∴ polar covalent C-O bonds, but molecule is nonpolar b/c of symmetry
∴ only has London

3. Rank the following substances that from the strongest to weakest bond strength with themselves.

↳ ie. intermolecular forces

sodium chloride, $NaCl_{(s)}$

↓

ionic compound

∴ ionic bonding = strongest

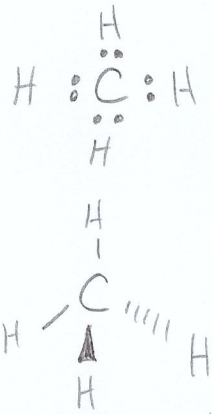
methane, $CH_{4(g)}$

↓

C = 4 ve⁻

H = 1 ve⁻ (x4)

= 8 ve⁻



symmetrical

= nonpolar molecule

∴ only London (dispersion) forces

paraffin wax, $C_{20}H_{42(s)}$

↓

molecular compound that is nonpolar

∴ only London (dispersion) forces

ammonia, $NH_{3(l)}$

↓

molecular compound with H–N bonds

∴ hydrogen bonding is present

$NaCl, NH_3, C_{20}H_{42}, CH_4$

larger molecule = stronger London (dispersion) forces

*****Now try Practice Problems #3-10*****

Practice Problems

1. Distinguish between dipole-dipole attractive forces and an ionic bond.

2. Compare $NH_{3(g)}$ and $C_2H_{4(g)}$ by
   a. identifying the intramolecular forces that exist in each molecule (ie. ionic, nonpolar covalent, or polar covalent).
   b. identifying which molecule/(s) form dipole-dipole attractions amongst themselves (ie. $NH_{3(g)}$,$C_2H_{4(g)}$ or both).

3. Compare CH_3F and NH_2F by
   a. identifying the intermolecular forces that exist between molecules of each compound.
   b. identify which compound has a stronger intermolecular force.

4. Identify which substance will have the weakest intermolecular forces, $CH_3Cl_{(l)}$ or $CHCl_{3(l)}$.

5. Rank the following four moleucles from weakest to strongest intermolecular forces: H_2S, NH_3, H_2, H_2O

6. Dipole-dipole interactions are also known as Keesom forces, named after Willem Hendric Keesom. Keesom developed the theory of interactions between molecules with a permanent dipole. Which one of the following compounds will **not** have Keesom forces between its molecules?
   a. HCl
   b. NH_3
   c. H_2O
   d. CCl_4

7. Which of the following is not an example of an intramolecular bond or force?
   a. The bond between potassium and chlorine in potassium chloride.
   b. The bond between hydrogen and chlorine in hydrogen chloride.
   c. The force that binds together the atoms of sodium.
   d. The attraction between two molecules of ethanol.

8. Identify the substance that has hydrogen bonding.
   a. methanol, $CH_3OH(l)$
   b. carbon dioxide, $CO_2(g)$
   c. difluormethane, $CH_2F_2(l)$
   d. fluoromethane, $CH_3F(l)$

9. Which intermolecular force is found in each of the following compounds: Cl_2, CO_2, N_2O_4, CH_4?
   a. Dipole-dipole forces
   b. London (dispersion) forces
   c. Hydrogen bonding
   d. Covalent bonding

10. Between molecules of which of the following compounds will London (dispersion) forces be the greatest?
   a. n-hexane, $CH_3(CH_2)_4CH_3$
   b. 2,2-dimethyl propane, $CH_3C(CH_3)_2CH_3$
   c. 2-methylbutane, $CH_3CH(CH_3)CH_2CH_3$
   d. butane, $CH_3(CH_2)_2CH_3$

Answers to Practice Problems

1.) • dipole-dipole forces are due to the electrostatic attraction b/w the negative & positive ends of polar molecular compounds

• an ionic bond is due to the electrostatic attraction b/w a cation & anion

2.) a.) N—H

$\Delta EN = 3.0 - 2.2$

$\Delta EN = 0.8$

∴ N-H bonds are polar covalent

C-H

$\Delta EN = 2.6 - 2.2$

$\Delta EN = 0.4$

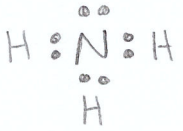
∴ C-H bonds are polar covalent

∴ both molecules have polar covalent intramolecular forces

b.) N = 5 ve⁻

H = 1 ve⁻ (x3)

= 8 ve⁻



not symmetrical

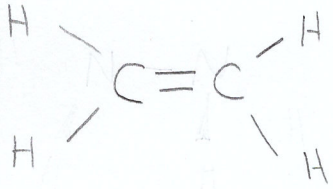
= polar

∴ has dipole-dipole forces

C = 4 ve⁻ (x2)

H = 1 ve⁻ (x4)

= 12 ve⁻



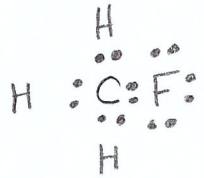
symmetrical

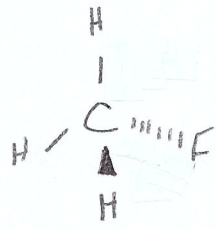
= not polar

∴ no dipole-dipole forces

3.) a.)

C = 4 ve⁻
H = 1 ve⁻ (x3)
F = 7 ve⁻
= 14 ve⁻





not symmetrical
= polar molecule
∴ dipole-dipole forces exist

N = 5 ve⁻
H = 1 ve⁻ (x2)
F = 7 ve⁻
= 14 ve⁻

not symmetrical
= polar molecule
∴ dipole-dipole forces exist
this molecule also has hydrogen bonding due to the N-H bond

b.) NH_2F has stronger intermolecular forces

4.) Both $CHCl_3$ & CH_3Cl are polar molecules with dipole-dipole forces. However $CHCl_3$ has more electrons than CH_3Cl, therefore $CHCl_3$ will have stronger London (dispersion) forces.
∴ CH_3Cl will have the weakest intermolecular forces.

5.) H_2 - weakest b/c it is linear in shape with a nonpolar covalent bond H — H

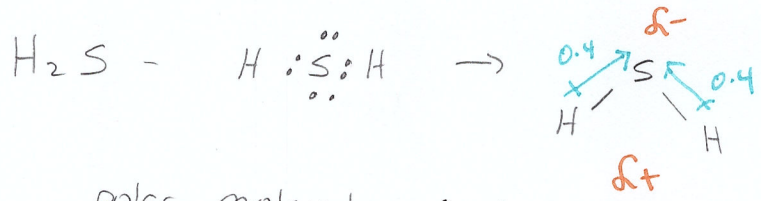
∴ only London (dispersion) forces exist

NH_3 & H_2O have hydrogen bonding

N — H
ΔEN = 3.0 - 2.2
ΔEN = 0.8

H — O
ΔEN = 3.4 - 2.2
ΔEN = 1.2

H_2O will have stronger hydrogen bonding than NH_3 b/c of the greater difference in electronegativity b/w the atoms

H_2S - 

polar molecule ∴ H_2S has dipole - dipole forces

H_2, H_2S, NH_3, H_2O
weakest ⟶ strongest

6.) D

7.) D

8.) A

9.) B

10.) C