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VCE Chemistry ½
Intermolecular Bonding [1.8]
Workbook

Outline:

Learning Objectives:

- ☐ **CH12 [1.8.1]** - Explain how dispersion forces form & identify molecules that can exhibit them
- ☐ **CH12 [1.8.2]** - Explain how dipole-dipole attractive forces form & identify molecules that can exhibit them
- ☐ **CH12 [1.8.3]** - Explain how hydrogen bonds form & identify molecules that can exhibit them
- ☐ **CH12 [1.8.4]** - Apply intermolecular bonding to compare molecules' melting & boiling points

Section A: Intermolecular Bonding

Sub-Section: Types of Bonding

Context

- Covalent bonds, ionic bonds, and metallic bonds are examples of **intramolecular bonds**.

What even is a bond?

Chemical Bond

- **Definition:**
  - A chemical bond is a strong force of attraction.
- There are two main categories of chemical bonds covered in VCE Chemistry. They include:
  - Intramolecular Bonds.
  - Intermolecular Bonds.

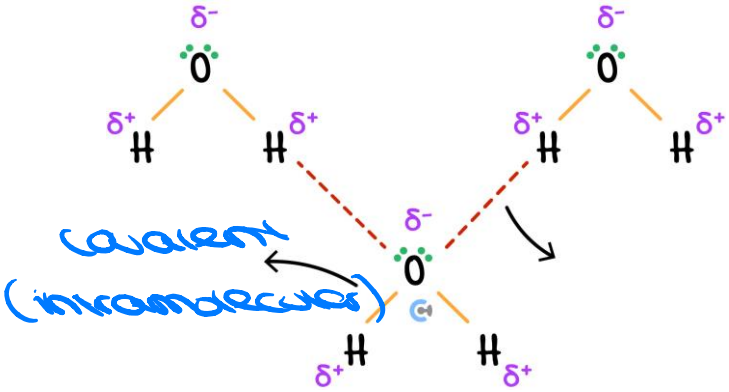
Discussion: What is the difference between intramolecular and intermolecular bonding?

between molecules

Space for Personal Notes

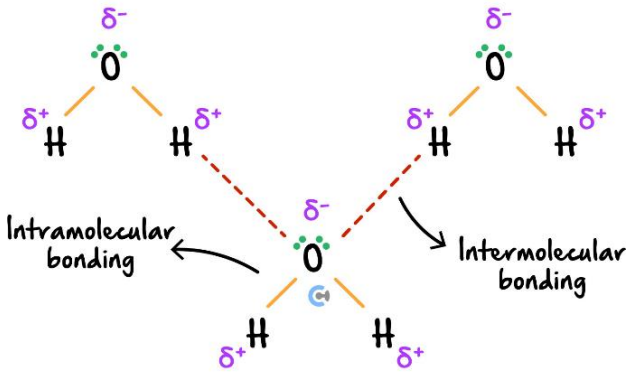
Exploration: Intramolecular vs Intermolecular Bonds

- Consider 3 water molecules:
- Type of bond between O and H: [Covalent] / [Ionic] / [Metallic]
- Location of covalent bond: [Within] / [Between]
- As such, what type of bond is it? *(Label Below)*
- What bonds exist **between** each of the molecules of water? *(Label Below)*



Intramolecular vs Intermolecular Bonding

- Intramolecular bonding - happens _____ molecules.
- Intermolecular bonding - happens _____ molecules.



TIP: You can think of intermolecular as going between molecules as international flights go between countries.

Sub-Section: Dispersion Forces

Let's have a look at the first type of intermolecular bonding!

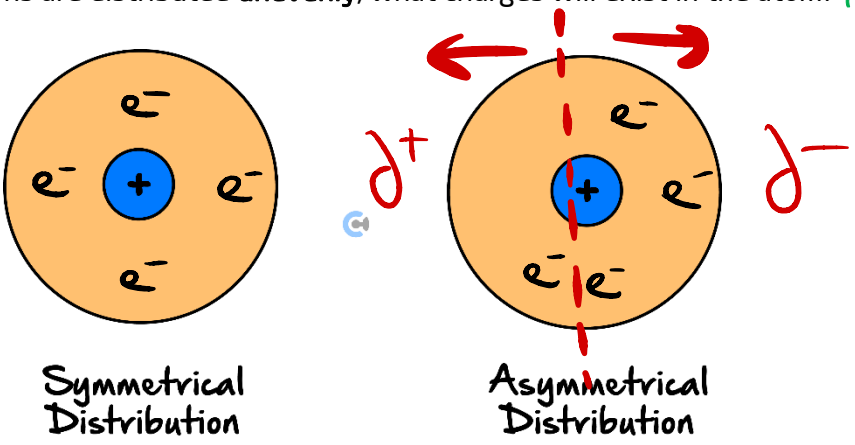
Active Recall: What is a dipole?

uneven e⁻ distribution → δ+ end

δ⁻ end

Exploration: Dispersion Forces

- Inside atoms, electrons exist in a region of space called the electron cloud.
  - The electrons inside this electron cloud move around randomly
- Consider Beryllium:
  - The electrons *could* be distributed symmetrically. *(Label Below)*
  - However, as they move randomly, they *could* also be distributed asymmetrically. *(Label Below)*
  - When the electrons are distributed **unevenly**, what charges will exist in the atom? *(Label Below)*

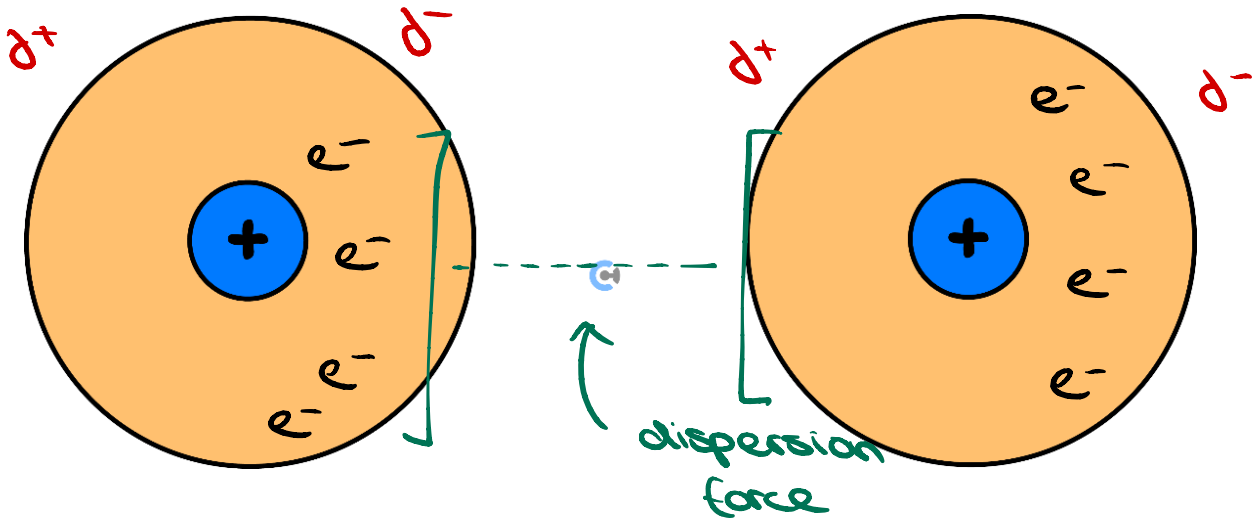


- Electron Movement: [Fixed Positions] / [Constant Motion]
- Will they remain in these positions for a long time? [Yes] / [No]

- Dipole Formation: [Temporary] / [Permanent]

- Consider two molecules, both of which have a **temporary, uneven** distribution of electrons. *(Label Below)*

- What type of **intermolecular bond** will form between the two molecules? *(Label Below)*

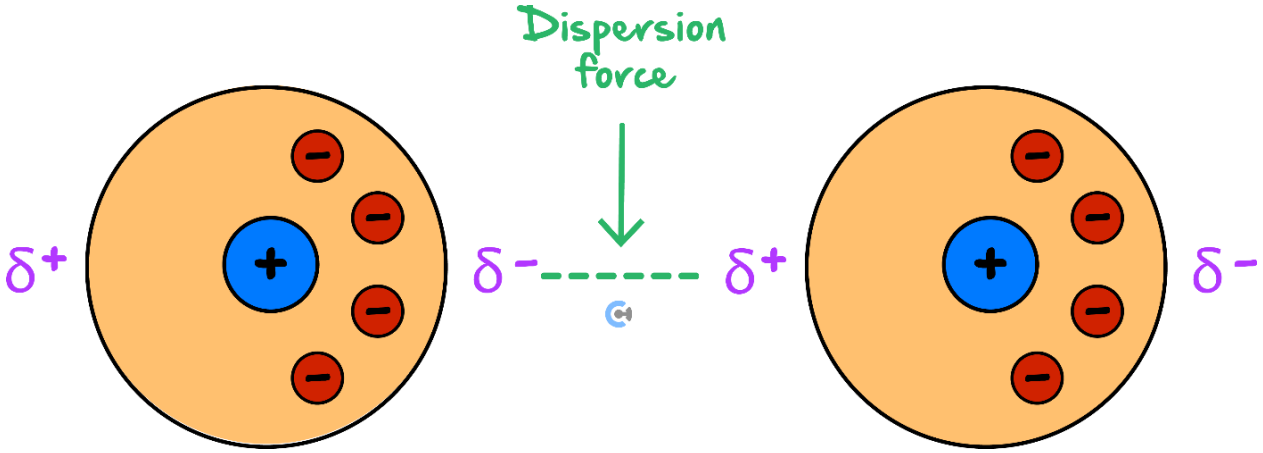


Dispersion Forces

- **Definition:**

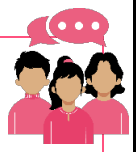
  - When two or more **temporary** or ~~instantaneous~~ dipoles come together, arising from the **asymmetrical** distribution of electrons.

  - Arises due to electrons randomly moving in molecules and temporarily group together on one side.



Discussion: Are dispersion forces a strong type of intermolecular bond?

weak



Discussion: Which molecules have dispersion forces?

everything

NOTE: Dispersion forces are the weakest type of intermolecular bonding that exists, as they are **[temporary] / [permanent]** and last for short periods of time.

ALSO NOTE: Dispersion forces occur in every molecules.

Are dispersion forces equally strong in every molecule?

Exploration: Strength of Dispersion Forces

- Will a molecule with more or less electrons have a greater chance of forming temporary dipoles?

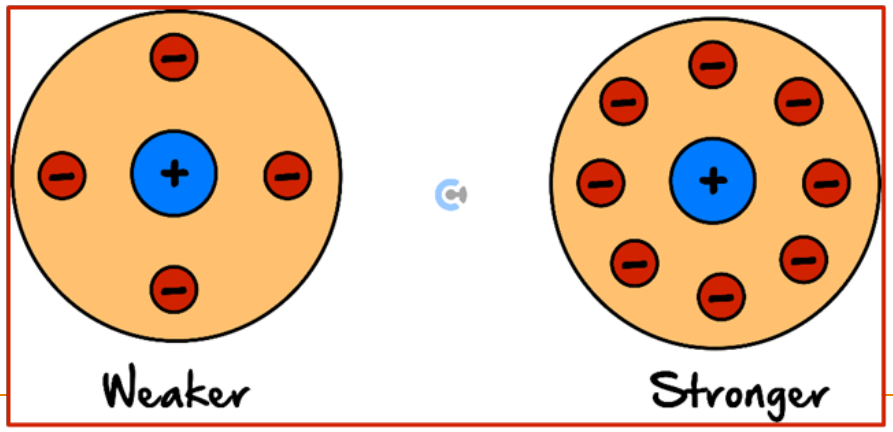
  [More] / [Less] electrons

- Will a molecule with more or less electrons have stronger dispersion forces?

  [More] / [Less] electrons

CH_4 → $C_{10}H_{22}$

- What will this look like? *(Label Below)*



Definition

Features of Dispersion Forces

- **Weakest** type of intermolecular bonding due to temporary dipoles.
- Occurs in **all** molecules.
- Atoms/molecules with **more electrons** have a **greater chance for temporary dipoles** to be formed and have **stronger** dispersion forces.

Let's have a look at a question together!

Question 1 (2 marks) **Walkthrough.**

Explain whether hydrogen gas (H_2) or fluorine gas (F_2) will form stronger intermolecular bonds.

F_2 → more e^- → more random e^- mov
∴ more instantaneous dipole ∴ ↑ disp
forces.

TIP: A quick way to figure out which molecule will have stronger dispersion forces is by checking which one has a greater atomic number/mass number!

1. Periodic table of the elements

1 **H** 1.0 hydrogen																	**2** **He** 4.0 helium
3 **Li** 6.9 lithium	**4** **Be** 9.0 beryllium											**5** **B** 10.8 boron	**6** **C** 12.0 carbon	**7** **N** 14.0 nitrogen	**8** **O** 16.0 oxygen	**9** **F** 19.0 fluorine	**10** **Ne** 20.2 neon
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atomic number — **79** **Au** 197.0 gold — symbol of element; relative atomic mass; name of element

57 **La** 138.9 lanthanum	**58** **Ce** 140.1 cerium	**59** **Pr** 140.9 praseodymium	**60** **Nd** 144.2 neodymium	**61** **Pm** (145) promethium	**62** **Sm** 150.4 samarium	**63** **Eu** 152.0 europium	**64** **Gd** 157.3 gadolinium	**65** **Tb** 158.9 terbium	**66** **Dy** 162.5 dysprosium	**67** **Ho** 164.9 holmium	**68** **Er** 167.3 erbium	**69** **Tm** 168.9 thulium	**70** **Yb** 173.1 ytterbium	**71** **Lu** 175.0 lutetium

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The value in brackets indicates the mass number of the longest-lived isotope.

Your Turn!

Question 2

State which molecule of the pair has stronger dispersion forces.

a. Methane (CH_4) vs Hydrogen Gas (H_2)

CH_4

b. Nitrogen (N_2) vs Bromine (Br_2)

Br_2

Question 3 (2 marks)

Navindu is investigating intermolecular bonding and doesn't quite understand how dispersion forces work. Explain how dispersion forces form in molecules.

- e^- move around randomly in a cloud
- this forms instantaneous dipoles
- this creates attraction b/w atoms → disp forces.

Question 4 (2 marks) Fa Ne HNFOICB

State whether Fluorine gas or Neon gas will have stronger dispersion forces. Justify your answer.

F_2 gas, ↑ e^- than Ne (g) ∴ more dispersion forces.

Question 5 (1 mark) **Additional Question.**

Select which of the following correctly explains the difference in intermolecular bonding strength between CO_2 and N_2.

A. CO_2 has stronger bonding as it is polar whereas N_2 is non-polar.

B. CO_2 is a larger molecule, making the bonds heavier and thus stronger.

C. There are more electrons present in CO_2, which increases the chance of temporary dipoles to form, thereby increasing the strength of the dispersion forces.

D. CO_2 is heavier and as such can form permanent dipoles.

Space for Personal Notes

Sub-Section: Dipole-Dipole Attraction

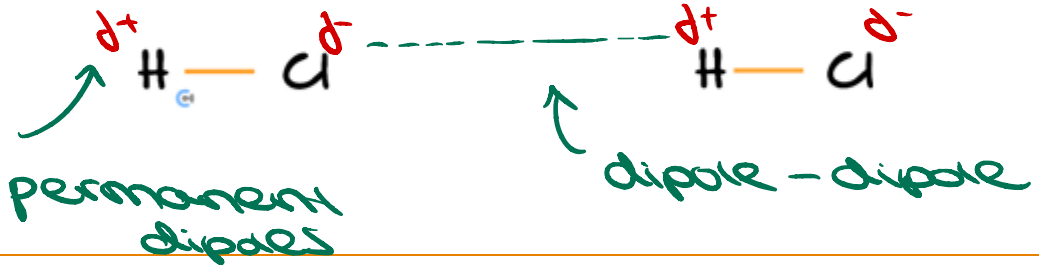
Let's take a look at another type of intermolecular bonding!

Discussion: What type of molecules contain permanent dipoles?

polar molecules

Exploration: Hydrogen Chloride (HCl) Molecules

- Two adjacent HCl molecules:
- What is the more electronegative atom? [Chlorine] / [Hydrogen]
- What are the partial charges within each of the HCl molecules? *(Label Below)*
- What will form in each HCl molecule? dipoles *(Label Below)*
- What will occur between the adjacent ends of the two molecules? *(Label Below)*
- What do we call this intermolecular bond formed? *(Label Below)*



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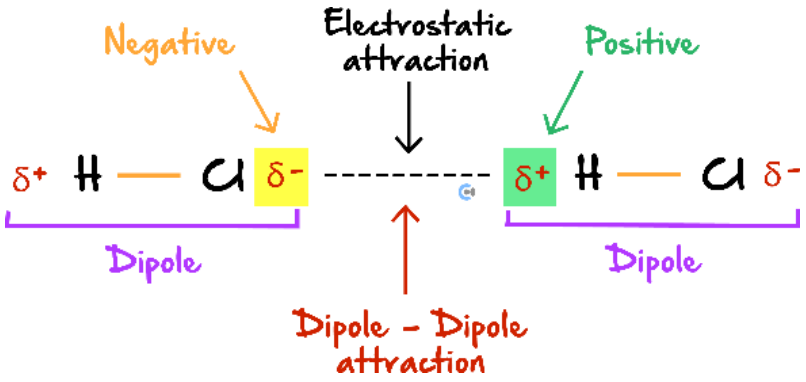
Dipole-Dipole Attraction

- **Definition:**
  - Dipole-Dipole Attractions are an intermolecular bond that occurs between **two dipoles**.
  - Dispersion forces occur in **all** molecules, but dipole-dipole attractions only occur in **polar molecules**.

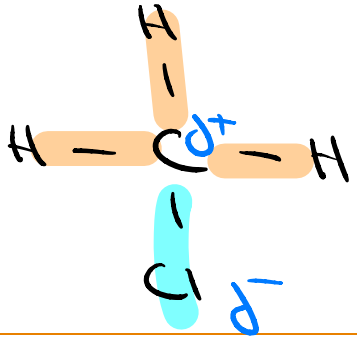


NOTE: Non-polar molecules can **only** undergo the weaker dispersion forces.

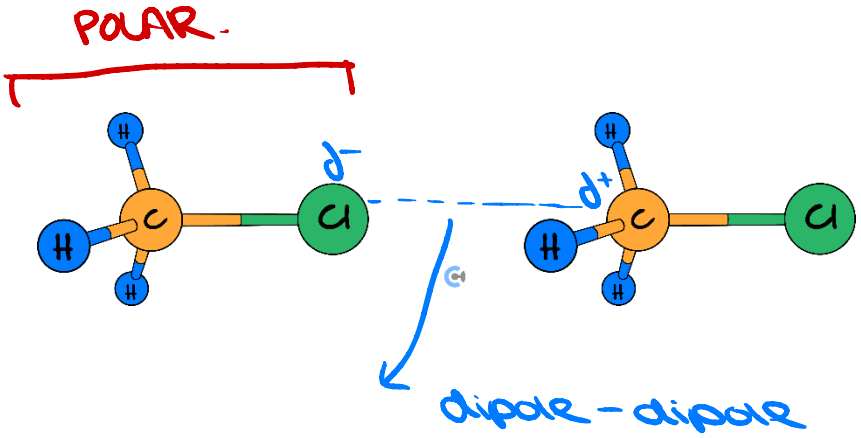
Can dipole-dipole attractions form between any polar molecules or do the molecules have to be diatomic?

Exploration: Chloromethane (CH_3Cl)

- How can the $C-H$ bond be classified? [Polar] / [Non-polar]
- Which atom is more electronegative? [Chlorine] / [Hydrogen]
- What will the partial charges and dipoles look like? *(Label Below)*



- What type of intermolecular bond will exist between the two molecules? *(Label Below)*



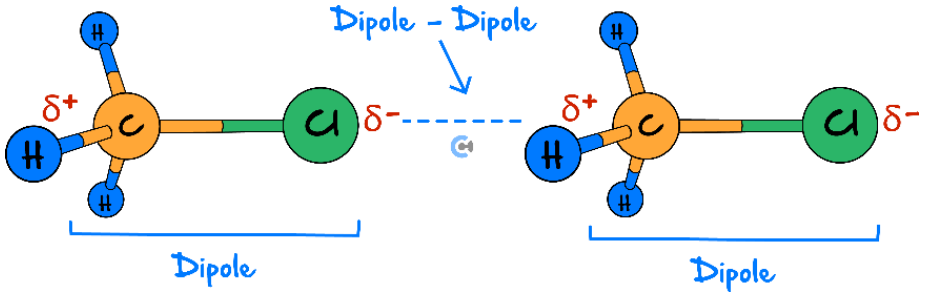
NOTE: Regardless of how the polar molecule is arranged, some parts of the polar molecule can act as a dipole, and thus dipole-dipole interactions can form.

Discussion: What type of intermolecular bonding is stronger? Dispersion forces or dipole-dipole?

dipole - dipole

Features of Dipole-Dipole Attractions

- Dipole-dipole attractive forces also exist in polar molecules that are **not diatomic**:



- Dipoles in polar molecules are permanent these are stronger than **temporary** dispersion forces.

NOTE: The **more polar** the molecule is, the stronger the dipole-dipole attraction will be.

HF HCl

Let's have a look at a question together!

Question 6 Walkthrough.

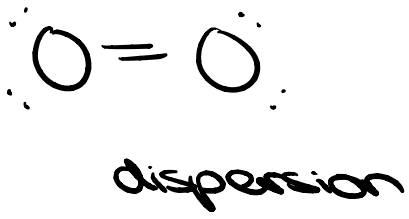
For each of the following molecules:

i. Draw the Lewis structure.

ii. Draw any relevant polarity arrows.

iii. State the strongest type of intermolecular bonding they can exhibit.

a. O_2



dispersion

b. CO_2

dispersion

c. HF

dipole - dipole

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atomic number — **79** **Au** 197.0 gold — symbol of element

relative atomic mass — name of element

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The value in brackets indicates the mass number of the longest-lived isotope.

REMINDER: Don't forget If the polarity arrows cancel due to the molecule being symmetric, the molecule is **non-polar** overall, despite having polar bonds.

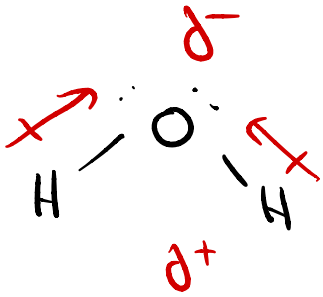
Your Turn!

Question 7 (2 marks)

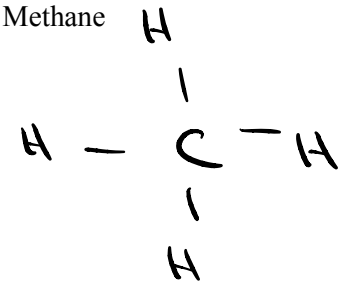
Flynn is investigating two of the most abundant chemicals used in society, methane (CH_4) and water (H_2O).

a. Draw the Lewis structures of:

i. Water



ii. Methane



b. State the polarity of:

i. Water

polar

ii. Methane

non-polar

c. Hence or otherwise, explain whether water or methane will have stronger intermolecular bonding. (2 marks)

- water → polar → strong dipole-dipole
- CH_4 → non-polar → weaker dispersion forces

Question 8 (2 marks)

Explain whether Hydrofluoric acid (HF) or Hydrochloric acid (HCl) will have stronger intermolecular bonding.

- HF → H–F ↑ e– neg difference

∴ HF has stronger dipoles ∴ stronger dipole-dipole forces

Question 9 (2 marks)

State whether Br_2 or HCl will have stronger intermolecular bonding. Justify your reasoning.

NOTE: You are not expected to know the cases in which dispersion forces overpower dipole-dipole forces of attraction, but the idea is very important!

Space for Personal Notes

Question 10 Additional Question.

For each of the following, list **all** the types of intermolecular forces present between the molecules.

a. Hydrochloric acid (HCl)

Dipole-dipole, dispersion

b. Methane (CH_4)

dispersion

c. Ammonia (NH_3)

Dipole-dipole, dispersion
(and technically H-bond but we'll cover later)

d. Methanol (CH_3OH)

Dipole-dipole, dispersion
(and technically H-bond but we'll cover later)

REMINDER: Don't forget that every molecule contains dispersion forces!

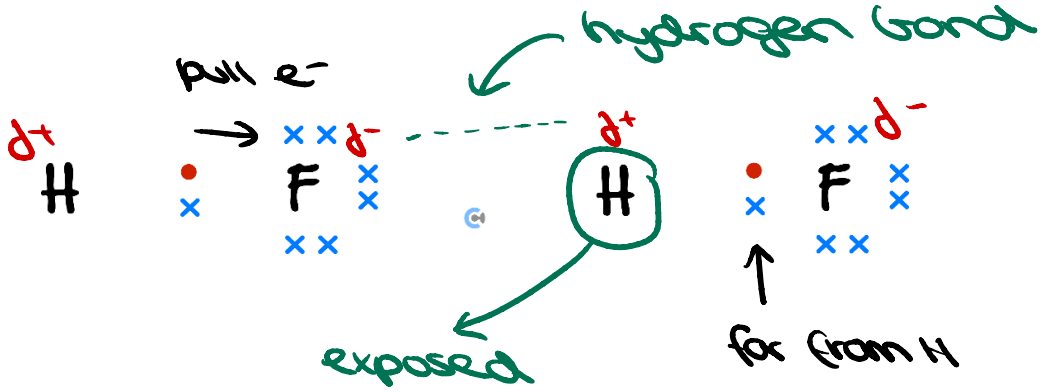
Space for Personal Notes

Sub-Section: Hydrogen Bonding

Let's have a look at the final type of intermolecular bonding!

Exploration: Hydrofluoric Acid (HF) Bonding

- Consider adjacent HF molecules:
  - What will happen to the shared pair of electrons and their partial charges? *(Label Below)*
  - What force will exist between the F on the left and the H on the right? *(Label Below)*
  - What is the electronegativity difference between H and F?
  - What will happen to the hydrogen atom? What will the fluorine atom now be able to do? *(Label Below)*



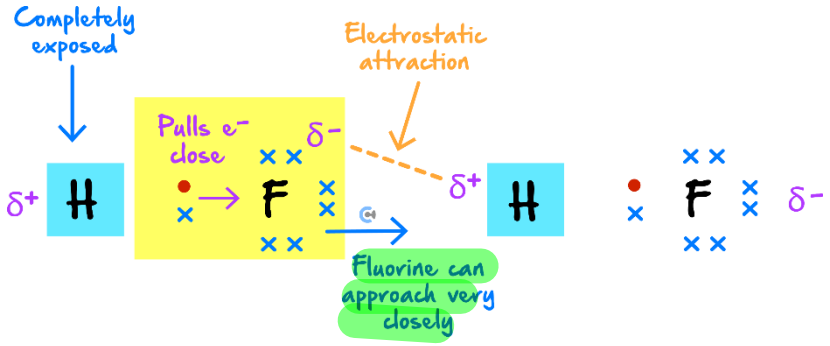
- Hence, is this a strong or weak dipole-dipole bond? [Strong] / [Weak]
- This type of bonding is given a special name, which is called a hydrogen bond.

Discussion: How does the strength of hydrogen bonding compare with dispersion forces and dipole-dipole attractions?

Strongest

Features of Hydrogen Bonding

- **Definition:**
  - Hydrogen bonds are a **special type of dipole-dipole bond** which are very strong. They are the strongest type of intermolecular bond due to:
  - The **large** electronegativity difference.
  - The hydrogen atom which is **small in nature,** allows molecules to approach close to it, as it is left exposed to the large electronegativity difference.



Discussion: What other highly electronegative elements can bond with H to form a hydrogen bond?

Exploration: Hydrogen Bond Formation

- Hydrogen Bonds can form when there are **hydrogens** that are **covalently bonded** to one of the three following atoms:
  - fluorine (F)
  - oxygen (O)
  - nitrogen (N)
- These hydrogen bonds which form are one of the strongest intermolecular bonds which exist.

1. Periodic table of the elements

1 **H** 1.0 hydrogen																	**2** **He** 4.0 helium
3 **Li** 6.9 lithium	**4** **Be** 9.0 beryllium											**5** **B** 10.8 boron	**6** **C** 12.0 carbon	**7** **N** 14.0 nitrogen	**8** **O** 16.0 oxygen	**9** **F** 19.0 fluorine	**10** **Ne** 20.2 neon
11 **Na** 23.0 sodium	**12** **Mg** 24.3 magnesium											**13** **Al** 27.0 aluminium	**14** **Si** 28.1 silicon	**15** **P** 31.0 phosphorus	**16** **S** 32.1 sulfur	**17** **Cl** 35.5 chlorine	**18** **Ar** 39.9 argon
19 **K** 39.1 potassium	**20** **Ca** 40.1 calcium	**21** **Sc** 45.0 scandium	**22** **Ti** 47.9 titanium	**23** **V** 50.9 vanadium	**24** **Cr** 52.0 chromium	**25** **Mn** 54.9 manganese	**26** **Fe** 55.8 iron	**27** **Co** 58.9 cobalt	**28** **Ni** 58.7 nickel	**29** **Cu** 63.5 copper	**30** **Zn** 65.4 zinc	**31** **Ga** 69.7 gallium	**32** **Ge** 72.6 germanium	**33** **As** 74.9 arsenic	**34** **Se** 79.0 selenium	**35** **Br** 79.9 bromine	**36** **Kr** 83.8 krypton
37 **Rb** 85.5 rubidium	**38** **Sr** 87.6 strontium	**39** **Y** 88.9 yttrium	**40** **Zr** 91.2 zirconium	**41** **Nb** 92.9 niobium	**42** **Mo** 96.0 molybdenum	**43** **Tc** (98) technetium	**44** **Ru** 101.1 ruthenium	**45** **Rh** 102.9 rhodium	**46** **Pd** 106.4 palladium	**47** **Ag** 107.9 silver	**48** **Cd** 112.4 cadmium	**49** **In** 114.8 indium	**50** **Sn** 118.7 tin	**51** **Sb** 121.8 antimony	**52** **Te** 127.6 tellurium	**53** **I** 126.9 iodine	**54** **Xe** 131.3 xenon
55 **Cs** 132.9 caesium	**56** **Ba** 137.3 barium	**57–71** lanthanoids	**72** **Hf** 178.5 hafnium	**73** **Ta** 180.9 tantalum	**74** **W** 183.8 tungsten	**75** **Re** 186.2 rhenium	**76** **Os** 190.2 osmium	**77** **Ir** 192.2 iridium	**78** **Pt** 195.1 platinum	**79** **Au** 197.0 gold	**80** **Hg** 200.6 mercury	**81** **Tl** 204.4 thallium	**82** **Pb** 207.2 lead	**83** **Bi** 209.0 bismuth	**84** **Po** (210) polonium	**85** **At** (210) astatine	**86** **Rn** (222) radon
87 **Fr** (223) francium	**88** **Ra** (226) radium	**89–103** actinoids	**104** **Rf** (261) rutherfordium	**105** **Db** (262) dubnium	**106** **Sg** (266) seaborgium	**107** **Bh** (264) bohrium	**108** **Hs** (267) hassium	**109** **Mt** (268) meitnerium	**110** **Ds** (271) darmstadtium	**111** **Rg** (272) roentgenium	**112** **Cn** (285) copernicium	**113** **Nh** (280) nihonium	**114** **Fl** (289) flerovium	**115** **Mc** (289) moscovium	**116** **Lv** (292) livermorium	**117** **Ts** (294) tennessine	**118** **Og** (294) oganesson

atomic number — **79** **Au** 197.0 gold — symbol of element

relative atomic mass — name of element

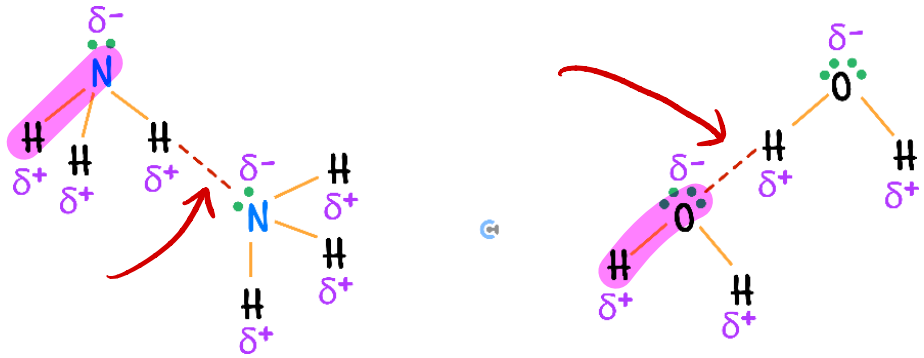
57 **La** 138.9 lanthanum	**58** **Ce** 140.1 cerium	**59** **Pr** 140.9 praseodymium	**60** **Nd** 144.2 neodymium	**61** **Pm** (145) promethium	**62** **Sm** 150.4 samarium	**63** **Eu** 152.0 europium	**64** **Gd** 157.3 gadolinium	**65** **Tb** 158.9 terbium	**66** **Dy** 162.5 dysprosium	**67** **Ho** 164.9 holmium	**68** **Er** 167.3 erbium	**69** **Tm** 168.9 thulium	**70** **Yb** 173.1 ytterbium	**71** **Lu** 175.0 lutetium

89 **Ac** (227) actinium	**90** **Th** 232.0 thorium	**91** **Pa** 231.0 protactinium	**92** **U** 238.0 uranium	**93** **Np** (237) neptunium	**94** **Pu** (244) plutonium	**95** **Am** (243) americium	**96** **Cm** (247) curium	**97** **Bk** (247) berkelium	**98** **Cf** (251) californium	**99** **Es** (252) einsteinium	**100** **Fm** (257) fermium	**101** **Md** (258) mendelevium	**102** **No** (259) nobelium	**103** **Lr** (262) lawrencium

The value in brackets indicates the mass number of the longest-lived isotope.

TURN OVER

- Consider ammonia (NH_3) and water (H_2O) molecules:
  - Is there a H atom **covalently** bonded to one of F, O, or N? **[Yes] / [No]**
  - What does this look like on NH_3 and H_2O? *(Label Below)*
  - Is that same H atom able to form a **dipole-dipole attraction** with a F, O, or N atom on an adjacent molecule? **[Yes] / [No]**
  - What will this look like on NH_3 and H_2O? *(Label Below)*



TIP: Remember Hydrogen has to be covalently bonded to one of **FON** (Fluorine, Oxygen or Nitrogen).

NOTE: It is actually the ___lone pair/s___ of electrons on the adjacent molecule's F, O or N that the hydrogen atom is attracted to a hydrogen bond!

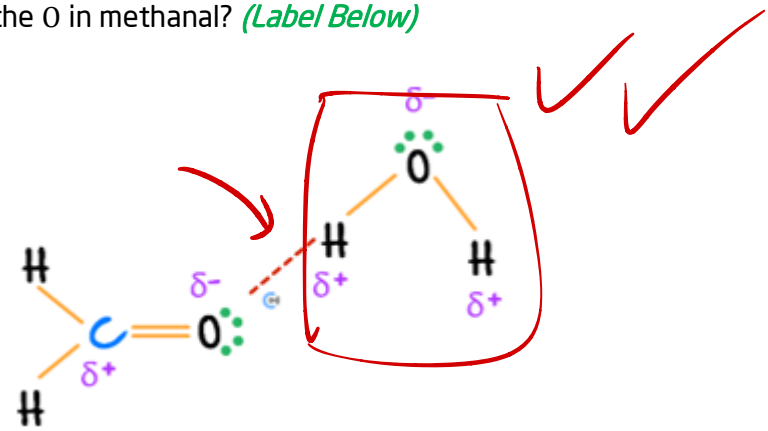
Misconception

"Hydrogen bonds have to occur in molecules which only have a $H-F$, $H-O$ *or* $H-N$ *bond"*

Truth:
It can occur with any F, O, *or* N *atom on a neighbouring molecule and a hydrogen which is covalently bonded to one of* **FON**.

- Consider Methanal and water:
  - Where would a hydrogen bond exist? *(Label Below)*

- What is different about the O in methanal? *(Label Below)*

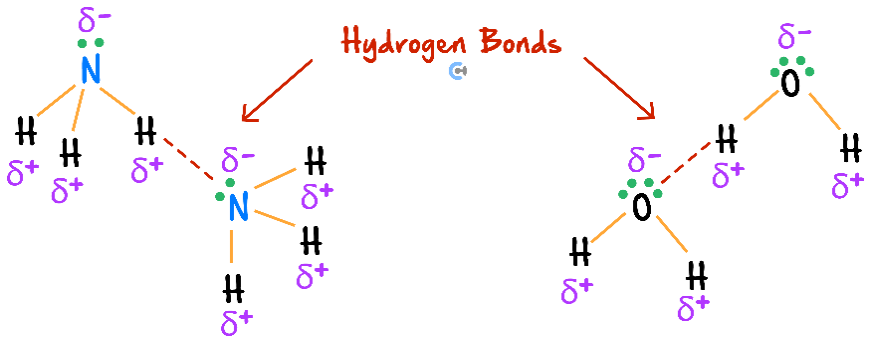


- Is this still a hydrogen bond? [Yes] / [No]

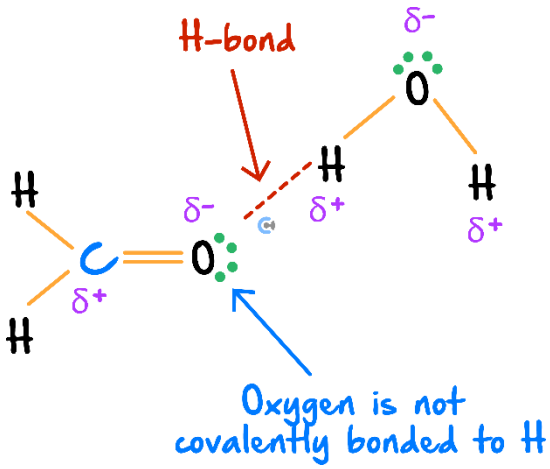
Definition

Hydrogen Bond Formation

- Hydrogen has to be covalently bonded to one of **FON** (Fluorine, Oxygen or Nitrogen):



- It can occur with any **F, O or N atom** on a **neighbouring molecule,** and hydrogen which is covalently bonded to one of **FON**:

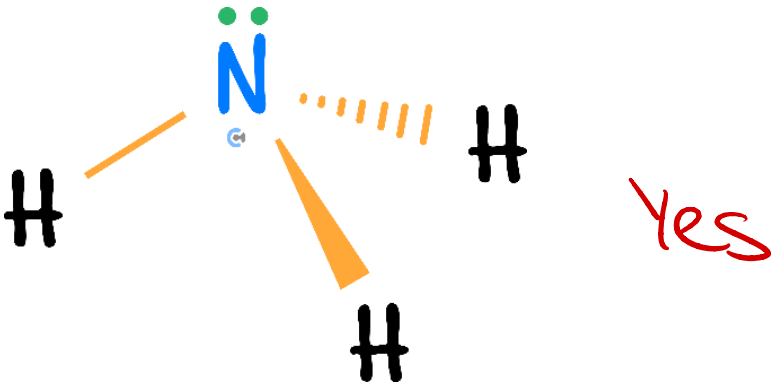


Let's have a look at a question together!

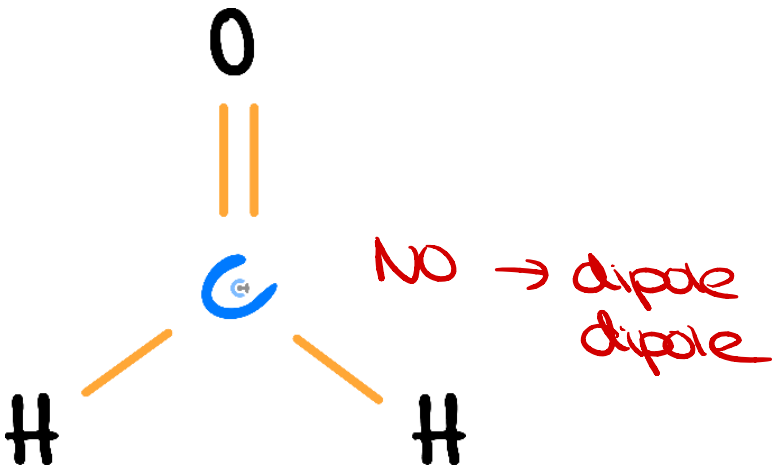
Question 11 Walkthrough.

State whether or not the following molecules can form hydrogen bonds.

a. Ammonia (NH_3)



b. Methanal



TIP: When trying to determine whether a substance can form hydrogen bonds with itself, simply check there is a H atom covalently bonded to one of F, O or N!

Space for Personal Notes

Recall!

Active Recall: Rank the 3 intermolecular bonds from strongest to weakest, and state the condition(s) for each of them to form.

hydrogen → polar & H–F/O/N

dipole–dipole → polar

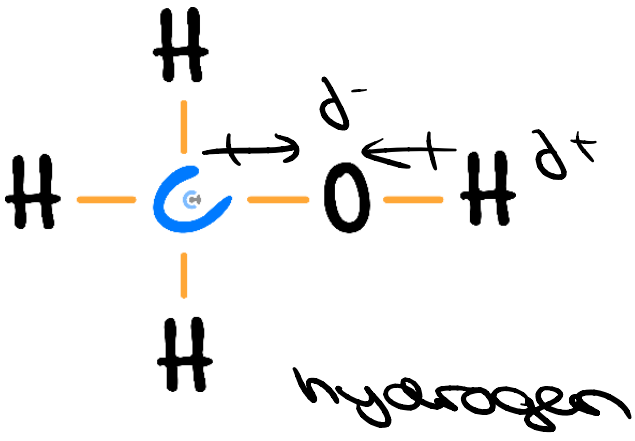
dispersion → N/A

Your Turn!

Question 12

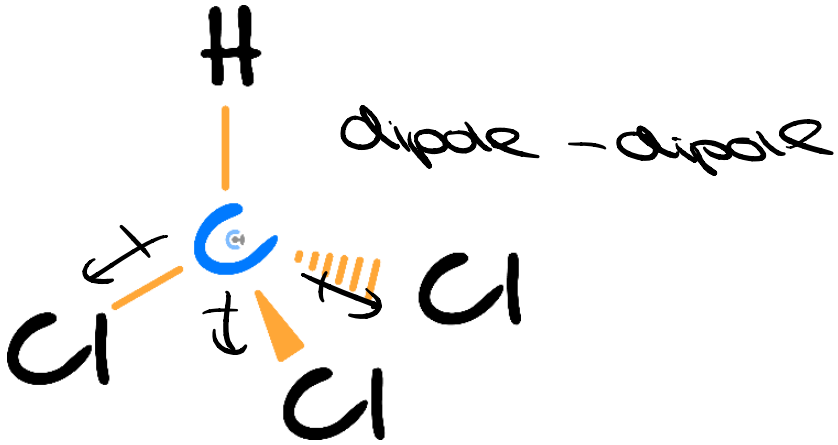
State the strongest type of intermolecular bonding in the following molecules.

a. Methanol (CH_3OH)

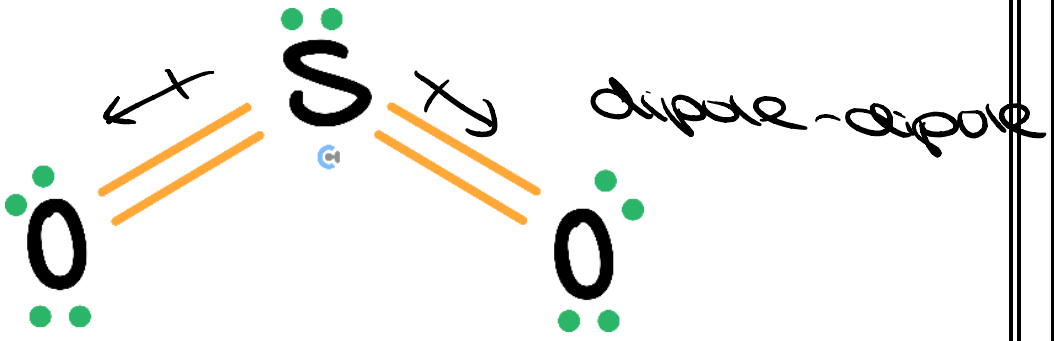


hydrogen

b. $CHCl_3$

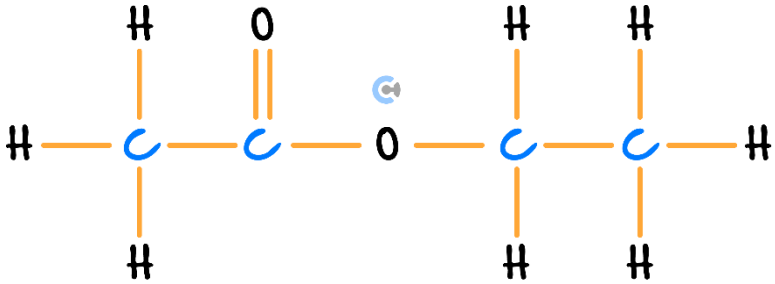


c. SO_2

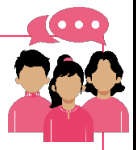


Question 13 Additional Question.

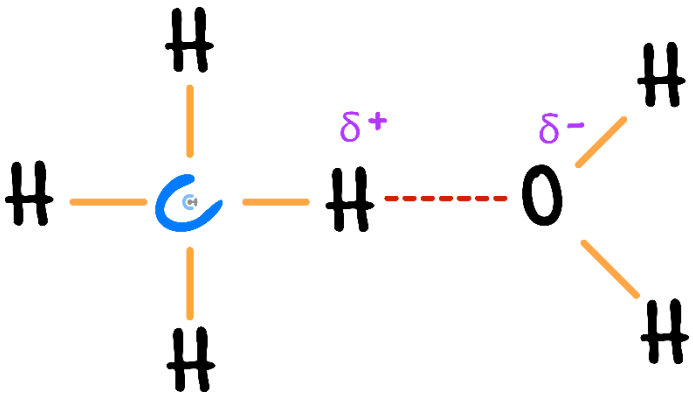
List **all** the intermolecular bonds that can exist between the following molecule:



Dipole-dipole, and dispersion forces



Discussion: Is the following a hydrogen bond?



Misconception

" … and any one of Fluorine, Oxygen or Nitrogen"

TRUTH:
Hydrogen Bonds can only form between one of **FON** *and a hydrogen which is covalently bonded to one of* **FON**

- What is the issue with the example in the discussion? *(Label Above)*

NOTE: Understanding intermolecular bonding, especially hydrogen bonding, is something that is essential for ¾ Chemistry as well!

Space for Personal Notes

Let's have a look at another example together!

Question 14 Walkthrough.

State the strongest type of intermolecular bonding that will exist between the following molecules:

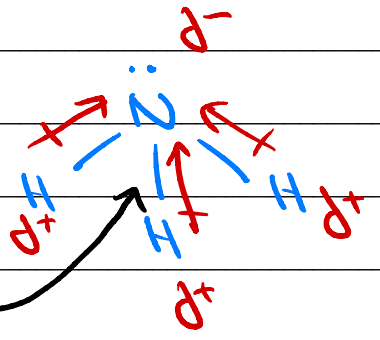
~~a.~~ Methanol (CH_3OH) and nitrogen gas (N_2)	**b.** Methane (CH_4) and carbon dioxide (CO_2) non - polar non - polar dispersion forces

Try a few more questions!

Question 15 (3 marks) NH_3

Explain why ammonia can form hydrogen bonds. Use a diagram to support your answer.

- ammonia has dipoles as it is a polar molecule
- it also has H bonded to N (exposed)



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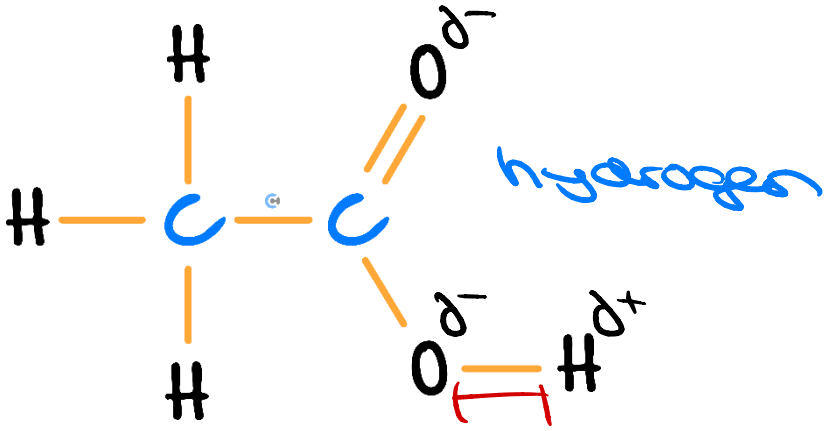
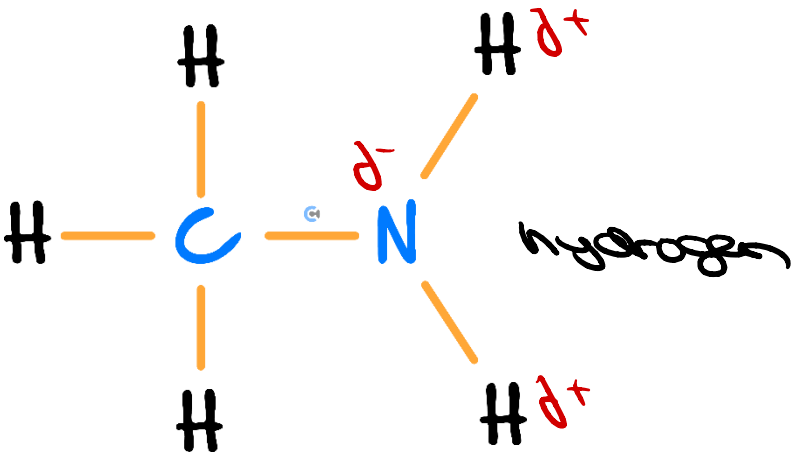
Question 16

State the strongest type of intermolecular bonding in the following molecules.

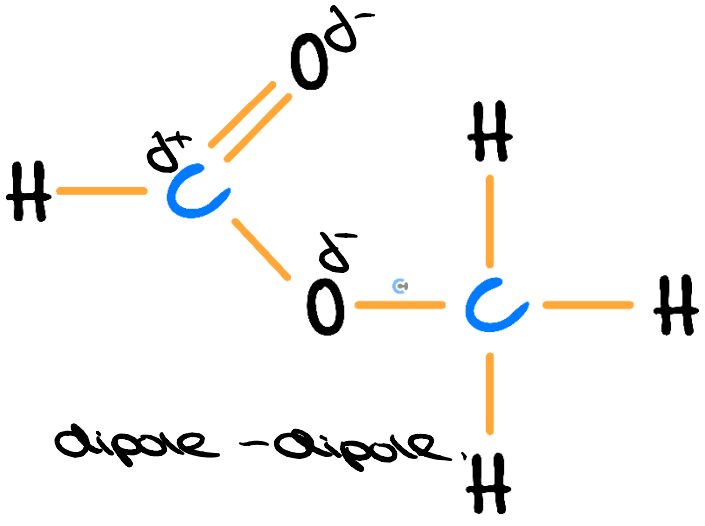
a. Ethanoic Acid



b. Methanamine (CH_3NH_2)



c. Methyl Methanoate (CH_3COCH_3)

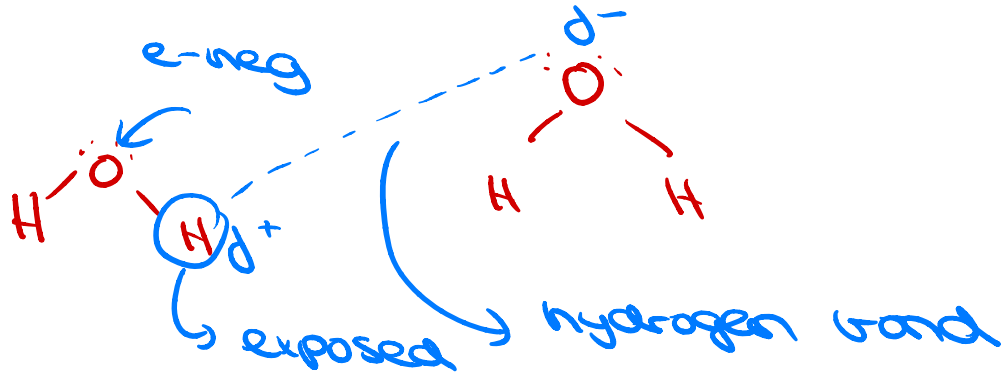


REMINDER: Don't forget When trying to determine whether a substance can form hydrogen bonds **with itself**, simply check if there is a H atom covalently bonded to one of F, O or N!

NOTE: We'll cover the naming of these organic compounds later on in the year!

Question 17 Additional Question.

Draw two water molecules, explaining and labelling the strongest intermolecular bonding between them.



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Sub-Section: Comparing Intermolecular Bonding

Let's now compare these bonds!

Comparing Intermolecular Bonding

Dispersion Forces	Dipole-dipole	Hydrogen Bonds
Weakest Intermolecular Bond.	Stronger Intermolecular Bond.	**Strongest** Intermolecular Bond.
Occurs in **all** molecules.	Only occurs in polar molecules.	Only occurs between one of FON and a hydrogen which is covalently bonded to FON.
Formed by temporary/instantaneous dipoles which form temporary partial charges.	Formed from permanent dipoles due to polarity of molecules which results in electrostatic attraction.	Formed from the high electronegativity between hydrogen (H) and one of FON which exposes the hydrogen atom to even stronger electrostatic attraction.

Space for Personal Notes

Let's have a look at a question together!

Question 18 (5 marks) **Walkthrough.**

Matthew is investigating hydrochloric acid (HCl) and water (H_2O).

a. Draw the Lewis structures for each of these molecules. (2 marks)

b. Hence or otherwise, explain whether hydrochloric acid (HCl) or water (H_2O) will have stronger intermolecular bonding. (3 marks)

- H_2O
- Both polar → both dipole – dipole
- However H_2O also has hydrogen bonds, stronger

exposed H – O

e- neg

Space for Personal Notes

Your Turn!

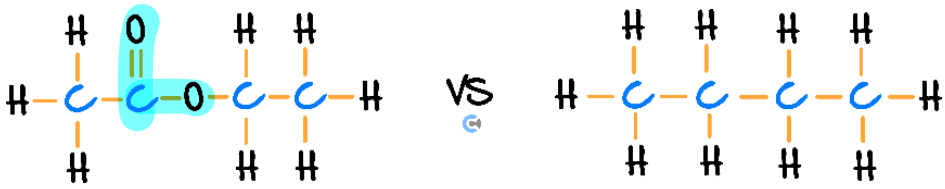
Question 19 (6 marks)

State which of the following has stronger intermolecular bonding, and briefly justify your answer.

a. CH_2Cl_2 vs HF. (2 marks)

HF → can form H-bonds, stronger than dipole-dipole (DCM)

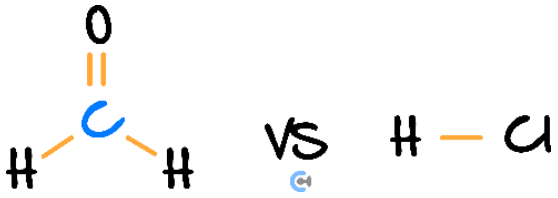
b. Ethyl ethanoate vs ~~Ethane~~ BUTANE. (2 marks)



ethyl ethanoate is polar → dipole-dipole

butane is non-polar → disp forces (weak)

c. Methanal vs Hydrochloric acid. (2 marks)



- Both polar → dipole-dipole.
- HCl has a greater δ- $\rightarrow$ δ+ difference
  ∴ stronger dipoles.

Question 20

Which of the following substances exhibits the strongest hydrogen bonding?

A. CH_4 (Methane)

B. H_2O (Water)

C. HF (Hydrogen fluoride)

D. NH_3 (Ammonia)

Question 21

Select the statement that describes the two requirements for hydrogen bonding.

A. A hydrogen atom covalently bonded to any atom and a non-bonding pair of electrons on any atom.

B. A hydrogen atom covalently bonded to an oxygen, a nitrogen or a fluorine atom and a non-bonding pair of electrons on any other atom.

C. A hydrogen atom covalently bonded to any atom and a non-bonding pair of electrons on a neighbouring oxygen, nitrogen or fluorine atom.

D. A hydrogen atom covalently bonded to an oxygen, nitrogen or fluorine atom and a non-bonding pair of electrons on a neighbouring oxygen, nitrogen or fluorine atom.

Question 22 Additional Question.

Identify which of the following molecules would form hydrogen bonds with water.

a. Ethanol, CH_3CH_2OH Yes	**d.** Ethanoic acid, CH_3COOH Yes
b. Ammonia, NH_3 Yes	**e.** Tetrachloromethane, CCl_4 No
c. Phosphine, PH_3 No	**f.** Ethanal, CH_3CHO No

Key Takeaways

- Intramolecular bonding – happens **within** molecules.
- Intermolecular bonding – happens **between** molecules.
- **Dispersion forces** occur when two or more **temporary** or **instantaneous** dipoles come together, arising from the **asymmetrical** distribution of electrons
- Dispersion forces occur as electrons are **randomly** moving in molecules, and so they may **temporarily group closely together** on one side
- Dispersion forces are the **weakest** type of intermolecular bonding that exist, and occur in **all** molecules.
- Atoms/molecules with **more electrons** have a **greater chance for temporary dipoles** to be formed, and as such, have **stronger** dispersion forces
- **Dipole-Dipole Attractions** are an intermolecular bond that occurs between **two dipoles**.
- While dispersion forces can occur in **all** molecules, dipole-dipole attractions only occur in **polar molecules**.
- Dipoles in polar molecules are **permanent**, these forces are **stronger** than temporary dispersion.
- Hydrogen bonds are a **special type of dipole-dipole bond.** They are the **strongest** type of intermolecular bond due to:
  - The **large electronegativity difference.**
  - The **hydrogen atom** which is **small in nature** allows molecules to approach close to it as it is left exposed from the large electronegativity difference.
- For a H-bond to form:
  - A hydrogen atom has to be **covalently bonded** to one of **FON** (Fluorine, Oxygen or Nitrogen):

- That same H atom can form a dipole-dipole bond with **any F, O or N atom** on a **neighbouring molecule**

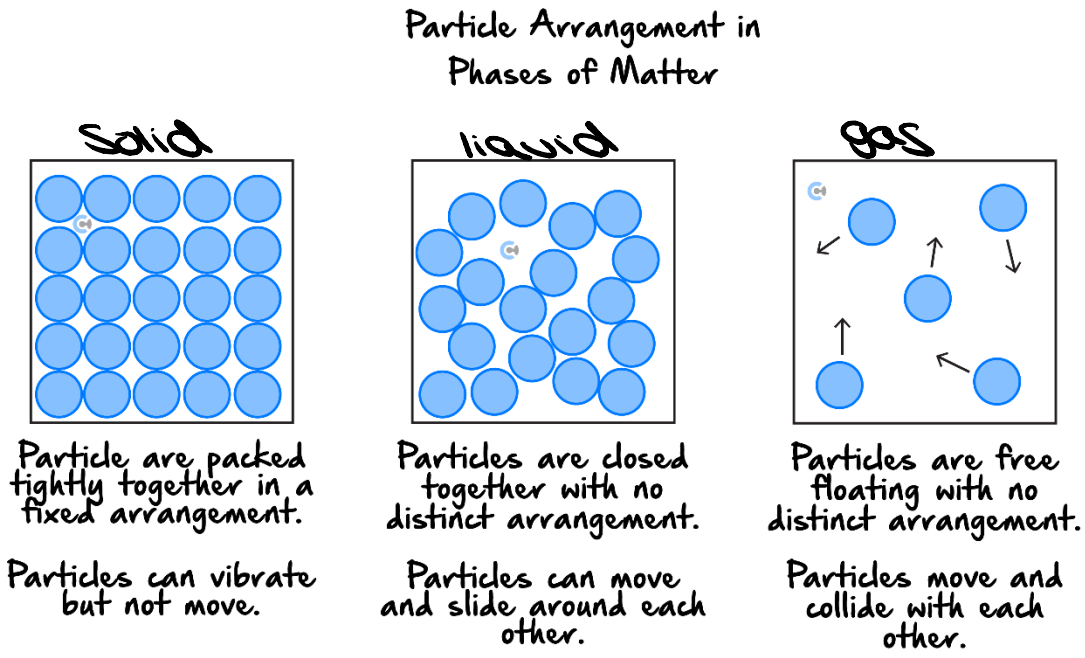
Dispersion Forces	Dipole-dipole	Hydrogen Bonds
Weakest Intermolecular Bond.	Stronger Intermolecular Bond.	Strongest Intermolecular Bond.
Occurs in all molecules.	Only occurs in polar molecules.	Only occurs between one of FON and hydrogen which is covalently bonded to FON.
Formed by temporary/instantaneous dipoles which form temporary partial charges.	Formed from permanent dipoles due to polarity of molecules which results in electrostatic attraction.	Formed from the high electronegativity between hydrogen (H) and one of FON which exposes the hydrogen atom to even stronger electrostatic attraction.

Space for Personal Notes

Section B: Boiling and Melting Points

Context

- Substances can generally exist in one of three physical states:



Boiling & Melting Points

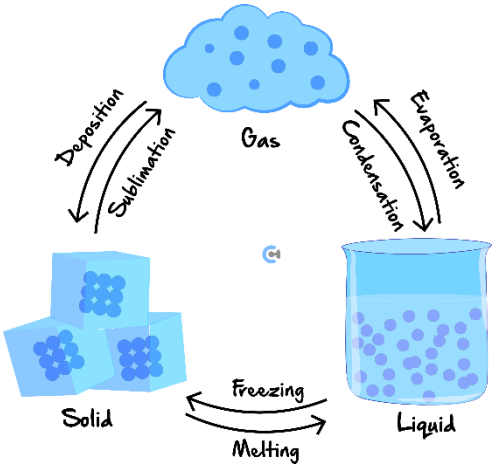
- Boiling is the state change between liquid and gas.
- Melting is the state change between solid and liquid.

Discussion: What makes something a solid, liquid or gas at a given temperature?

Strength of intermolecular forces

Space for Personal Notes

Exploration: Changing State of Matter



- When substances melt (go from solid to liquid), what happens to the intermolecular bonds?

weakening

- When substances boil (go from liquid to gas), what happens to the intermolecular bonds?

broken

Discussion: If a substance has stronger intermolecular bonds, is it more or less likely to melt?

less likely

Changing States of Matter

- Substances exist either as a solid, liquid or gas at a given temperature.
- State depends on the strength of intermolecular bonds.

Melting (Solid to Liquid)	Intermolecular bonds are weakened
Boiling (Liquid to Gas)	Intermolecular bonds are broken

NOTE: Intramolecular bonds (covalent bonds) are NOT disrupted when a phase change takes place!

Let's have a look at a question together!

Question 23 (4 marks) **Walkthrough.**

Explain whether water or hydrogen gas (H_2) is likely to have a higher melting point.

- H_2O
- H_2O has strong hydrogen bonds, whereas H_2 is non-polar ∴ weak dispersion.
- H_2O ↑ thermal energy to weaken the intermolecular bonds
- ∴ H_2O ↑ M.P

Sample Response: Melting/Boiling Point

- Substance *X* has stronger **intermolecular** bonding because *insert reasoning*.
  - It undergoes *insert type of bond*, which is a stronger intermolecular bond than *insert Substance *Y*'s bonding*.
  - It is a larger molecule, and therefore, can exhibit stronger dispersion forces than Substance *Y*.
- As such, more **thermal energy** is required to vibrate and weaken (for melting point) / break (for boiling point) the intermolecular bonds for Substance *X*.
- This leads to a higher melting/boiling point for Substance *X*.

Space for Personal Notes

Your Turn!

Question 24 (4 marks)

Explain whether hydrogen chloride (HCl) or oxygen gas (O_2) has a higher boiling point.

- HCl
- HCl is polar → d/d vdWs, O_2 is non-polar → weak dispersion forces
- ∴ more thermal energy is need to break the bonds ∴ HCl ↑ B.P

REMINDER: Don't forget!

- Melting point only requires intermolecular bonds to be weakened.
- Boiling point only requires intermolecular bonds to be completely broken.

Question 25

Which statement best explains the difference in bond strengths **within** a water molecule compared to **between** water molecules?

A. The covalent bonds within water molecules are stronger than the hydrogen bonds between water molecules

B. Hydrogen bonds within water molecules are stronger than covalent bonds between water molecules, leading to water's low boiling point.

C. The covalent and hydrogen bonds in water have similar strengths, which accounts for water's high melting point.

D. Hydrogen bonds between water molecules are non-existent, resulting in water's unique physical properties.

Question 26 Additional Question.

Which statement correctly explains the difference in boiling points between ammonia (NH_3), phosphine (PH_3), and arsine (AsH_3)?

A. Arsine has the highest boiling point due to strong hydrogen bonding.

B. Ammonia has a higher boiling point than phosphine and arsine due to hydrogen bonding.

C. Phosphine and arsine have higher boiling points than ammonia because they are heavier.

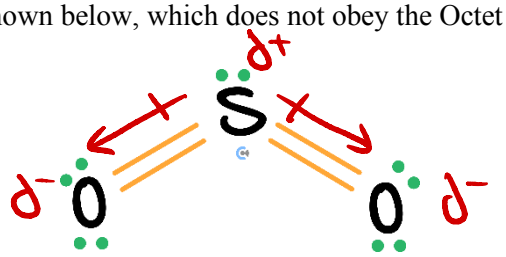
D. All have similar boiling points due to similar dispersion forces.

Try one more question to bring everything together!

Question 27 (6 marks)

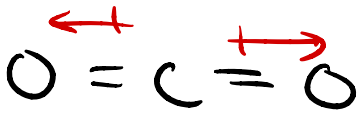
Luque is a funny lad, and thus tries to investigate two molecules – sulphur dioxide (SO_2) and carbon dioxide (CO_2).

The structure of sulphur dioxide is shown below, which does not obey the Octet Rule. (Outside the study design.)



a. Draw the polarity arrows **and** partial charges on the sulphur dioxide molecule provided. (1 mark)

b. Draw the Lewis Structure of carbon dioxide (CO_2). (1 mark)



c. With reference to their structure and bonding, state and explain which molecule is most likely to have a higher boiling point. (4 marks)

- SO_2
- SO_2 is V-shaped, CO_2 is linear
- SO_2 has dipole-dipole whereas CO_2 only has weak dispersion forces.
- ∴ SO_2 ↑ thermal energy to break the bonds → SO_2 ↑ B.P.

Space for Personal Notes

Contour Checklist

☐ Learning Objective: [1.8.1] - Explain how dispersion forces form & identify molecules that can exhibit them

Study Design

"the relative strengths of intramolecular bonding (covalent bonding) and intermolecular forces (dispersion forces, dipole-dipole attraction and hydrogen bonding)"

Key Takeaways

- ☐ Dispersion forces: when two or more ~~temporary~~ or **instantaneous** dipoles come together, arising from the **[symmetrical] / [asymmetrical]** distribution of electrons.
- ☐ This intermolecular bond occurs because electrons are **[fixed] / [randomly moving]** in molecules, and so they may temporarily group closely together on one side.
- ☐ Dispersion forces are the **[strongest] / [weakest]** type of intermolecular bonding that exists.
- ☐ Dispersion forces occur in **[polar] / [non-polar] / [all] / [specific]** molecules.
- ☐ Atoms/molecules with **more electrons** have a **[greater] / [same] / [lesser] chance for temporary dipoles** to be formed, and as such, have **[stronger] / [identical] / [weaker]** dispersion forces.

Learning Objective: [1.8.2] - Explain how dipole-dipole attractive forces form & identify molecules that can exhibit them

Study Design

"the relative strengths of intramolecular bonding (covalent bonding) and intermolecular forces (dispersion forces, dipole-dipole attraction and hydrogen bonding)"

Key Takeaways

- dipole – dipole bond are an intermolecular bond that occurs between **two dipoles**.
- While dispersion forces can occur in **all** molecules, dipole-dipole attractions only occur in polar **molecules**.
- As dipoles in polar molecules are **[temporary] / [permanent]**, these forces are **[stronger] / [weaker]** than dispersion forces, wherein the dipoles are only temporarily formed.

Learning Objective: [1.8.3] - Explain how hydrogen bonds form & identify molecules that can exhibit them

Study Design

"the relative strengths of intramolecular bonding (covalent bonding) and intermolecular forces (dispersion forces, dipole-dipole attraction and hydrogen bonding)"

Key Takeaways

- Hydrogen bonds are a **special type of dipole-dipole bond.** They are the strongest type of intermolecular bond out of the three major intermolecular bonds. This is due to:
- The **large** electronegativity difference
- The hydrogen **atom** which is **[small] / [large] in nature** allows molecules to approach close to it as it is left exposed from the large electronegativity difference.
- For a H-bond to form:
  - A hydrogen atom has to be covalently **bonded** to one of **FON** (Fluorine, Oxygen or Nitrogen):
  - That same H atom can form a **dipole-dipole** bond with **any F, O or N atom** on a neighbouring molecule

Learning Objective: [1.8.4] - Apply intermolecular bonding to compare molecules' melting & boiling points

Study Design

"physical properties of molecular substances (including melting points and boiling points and non-conduction of electricity) with reference to their structure and bonding"

Key Takeaways

- Intramolecular bonding - happens **[within]** / **[between]** molecules.
- Intermolecular bonding - happens **[within]** / **[between]** molecules.
- Substances exist either as a (s) (l) (g) a given temperature.
- Their state depends on the **strength** of its intermolecular bonds.
- melting is the phase change from Solid → Liquid: Intermolecular bonds are broken.
- boiling is the phase change from Liquid → Gas: Intermolecular bonds are broken.

Dispersion Forces	Dipole-dipole	Hydrogen Bonds
Weakest Intermolecular Bond.	Stronger Intermolecular Bond.	Strongest Intermolecular Bond.
Occurs in all molecules.	Only occurs in polar molecules.	Only occurs between one of FON and hydrogen which is covalently bonded to FON.
Formed by temporary/instantaneous dipoles which form temporary partial charges.	Formed from permanent dipoles due to polarity of molecules which results in electrostatic attraction.	Formed from the high electronegativity between hydrogen (H) and one of FON which exposes the hydrogen atom to even stronger electrostatic attraction.

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