

PROPERTIES OF ORGANIC MOLECULES

Many of the properties of organic compounds are dependent on the strength of bonding that exists between molecules and their size.

The forces acting between organic molecules are referred to as **interparticle** bonding.

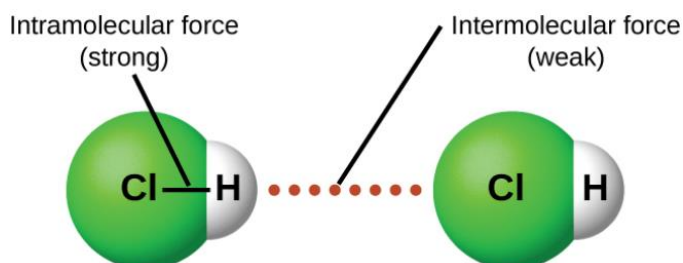
Examples include:

INTERPARTICLE FORCE	BOND STRENGTH	INTERACTING SPECIES
Ion – Ion	Strongest	Ion charge (+) – Ion charge (–) (Two ions with opposite charges (Ionic Bonds))
Ion – Dipole		Ion charge – Dipole charge (Ions & polar molecules)
Hydrogen bonding		Polar molecule – Polar molecule (Molecule with F/O/N – H attached to a F/O/N on another molecule)
Dipole – Dipole		Polar molecule – Polar molecule
Dispersion	Weakest	Electron clouds in all compounds and ions

interaction	nature of attraction	strength	types of functional groups
ion-ion	the attraction of a positively and negatively charged ions	very strong	molecules with charges such as ionic species
ion-dipole	interaction of a molecule with a charge and a molecule with a dipole	strong	an example is the interaction of water (that has strong dipole) with positive and negative ions (like Na ⁺ or Br ⁻)
hydrogen-bond	special type of dipole-dipole interaction between an acidic hydrogen (δ^+) and a lone pair (δ^-).	medium	alcohols, carboxylic acids, 1° and 2° amides, thiols, 1° and 2° amines (any molecule with a lone pair and an acidic hydrogen)
dipole-dipole	strong molecular dipoles generate partial charges (δ^+ and δ^-)	weak	ketones, esters, (C=O), alkyl halides , (any molecule with a dipole or a strongly polarized bond)
dispersion (London forces)	attraction of weak random dipoles formed on molecular surfaces	very weak	alkanes, alkenes, benzenes (larger the surface area the better - shape and size matters) (every molecule can form these but they are weak so if there are other interactions, those interactions will be dominant.)

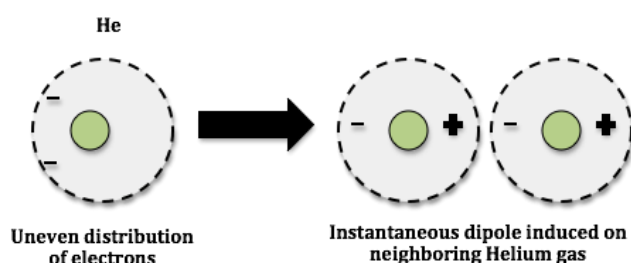
INTERMOLECULAR FORCES

The forces that attract molecules to one another are called **intermolecular forces**. These forces are much smaller than covalent, ionic or metallic bonding but still play an important role in determining the properties of a substance. Since these forces are so weak, much less energy is required to overcome them. This is why molecular substances have much lower melting and boiling points than ionic or metallic substances.



DISPERSION FORCES

- Dispersion forces (van de Waal's forces) are the weakest bonding forces that exist between particles.
- Dispersion forces exist in all substances and are the **only attractive** force that exists between noble gas atoms and non-polar molecules such as H_2 , N_2 , O_2 , P_4 , S_8 .
- These forces are temporary and arise due to the formation of instantaneous dipoles in atoms i.e. electrons arrange themselves in such a manner that an overall negative end is formed (δ^-).
- This instantaneous dipole in one atom can distort the electron arrangement in another atom and cause another dipole to be produced.



- An attraction then occurs between the slightly positive end of one molecule and the slightly negative end of another. This attraction is called a dispersion force. Since the dipoles are instantaneous, this attraction does not form for long.
- Dispersion forces are constant form, disperse and reform.

The strength of dispersion forces depends upon:

- How often the electrons can cluster to produce an overall negative end.
- How easily electron arrangements in adjacent atoms may be distorted to create other dipoles.
- The number of electrons in an atom, or molecule. The bigger the molecule, for example, the stronger the dispersion forces.
- The shape of the molecule. Molecules that have shapes that can pack effectively together will experience stronger dispersion forces.

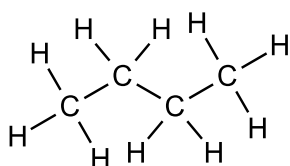
Important Notes:

- If the shape of the molecules are the same, the strength of the dispersion forces will depend on the size of the molecule. This trend is shown in the halogen series, all of which form linear diatomic molecules.

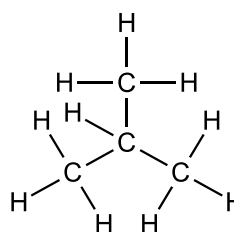
Molecule	Molecular weight	Boiling point °C
F-F	38	-188
Cl-Cl	71	-34
Br-Br	160	59
I-I	254	184

- If the size of the molecules are the same (E.g. when comparing isomers), then the strength of the dispersion forces is likely to depend on the shape of the molecules.

Molecules that can pack more closely together will experience stronger attractions to one another via dispersion forces and have higher melting and boiling points.



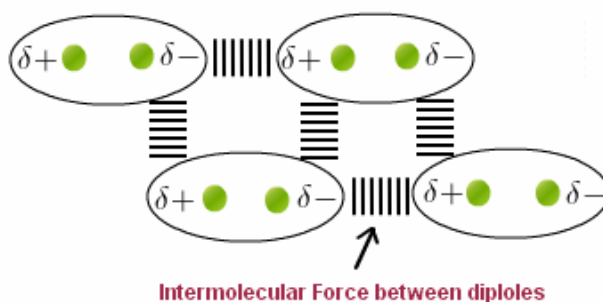
Butane b.p. -0.5°C



2-methylbutane b.p. -11.7 °C

The net strength of dispersion forces between polar molecules is usually stronger than their dipole-dipole interactions, particular for larger molecules.

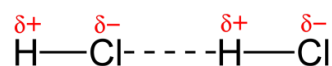
DIPOLE – DIPOLE ATTRACTIONS



Dipole-dipole attractions are electrostatic forces of attraction that occur between oppositely charged ends of polar molecules. These charges are permanent and are referred to as partial charges.

Important Points:

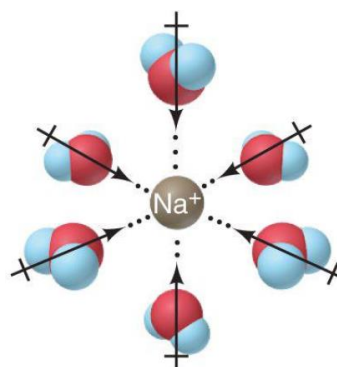
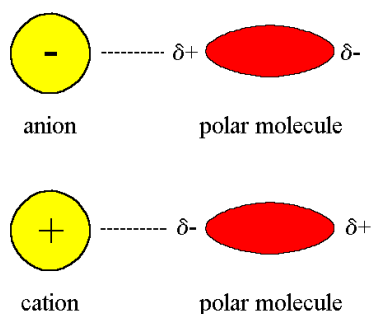
- Dipole-dipole bonding will only occur between polar molecules.



- The greater the polarity (difference in electronegativity of the atoms in the molecule), the stronger the dipole-dipole attraction.
- Melting may overcome the attraction between dipoles, but they still exist.

ION – DIPOLE BONDING

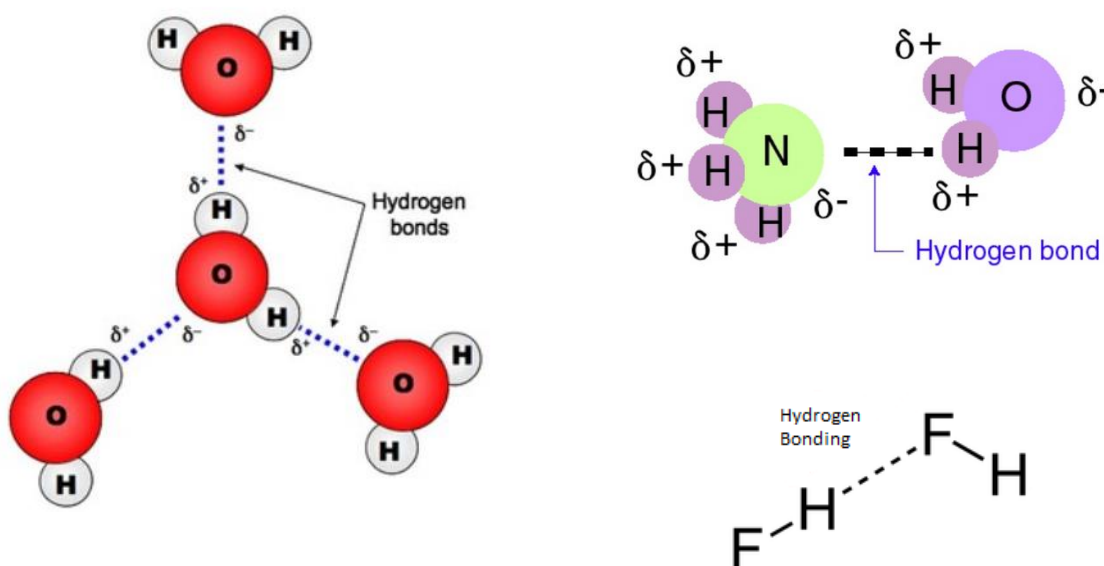
Ion – dipole bonding describes the interaction between an ion (or a molecule with a charge) and a molecule with a dipole.



HYDROGEN BONDING

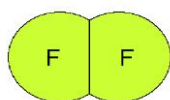
When hydrogen is bonded to fluorine, oxygen or nitrogen (which have particularly high electronegativities) **within** a molecule, a particularly polar dipole is formed. Due to this highly polar bond, the hydrogen will have a partial positive charge. A hydrogen bond can then form **between** this hydrogen and a polar fluorine, oxygen or nitrogen atom in a neighbouring molecule.

Hydrogen bonding is the attraction **between** a partially positive hydrogen attached to F, O or N in one molecule and a F, O or N with a partially negative charge in a neighbouring molecule.

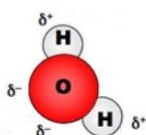


Hydrogen bonding is the **strongest** type of intermolecular bonding due to the high polarity of the H-F, H-O or H-N bonds within the molecules involved.

Will hydrogen bonding occur between water and fluorine molecules?



Fluorine is a non-polar molecule. There is no δ^- on either F atom.

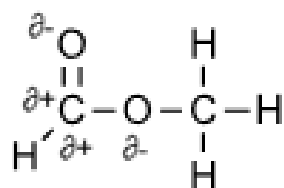


Water has two very polar H-O bonds. Each H atom is δ^+ . Each O is δ^- .

Hydrogen bonding will not occur between these molecules. Even though the hydrogen atoms in water have a partial positive charge, there is no partial negative charge on any fluorine atoms in the fluorine molecule. Therefore the two molecules are not attracted to each other via hydrogen bonding.

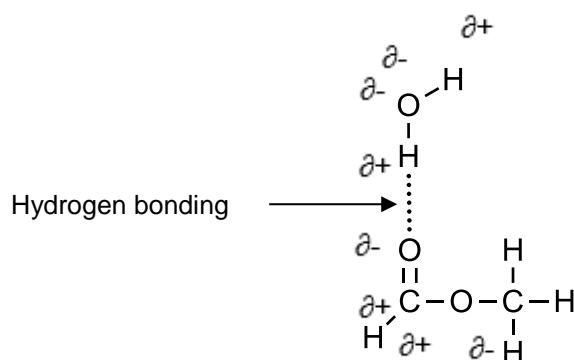
Will hydrogen bonding occur between

- i. Methyl methanoate molecules?



Hydrogen bonding will not occur **between** these molecules since there is no H-F, H-O or H-N bonds within it.

- ii. Methyl ethanoate and water molecules?



Hydrogen bonding will occur between these molecules. The large dipole in water gives each hydrogen atom a partial positive charge. This hydrogen is attracted via hydrogen bonding to the oxygen in the methylmethanoate molecule which has a partial negative charge.

Water is acting as a 'hydrogen bond donor'.

Methyl methanoate is acting as a 'hydrogen bond acceptor'.

Important Notes:

- Hydrogen bonds are strong intermolecular forces as the hydrogen atom involved essentially gives its single electron to the neighboring atom and is therefore left unshielded.
- Species that are both hydrogen bond donors and acceptors are able to form hydrogen bonds between themselves. For example, alcohols and carboxylic acids.
- A substance will dissolve in water if it is relatively small and can form hydrogen bonds with water. As water is both a donor and acceptor, the solute only needs to be either a donor or acceptor (or both) to dissolve.

QUESTION 22

Explain why hydrogen bonding exists between an aldehyde and water but not between two aldehyde molecules.

Solution

PROPERTIES OF ORGANIC MOLECULES

The physical properties of a compound are determined by the strength of the intermolecular forces of attraction.

As the strength of the intermolecular bonding increases:

- Melting points increase.
- Boiling points increase.
- Volatility decreases.
- Flash points increase.
- Viscosity increase.
- Density increases.

The strength of the intermolecular bonding is determined by:

- The type of intermolecular bonding present.
- The shape of the molecule.
- The size of the molecule.
- The polarity of the molecule.

Generally, the strength of intermolecular bonding increases in the following order **when comparing molecules of roughly the same size and shape**.

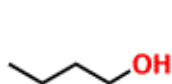
Weakest ↓ Strongest	Dispersion forces Dipole – dipole bonding Hydrogen bonding Ion – dipole bonding Ion – ion bonding
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Branching decreases the strength of intermolecular bonding since molecules cannot pack as efficiently together which reduces the area of contact between the molecules. Therefore, less energy is needed to overcome the intermolecular forces of attraction.

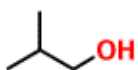
For isomers of the same compound, as branching increases:

- Melting and boiling temperatures decrease.
- Volatilities increase.
- Densities decrease.
- Viscosities decrease.
- Flash points decrease.

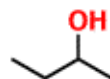
For example:



1-butanol
BP 117°C
(primary)



2-methyl-1-propanol
BP 107°C
(primary)



2-butanol
BP 98°C
(secondary)

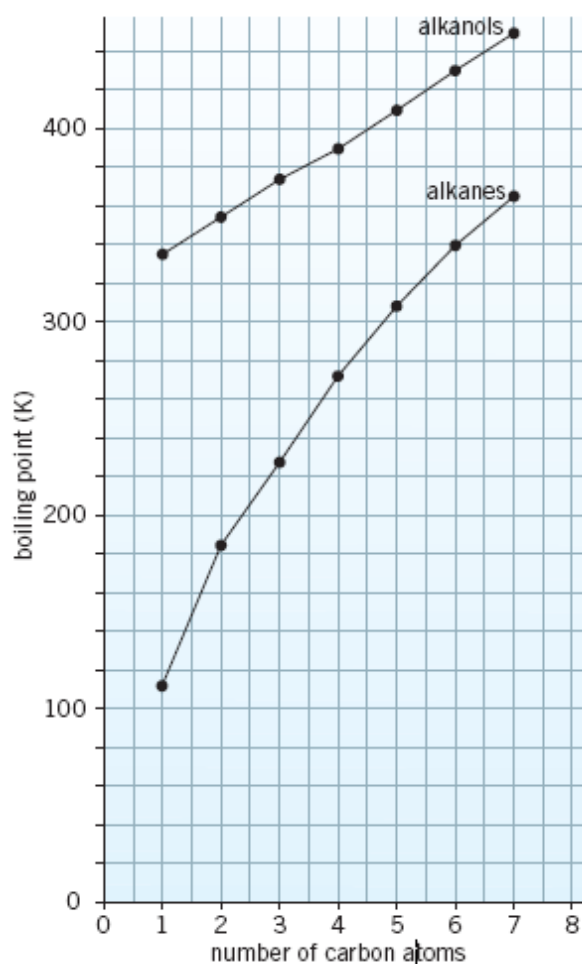


2-methyl-2-propanol
BP 82°C
(tertiary)

Increasing the chain length increases the strength of intermolecular bonding due to the increased number of instantaneous dipoles that can form. This increases the overall attraction due to dispersion forces.

The longer the hydrocarbon chain, the stronger the dispersion forces between molecules. Therefore, as the chain length of any homologous series increases:

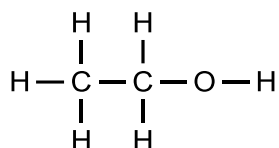
- Melting and boiling temperatures increase.
- Volatilities decrease.
- Densities increase.
- Viscosities increase.
- Flash points increase.
- Solubilities in aqueous solutions decrease.



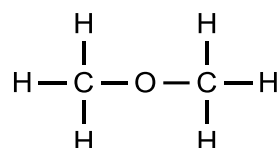
The greater the polarity of the molecule, the stronger the intermolecular bonding.
Higher polarity causes stronger electrostatic attraction between the molecules.

This only holds true for molecules of approximately the same size.

For example



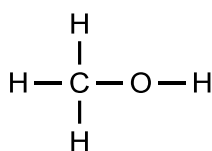
B.P.= 78°C



B.P.= -24°C

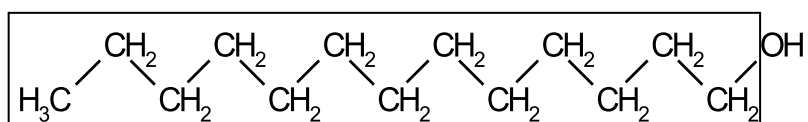
Important Note:

Within a homologous series, the polarity of the molecules decreases with increased chain length. This is because a greater proportion of the molecule is made up of a non-polar hydrocarbon chain. However, **boiling points will increase** due to the increased strength of dispersion forces.



B.P.= 64.7°C

Polar molecule

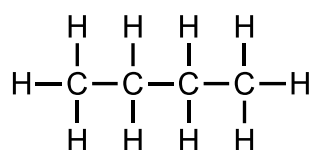


B.P.= 234°C

Essentially non-polar due to large hydrocarbon chain.

WEAKEST INTERMOLECULAR BONDING

HYDROCARBONS

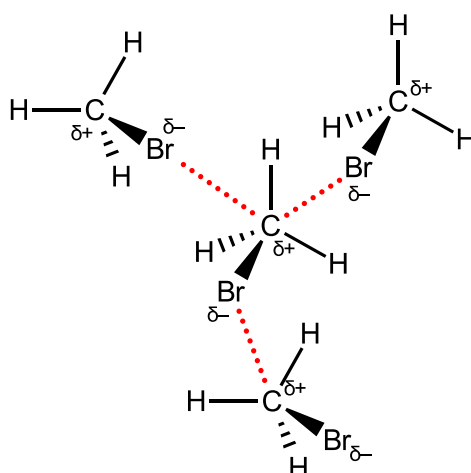


Dispersion forces only

All hydrocarbon molecules are non – polar and as such are only attracted to each other via dispersion forces.

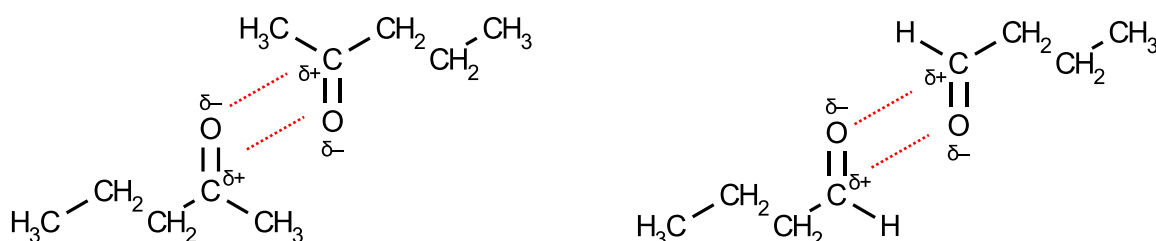
INTERMEDIATE STRENGTH OF INTERMOLECULAR BONDING

ALKYLHALIDES



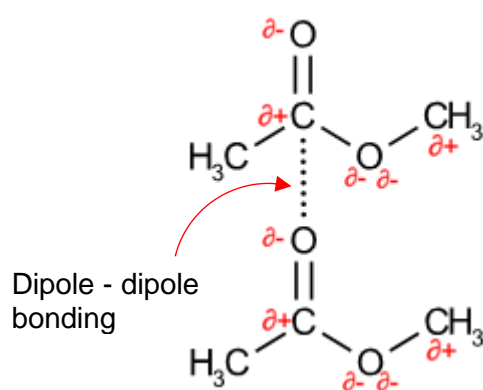
Dispersion forces
Dipole – dipole bonding

KETONE/ALDEHYDES



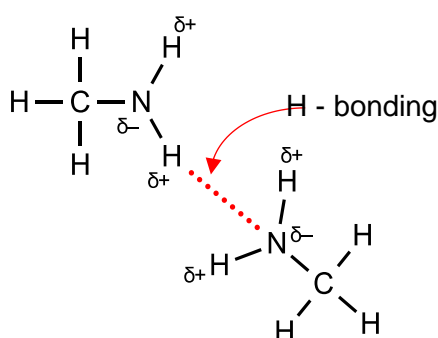
Dispersion forces
Dipole – dipole bonding

ESTERS



Dispersion forces
Dipole – dipole bonding

AMINES



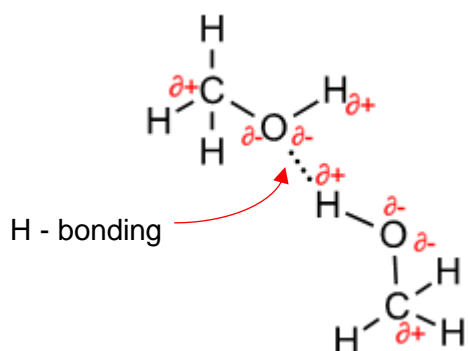
Dispersion forces
Dipole – dipole bonding
Hydrogen bonding

It is difficult to order alkylhalides, esters, ketones, aldehydes and amines in terms of weakest intermolecular bonding to strongest since:

- Even though amines experience hydrogen bonding and the other molecules do not, the N-H bond is not as polar as C-O or O-H bonds. Therefore, the strength of intermolecular bonding in amines is still similar to esters, ketones and aldehydes.
- Esters, ketones and aldehydes are all similar functional groups and hence experience a similar strength of intermolecular bonding. Comparing molecules of similar size is made difficult due to the multiple positions that the functional group can be placed which slightly alters the relative strengths of the intermolecular bonding.
- The strength of bonding in the alkylhalides depends on which halogen is present. Larger halides will cause significant increases in the strength of dispersion forces.
- It is difficult to determine the effect that the shapes of the molecules is having on the strength of the intermolecular bonding.

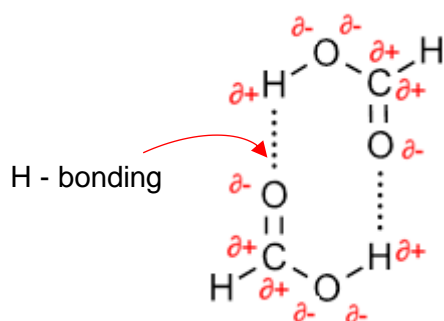
STRONGEST INTERMOLECULAR BONDING

ALCOHOLS



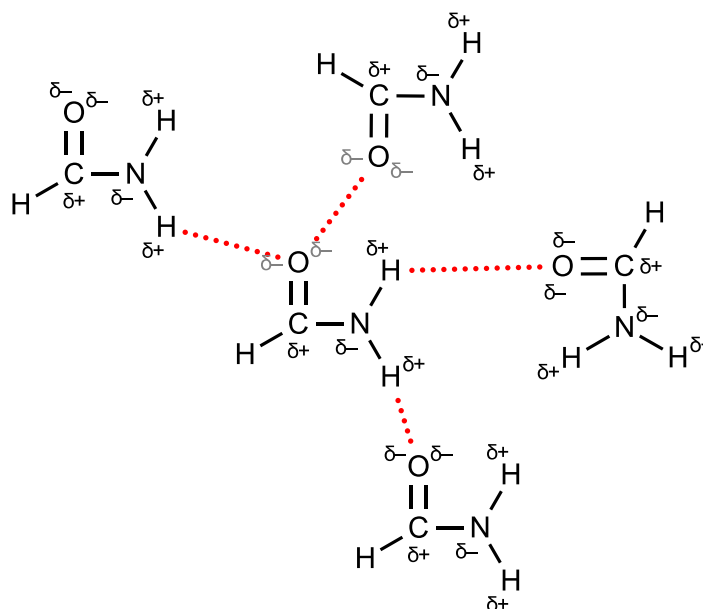
Dispersion forces
Dipole – dipole
Hydrogen bonding

CARBOXYLIC ACIDS



Dispersion forces
Dipole – dipole
Multiple sites of hydrogen bonding

AMIDES



Dispersion forces
Dipole – dipole
Multiple sites of hydrogen bonding

There is a clear trend with the relative strength of intermolecular bonding between alcohols, carboxylic acids and amides which is related to the amount of hydrogen bonding which occurs in each of these groups.

The amount of hydrogen bonding found in these molecules increases in order of:

Alcohols < Carboxylic Acids < Amides

Therefore the strength of intermolecular bonding increases in order of:

Alcohols < Carboxylic Acids < Amides

SUMMARY

The strength of intermolecular bonding increases in the order:

Hydrocarbons < Esters, Aldehydes, Ketones, Amines < Alcohols < Carboxylic acids < Amides

Therefore, the physical properties of organic molecules will also follow this pattern:

Hydrocarbons < Esters, Aldehydes, Ketones, Amines < Alcohols < Carboxylic acids < Amides

↓ mp / bp
↓ density
↓ viscosity
↓ flash point
↑ volatility

↑ mp / bp
↑ density
↑ viscosity
↑ flash point
↓ volatility

STRENGTH OF INTERMOLECULAR BONDING	EXAMPLE	BOILING POINT
Weakest: Hydrocarbons.	Butane $\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{H} \\ & & & & \\ & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	-1 °C
Intermediate: In no particular order: <ul style="list-style-type: none"> • Esters. • Amines. • Aldehydes. • Ketones. 	Butanal $\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{O} \\ & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{H} \\ & & & & \\ & \text{H} & \text{H} & \text{H} & \end{array}$ Ethyl ethanoate $\begin{array}{cccc} & \text{H} & \text{O} & & \text{H} & \text{H} \\ & & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{O} & -\text{C} & -\text{C}-\text{H} \\ & & & & & \\ & \text{H} & & & \text{H} & \text{H} \end{array}$ Butanamine $\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{N} \\ & & & & & / \backslash \\ & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ Chlorobutane $\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{Cl} \\ & & & & \\ & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ Butanone $\begin{array}{cccc} & \text{H} & \text{H} & \text{O} & \text{H} \\ & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{H} \\ & & & & \\ & \text{H} & \text{H} & & \text{H} \end{array}$	74.8 °C 77.1 °C 77-79 °C 78 °C 79.64 °C
Strongest: (in order).	Butanol $\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{OH} \\ & & & & \\ & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	117.7 °C
	Butanoic acid $\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{O} \\ & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{OH} \\ & & & & \\ & \text{H} & \text{H} & \text{H} & \end{array}$	163.5 °C
	Butanamide $\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{O} & \text{H} \\ & & & & & \\ \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{N} \\ & & & & & / \backslash \\ & \text{H} & \text{H} & \text{H} & & \text{H} \end{array}$	216 °C

QUESTION 25

CH_3Cl , C_2H_5Cl , CH_3Br exist as gases at room temperature. The alkyl halides up to carbon 18 are colourless liquids, while larger alkyl halides are colourless solids. Give a reason for the differences in physical state.

Solution**QUESTION 26**

Which of the following bonds are not found between bromopropane molecules?

- A Dispersion forces
- B Dipole-dipole forces
- C Van de Waal's forces
- D Hydrogen bonding

QUESTION 27

Which of the following bonds are not produced between fluoromethane and water molecules?

- A Dispersion forces
- B Dipole-dipole forces
- C Ion-dipole bonding
- D Hydrogen bonding

QUESTION 28

The alcohol with the lowest volatility is:

- A Butanol
- B Ethanol
- C Methanol
- D Propanol

QUESTION 29

Rank the following in order of increasing boiling point.

Butanol
1-chlorobutane
Octanol

Solution**QUESTION 30**

Which of the species from the list below displays the highest volatility?

- A Butanoic acid
- B Decanoic acid
- C Methanoic acid
- D Pentanoic acid

QUESTION 31

Which of the species from the list below displays the highest boiling point?

- A Propane
- B Propene
- C Propanol
- D Propanoic acid

QUESTION 32

The alcohol with the lowest flash point is:

- A Butanol
- B Ethanol
- C Methanol
- D Propanol

QUESTION 33

Using structural formulae, show how ethanoic acid dissolves in water. State the bonding involved and label these bonds on your diagram.

Solution

QUESTION 34

Which of the following species is not an acid?

- A Nitric acid
- B Ethanoic acid
- C Ethanol
- D Carbon tetrachloride

QUESTION 35

The boiling points of two similarly sized organic species is given below.



Give a reason for the large differences in boiling point.

Solution**QUESTION 36**

The amine with the highest volatility and solubility in water is:

- A Ethylamine
- B Propylamine
- C Butylamine
- D Pentylamine

QUESTION 37

Which of the following intraparticle bonds are found in ethanamine molecules?

- A Dispersion forces
- B Covalent bonding
- C Electrostatic attractions
- D Hydrogen bonding

QUESTION 38

Which of the following statements is incorrect?

- A The ability of esters to form hydrogen bonds with water gives esters some solubility in water.
- B Esters cannot form hydrogen bonds between themselves.
- C Esters can act as hydrogen bond acceptors and hydrogen bond donors.
- D The predominant interparticle bonding between ester molecules is the dispersion force.

QUESTION 39

Which of the following species displays the highest volatility?
(Assume that each molecule is of the same chain length.)

- A Alcohol.
- B Amine.
- C Carboxylic acid.
- D Ester.

QUESTION 40

Two isomers with the formula $C_4H_8O_2$ display boiling points at $77.1^\circ C$ and $164^\circ C$. Draw a possible structural formula for these isomers and state which isomer is most likely to display the lower boiling temperature. Give a reason for your answer.

Solution