Chem Factsheet

www.curriculum-press.co.uk Number 77

The Importance of Hydrogen Bonding

To succeed in this topic you need to:
- Be able to recall the features of hydrogen bonding as represented in this Factsheet.
- Have a thorough knowledge of the importance of hydrogen bonding.
- Be able to decide between which molecules hydrogen bonding will occur, and draw them in diagrams.
- Have read factsheets and revised electronegativity and hydrogen bonding

After working through this Factsheet, you will:
- Have revised the chemistry relating to hydrogen bonds that are required for AS and A2 chemistry modules including option modules.
- Have a reference paper with you as you start to work through questions about hydrogen bonding.

Electronegativity

Electronegativity is a measure of how good atoms are at attracting electrons. The value given to any element is just an index, a way of comparing it with other elements. Electronegativity values have no units. You are not required to remember electronegativity values but it is a good idea to learn that the bottom left hand side of the periodic table has the lowest electronegativity and the top right hand side (excluding group VIII) has the highest. If a covalent bond is formed between two atoms of differing electronegativity, the electrons are unevenly distributed and the bond is described as **polar**. A bond between two atoms of similar electronegativity is not going to have areas of charge and the bond is **non-polar.** In the diagram below all the bonds are polar except the H–P bond.

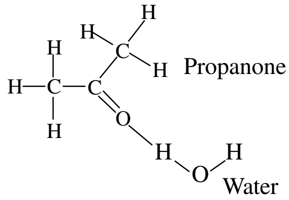
δ+ = small amount of positive charge	**δ+ H- - - - - - - -x- -N δ-**
δ- =small amount of negative charge	**δ+ H- - - - - - - - x -O δ-**
x = theoretical position of pair of electrons	**δ+ H - - - - - - - - - -x-F δ-**
	H- - - - - -x - - - - - -P

Hydrogen bonds are intermolecular forces that occur when hydrogen is covalently bonded to another atom with a high electronegativity value. In practise, H-bonds occur when hydrogen is bonded to oxygen, fluorine or nitrogen atoms. Oxygen in a molecule where it is only joined to carbon (C=O) form hydrogen bonds with hydrogen that is joined to oxygen in another molecule (O-H).

The strength of Hydrogen Bonds

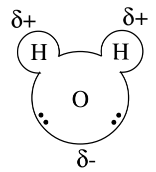
Hydogen bonding is an example of an intermolecular force which can be defined as weak attraction between molecules caused by weak electrostatic charge. You do not have to give a value for the strength of hydrogen bonds in exam answers but remember that hydrogen bonds are stronger than **Van der Waals** forces but nowhere near the strenghth of a typical covalent bond (between 5 and 10% the strength)

Hydrogen bonds are formed when propanone (which has no hydrogen bonds) is added to water in a test tube. This is an exothermic reaction and you can feel the heat given off as the two liquids mix together and the hydrogen bonds are formed.



The Water Molecule

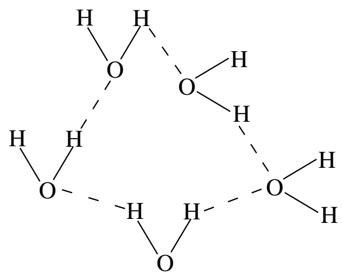
The distribution of charges on a water molecule is important for showing how hydrogen bonds are formed. The hydrogen atoms have their electrons involved in covalent bonds with oxygen. This leaves the hydrogen nuclei exposed and gives a small positive area of charge to this area of the molecule (δ+). The oxygen atom of the water molecule has all of the electrons in the molecule gathered around it, giving this part of the molecule a small negative charge (δ-).



In diagrams hydrogen bonds are usually drawn as dashed lines - - - - - . In exam questions candidates are often asked to draw in the hydrogen bonds between molecules

The structure of ice

As water gets colder the molecules lose kinetic energy and the random movement of particles gives way to the more regular structure of ice. In this structure oxygen atoms are held in position by two hydrogen bonds and two covalent bonds. The hydrogen bonds keep the molecules further apart than in the liquid state. This accounts for the fact that ice is less dense than water. Snow flakes have a structure based on a six pointed star which relates to the position of the hydrogen bonds.



Importance of hydrogen bonding in water
Physical properties

The fact that hydrogen bonds form between water molecules accounts for a large number of the unusual physical properties of water;

- Water is a liquid at room temperature. If we look at hydrogen sulphide H_2S, we see that it is closely related to water with the oxygen being replaced by the next element down the group - sulphur. H_2S is a gas at room temperature and we would expect water to be a gas as well. H-bonds are present in H_2O but not in H_2S.

- Liquids generally contract in volume as the temperature decreases. In the case of water however, it starts to **expand** at 4^{o}C. This is because the H-bonds prevent the water molecules from coming close together. As water molecules lose kinetic energy, the H-bonds form and a lattice starts to emerge. This accounts for the fact that ice is less dense than water and therefore floats on the water surface.

- On the surface of water, a large number of charged areas (δ+ and δ-) on molecules are exposed. This gives water a charged surface and gives rise to **surface tension,** which behaves like a 'skin'.
- The charged areas on water molecules makes them adhere to other charged surfaces; this accounts for the 'wetting' properties of water
- The small areas of charge on water molecules are responsible for the attraction between the water and the container it is in. This leads to the **meniscus** when water is placed in glass and to **capillary action** in which water is drawn up through fine tubes.
- Ice skating works because the high pressure applied by the blade of the skate crushes the hydrogen bonds and turns the ice back to water. This water provides a lubricant for the skater to move upon.

Biological importance of hydrogen bonding

As life is based on water, and proteins contain N—H bonds it is not too surprising that hydrogen bonding is of great biological importance;

- Many organisms use the surface tension of water to live on the surface of ponds and lakes (caddis fly lavae and water boatmen).
- Plants move water through the xylem in their stems relying on capillary action as part of the cohesion-tension process.
- Water living animals survive freezing conditions as ice floats on water leaving liquid water below this ice.
- DNA builds its double helix structure on hydrogen bonding between the bases on the DNA strands.
- The secondary and tertiary structures of many proteins has hydrogen bonds as one of its components. Hydrogen bonding between the peptide links in a protein cause the chains to fold or twist in a regular manner . The precise shape due to folding of its chains is critical for insulin to act in the way it does. Enzymes are proteins and they also require these highly specific shapes in order to catalyse the biological changes needed for life to exist and continue.

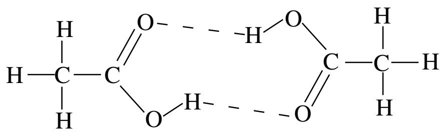
Hydrogen bonding in organic chemistry

Alchols, carboxylic acids and amimes:
These types of organic molecule exhibit hydrogen bonding due to their functional groups.

	Functional group
Alcohols	–OH
Carboxylic acids	$-\overset{\displaystyle O}{\overset{\|\|}{C}}-OH$
Amines	$-NH_2$

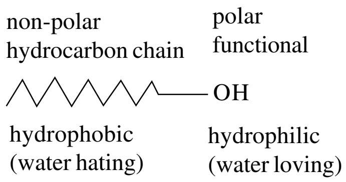
	$CH_3CH_2CH_2CH_3$	$CH_3CH_2CH_2NH_2$	$CH_3CH_2CH_2OH$	CH_3COOH
M_r	58	59	60	60
b.p. (K)	273	321	371	414
Intermolecular forces	Van der Waal's forces	Hydrogen bonding	Hydrogen bonding	Hydrogen bonding

The higher than expected boiling points are due to the stronger hydrogen bonding compared with the Van der Waal's forces present in alkanes with similar M_r value



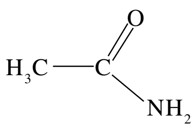
Dimerization is the name given to the situation where two carboxylic acid molecules form a pair of hydrogen bonds. On a cold day it is this hydrogen bonding that causes ethanoic acid to become 'glacial' - solid like ice (glacial ethanoic acid).

These organic molecules have two 'enols', e.g. alcohols



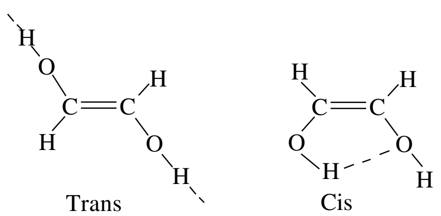
In smaller molecules the hydrophilic end dominates and they are readily soluble in water. As the molecule increases in size, the hydrocarbon chain becomes longer. The hydrophobic end starts to dominate and the solubility in water decreases

Acid amides e.g.



Acids amides are soluble in water and form crystalline solids due to extensive hydrogen bonds.

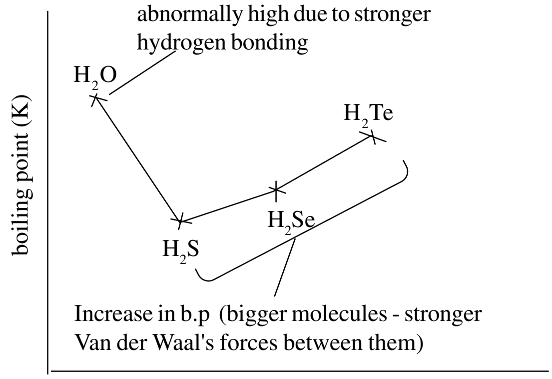
Cis-trans isomers e.g



The difference in physical properties in cis-trans isomers is due to the ease in which hydrogen bonds are formed. The *trans* example given is able to form two hydrogen bonds with its neighbouring molecules the *cis* form of this molecule would tend to form **internal hydrogen bonds** and would have a lower melting and boiling point.

The hydrides of fluorine oxygen and nitrogen have abnormally high melting and boiling points.

Hydrides of group 6



Hydrides of group 5 and 7

	Group 7				Group 5			
Hydride	HF	HCl	HBr	HI	NH_3	PH_3	ASH_3	SbH_3
b.p (K)	293	188	206	238	240	185	218	256

Practice Questions

Explain why:

(a) Ammonia (NH_3) has a higher boiling point than phosphine (PH_3)

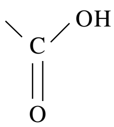
(b) Ethanoic acid (CH_3COOH) is more soluble in water than butanoic acid ($CH_3CH_2CH_2COOH$)

(c) Ice floats on water

(d) Hydogen bonding in enzymes is essential for them to speed up biological processes in the body

Answers

(a) Hydrogen bonding occurs between HN_3 molecules but not between PH_3 molecules. Hydrogen bonding is stronger than Van der Waal's forces, needing more heat energy to separate the molecules.

(b) The hydrophilic  is dominant in CH_3COOH

The longer hydrophobic hydrocarbon chain of $CH_3CH_2CH_2COOH$ is more dominant therefore its solubility is lower.

(c) Hydrogen bonds form as water molecules come closer together. The molecules are kept further apart than they were in liquid water. The density decreases, therefore the ice floats.

(d) Hydrogen bonding between the protein chains in enzymes cause folding and the formation of a precise shape which is essential for the enzyme to act as a biological catalyst.

Find out more

The following website has more information about hydrogen bonding which may help you prepare for your exam.

www.chemsoc.org/networks/learnnet/index.htm

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