BGCSE WORKSHOP TUTORIALS
“H-bonding (H-Bonding) Water and Ammonia”

Tutor: Mr. Mark Plummer
Email: info@thestudentshed.com
What to expect?

• Overview Van Der Waals Forces.
• Hydrogen and the structure of water
• Overview H-bonding with reference to water.
• Dipole and dipole moment.
• Hydrogen and the structure of ammonia
• Overview H-bonding with reference to ammonia.
• Shapes of ammonia and water.
• Why is this important?
Van Der Waals forces

- Simple covalent substances have strong bonds **BETWEEN** the atoms which make up the molecules / compounds.
- MP and BP tend to be low because the individual molecules are easily separated from each other.
- This explains why most simple molecular substances are gases or liquids at standard RTP.
Van Der Waals forces

Some simple covalent molecules – as liquids They ALL have attractive forces BETWEEN the molecules. But as gases they do not.
Van Der Waals forces

- As structures become larger or there are more molecules....
- The combined strength of the inter molecular forces *increases* – there are more molecules and so more forces.
- So the MP and BP will steadily *increase*.
- Forces are much weaker than the bonding which holds actual compounds and molecules together.
Van Der Waals Forces

- Van der Waals forces are the attractive force BETWEEN simple covalent molecules.
- Also called INTER-MOLECULAR FORCES.
- They are weaker than covalent bonds and ionic bonds.
- Examples include H-bonding between water molecules or ammonia molecules.

Johannes Diderick Van Der Waals (1837-1923)
https://www.biografiasyvidas.com/biografia/w/waals.htm
Van der Waals Forces

The four main types of chemical bond – these are the electrostatic forces between atoms which hold individual molecules or compounds together. Intermolecular forces exist between the molecules themselves.

Ionic (Metal + Non-metal)
- Only soluble in polar liquids
- Hard but brittle
- High boiling/melting points

Simple Covalent (Non-metal + Non-metal)
- Only soluble in non-polar liquids
- Weak and soft
- Low boiling/melting points

Giant Molecular (Non-metal + Non-metal)
- Not soluble at all
- Very hard and strong
- Very high melting/boiling points
- Insulator (except Graphite)

Metallic (Metal + Metal)
- Not soluble at all
- Hard and strong
- High melting/boiling points
- Conduct electricity as liquids and solids
Hydrogen

- Hydrogen is the simplest chemical element.
- It has one proton in the nucleus.
- Discovered by Henry Cavendish in 1776.
- Hydrogen gas is made from two hydrogen atoms held together by a single covalent bond.
- $\text{H}_2$ is an example of a DIATOMIC element.
- It is found every chemically bonded as part of inorganic and organic compounds.
- It has two isotopes – so 3 forms of hydrogen exist.
Sometimes hydrogen atom is called protium – a hydrogen ion is a hydrogen atom which has lost its only electron – so hydrogen (H\(^+\)) ions have a **POSITIVE** charge. This makes them **attracted to atoms or ions with a negative charge**.
Water

- **Water** is made from two atoms of hydrogen and one atom of oxygen.
- Each hydrogen atom has “space” for two electrons in its **ONLY** orbital or shell.
- But each hydrogen atom only has one electron.
- So it shares two pairs of electrons with the Oxygen atom.
- The result is a V shaped molecule.
Water

- The central oxygen atom has two lone \textit{pairs}.
- The oxygen atom is more electronegative than hydrogen.
- So Oxygen has a negative charge....
- ..Hydrogen has a positive charge.

Formula \( \text{H}_2\text{O} \) – two single covalent bonds are formed. Two pairs of electrons are shared.
Water

• The H atoms have no inner shells of electrons so the proton (its nucleus), has +ve charge.
• Each oxygen atom has two lone pairs of electrons and can make H-bonds with two different hydrogen atoms.
• The oxygen atom attracts the electrons which make up the O-H bond...
• It pulls electrons to itself, causing....
Water

• ..an unequal distribution of charge.
• A net **NEGATIVE** charge on the oxygen atom
• A net **POSITIVE** charge on **BOTH** hydrogen atoms.
• This creates a Dipole.
• The covalent bonds are pairs of electrons.
• They have the same charge so they repel each other.
• They are also pulled by positive charge from the nucleus – or other positively charged atoms which may be close by...
A polar compound is one which is ionic (bonding between metals and non-metals) or one that has a permanent dipole moment, like ammonia or water. This is a measure of the extent to which electrons (negative charge) are pulled toward one atom in the molecule relative to the others.
Dipole and Dipole Moment

• A dipole is a pair of separated but opposite charges.
• The dipole moment is the product of the positive charge and the distance between the charges.
• A polar molecule is any molecule which demonstrates or has a dipole moment.
• There is a separation of charge on the chemical bonds.
• One part of the molecule has a +ve charge the other part will be –ve.
H-bonding Water

- Mainly fluorine, nitrogen and oxygen.
- These elements are in the same PERIOD of the periodic table.
- This means they have the same number of electron shells....
- But different numbers of valence electrons.

Nitrogen atoms have 3 valence electrons.
Oxygen atoms have two andFluorine has one.

http://www.periodicvideos.com/
Ammonia

- NH₃ a colourless gas made of 3 atoms of hydrogen and one of Nitrogen.
- 3 Covalent bonds are formed with 3 hydrogen atoms.
- An ammonia molecule has the shape of a trigonal pyramid.
- This shape makes the molecule polar.
- Ammonia is very soluble in water.
- It has a very strong pungent odour.
Ammonia

- Density 0.59 / MP -77.7°C / BP -33.35°C
- In liquid form its chemistry can be compared to water.
- It also has H-bonds.
- It also has a negative end (N)
- And a positive end (H)
- So it is a polar molecule with a dipole moment.

As with water the hydrogen and nitrogen atoms each share electrons.... This forms the covalent bonds. Ammonia is held together by 3 single covalent bonds.
Shapes Covalent Molecules

Predicted by Valence Shell Electron Pair Repulsion (VSEPR) theory. Valence electrons orientate around the central atom(s) of the molecule. Repulsion by negative charge is minimised. Valence electrons are as far apart / close together as possible.
Ammonia

• Compared to water ammonia has a LOWER melting point, boiling point, density and viscosity.
• It is also less dense than air.
• The nitrogen atom in the molecule has a lone electron pair.
• Ammonia acts as a base when dissolved in water.

\[ \text{NH}_3(\text{aq}) + \text{H}_2\text{O} \quad \text{(reversible symbol)} \quad \text{NH}_4^+\text{(aq)} + \text{OH}^- \]
H-bonding Water

• H-bonds are formed when a hydrogen is bonded to electronegative atoms (-ve charge).
• A type of bonding which happens BETWEEN molecules...
• Attraction between the hydrogen nucleus (+ve) and the lone pair of electrons (-ve) on the oxygen atom in a neighbouring molecule.
H-bonding Water

Each oxygen atom has two lone pairs of electrons.
It makes H-bonds with two different hydrogen atoms.
The oxygen atoms and hydrogen atoms of different molecules are attracted to each other.
The bond is possible because of the different charges on the atoms.

These intermolecular forces are about a tenth of the strength of a normal covalent bond.
H-bonding Ammonia

• Ammonia has only ONE LONE pair of electrons – on the nitrogen atom.
• Ammonia is LESS electronegative than water
• This means there are less H-bonds.
• They are weaker.
• So at RTP Ammonia is a gas.
• In water there are TWO LONE pairs, more bonds and they are stronger.
• Water is MORE electronegative than ammonia.
• So water is a liquid at RTP.
Comparing H$_2$O and NH$_3$

- The H-bonding in water is much stronger.
- In liquid water they are constantly breaking and reforming.
- At RTP water is a liquid ammonia is a gas.
- Each water molecule can form up to 4 bonds with 4 other water molecules.
- In ammonia it is one –
- This is why water has a higher BP, MP and density at RTP than ammonia does.
- In vapour form there are no H-bonds present in either molecule – why?
Comparing \( \text{H}_2\text{O} \) and \( \text{NH}_3 \)

For ammonia there is only one lone pair on the N atom. In a group of ammonia molecules, there aren't enough lone pairs bond with the available hydrogen atoms. So at RTP there are not enough H bonds to keep ammonia as a liquid. For water there are enough. The only way for ammonia to be in liquid form is if temperature drops to less than -77 °C.

Liquid water and ice are sometimes called the perfect H-bonding system because the maximum number of H-bonds is formed in each state.
Comparing H$_2$O and NH$_3$

The difference in number of lone pairs on each molecule determines the different physical and chemical properties of each molecule – Oxygen (6) and Nitrogen (5) are in different groups of the periodic table. This also influences how the atoms of each element bond with other atoms and the physical and chemical properties of the compounds they form.
A lone pair is two electrons which are not involved in chemical bonding within a molecule – they create a repulsive force (a strong negative charge) – this makes them highly attractive to the positive of hydrogen atoms on other molecules – so for H-bonding to happen there has to be at least ONE lone pair
“A H-bond is defined as a dipole-dipole attractive force that exists between polar molecules containing a hydrogen atom covalently bonded to an atom of nitrogen, oxygen or fluorine”
Shapes Ammonia and water

• A key feature of covalent molecules is that they have a specific shape.
• When covalent bonds form the sharing of electrons produces a fix in a specific area for the valence (bonding) electrons.
• It is the repulsions and the orientation around the nucleus which gives the molecule its shape.
• Ammonia and water have the same number of electron pairs around the central atom...
• But different numbers of lone pairs.
A water molecule has two lone pairs of electrons on the oxygen atom – an ammonia molecule has one lone pair of electrons on the nitrogen molecule. The repulsive effect of the negative charge on each set causes the water molecule to have a V shape and the ammonia molecule to have a pyramidal / tetrahedral shape.
The shape of covalent molecules caused by these interactions is hugely important in biology and the chemistry of life because it influences which interactions are going to happen under a specific set of conditions and which ones don’t.
Why is this Important?

- A molecule of liquid water has an angular shape this causes a permanent dipole moment.
- Water is strongly H-bonded and has a high di-electric constant.
- A di-electric constant measures the polarity of a molecule.
- The higher the constant the more polar the molecule is.
- Water has a much higher di-electric constant than liquid ammonia.
- These properties make water a very powerful solvent for polar and ionic compounds....
Why is this Important?

- At RTP The MP of pure water is 0°C.
- At RTP The MP of pure ammonia is -77°C.
- So at RTP water is a liquid - ammonia is a gas.
- In the natural world ammonia is produced as part of the nitrogen cycle.
- It is an essential component of the process.
- It is released to the atmosphere or dissolves in water...
- Where it forms various compounds which are useful for life processes.
- In nature ammonia does not exist in high concentrations.
Why is this important?

- Bacteria in the nodules of legumes are able to form ammonia but at rtp.
- In the haber process this happens under high temperature and pressure.
- Ammonium ions ($\text{NH}_4^+$) are released into the soil.
- Then converted by nitrifying bacteria into nitrite and nitrate ions - in nodules.

The **Nitrogen** cycle is one of the bio-geo-chemical cycles and is an essential driver of life on Earth.
Why is this Important?

- When polar substances dissolve in polar solvents...
- The bonds between the solute particles are broken down because...
- The positive part of one molecule attracts the negative part of another...

Particle representation of ammonia a polar compound dissolving in water – a polar solvent. Water is called the universal solvent because so many substances dissolve in it – if it didn’t happen, life on Earth would not be possible.

\[
\text{NH}_3(\text{aq}) + \text{H}_2\text{O} \quad \text{(reversible symbol)} \quad \text{NH}_4^+(\text{aq}) + \text{OH}^- 
\]
Why is this Important?

• When polar substances dissolve in water or other polar solvent

• .. The **POSITIVE** charge on the hydrogen ions attracts the negative ions in the ionic compound.....

• The oxygen attracts the positive ions.

• Solute particles are separated from each other because they have different charges.

• Water molecules are able to separate the particles in ionic solids from each other......
Why is this important?

• Oxygen atoms form a shell around the positive charged particles from the ionic solid.
• The hydrogen atoms are attracted to the negatively charged particles in the ionic solid.
• This is an example of solvation.
• Hydration is a form solvation which refers specifically to water.
• Dissolving is an ENDOTHERMIC process.
• When ammonium nitrate dissolves in water the temp of the water falls.
• Energy has been taken from the surroundings.
Why is this important?

A polar substance is any substance which has different charges at opposite ends of the molecule – ionic solids are good examples.

• When NaCl dissolves in water the sodium ions attract polar water molecules.
• The negative charge on the oxygen atoms in the water attracts the Na\(^+\) ions – the hydrogen atoms attract the chloride ions (Cl\(^-\)).
• The same holds true for any ionic solid – all you have to do is remember the charge on each particle.
• This causes ionic solids to dissolve in water.
• The energy released compensates for the energy needed to break down the crystal lattice structure of the solid.
Non-Polar substances – those with no dipole – Have no uneven distribution of charge. Do not form ions when dissolved in water. Non-polar substances include organic compounds... And giant covalent structures....And the diatomic elements... And the Acidic gas CO₂ but the SO₂ and NO₂ are polar so will dissolve in water AND form ions.
Why is this important?

- All salts of sodium potassium and ammonium dissolve in water.
- All nitrates dissolve in water.
- All Chlorides except silver and lead dissolve in water.
- All sulphates except barium and lead – calcium sulphate is slightly soluble.
- Some small covalent substances will dissolve slightly in water E.G. CO$_2$, SO$_2$ and Cl$_2$.
- Larger covalent compounds won’t dissolve in water because they are non-polar.....
- And their intermolecular forces are so strong – Why might this be so?
Why is this important?

• In liquid water H-bonding pulls water molecules closer to each other...
• ...Than they would be if they didn’t exist.
• This produces a high degree of structure and order....
• The most ordered and densest form of liquid water exists at 4°C
• In the solid state (ice) the order and density decreases...
• So **liquid** water is **more dense** than **solid** water....
Why is this important?

Ice or solid water is LESS dense than liquid water – which is why icebergs do not sink but float on the oceans and gradually melt – it also why ice on a lake or pond does not sink and can support the mass of other objects too – the question is why? Well......
Why is this important?

- As water approaches 0°C...
- The arrangement of H-bonds changes...
- And more of them form...
- This forces the water molecules apart due to MORE repulsive forces...
- So ice expands as compared to water.....

Ordinary ice has an open structure built of six membered rings – each H₂O molecule is tetrahedrally bonded to four others.
So ice is less dense than water. Also in ice the H-bonds do not form and reform because they have less heat energy than liquid water molecules. At below 0°C water is no longer a fluid it is a solid so the hydrogen bonds become permanent and expand pushing the entire structure outwards – this makes solid water less dense than liquid water.

See if you can find any other PURE substance which is a liquid at RTP which behaves in this way?
Why is this important?

- Water directly underneath ice is more toward freezing than water which is not.
- This acts as an insulating but transparent layer. Keeping water temperature constant.
- The layer traps air allows sunlight to pass, so photosynthesis can carry on.
- In spring as the ice melts water is gradually formed.
- It takes alot of heat energy to melt ice this also prevents sudden increases in temperature.
- If ice was more dense than water – lakes and oceans would freeze from the bottom up.
- Ice would form, sink, and the water column would freeze upwards.
The physical and chemical properties of water at RTP are responsible for its surface tension – the tendency of liquid molecules to shrink to the lowest area under a given set of conditions.

In nucleic acids H bonding occurs between the bases which make up the chains in DNA.

H-bonding also occurs in proteins – so they are crucially important to bio-chemistry and therefore life itself.
Why is this important?

• Polar substances are said to be hydrophilic. Why?
• Non-polar substances are said to be hydrophobic. Why?
• Polarity is crucially important to the formation of cell membranes...
• ..and to the membranes which surround organelles.
• Whether a substance is polar or not influences its role in the biochemistry of organisms...
• And in the environment in general.
Water is highly absorbent of IR light and transparent to UV light, this makes atmospheric water vapour / clouds key component of the natural GHE. In daylight hours light from the sun in the form of UV light can pass through the atmosphere but when it is reflected from the surface of the earth, it is trapped in the atmosphere. This is why when clouds are not present, this is why even on very hot days it can get very cold at night, EG the desert.
Some Questions

- How does Molecular shape influence the BP and MP of the substance? What factors change the MP and BP of a substance?
- Suggest why simple covalent molecules do not have intermolecular forces acting between the molecules in the gaseous state but they do in the liquid state?
- Why might these substances be gases at RTP?
- How Does Ammonia have different properties to water? (you can make a table if you like)
- Explain how in terms of particles charge why polar substances dissolve in water and form ions but non-polar substances don’t?
- Explain why ionic, polar substances have a dipole and SUGGEST why larger covalent and most organic compounds do not?
- What is a lone pair? Why are they important? What do they do? Are they the same as valence / bonding electrons?
- Suggest with two examples what kind of substances will dissolve in Non-polar liquids?
- How Could Ammonia in theory act in the same way as water does on the Earth? What would have to change? How could that change happen? Why hasn’t it?
- Explain how if covalent molecules were the same shape life on Earth would not exist? What kind of reactions wouldn’t happen? What kind of processes wouldn’t happen?
- Suggest how hydrogen bonding is important for biological molecules, life processes and the environment? What might happen if they didn’t exist?
- If water was a linear molecule (like CO2) it would have different properties. Why? What factors make water a V shaped molecule but CO2 a linear molecule?
- If liquid water didn’t have H-bonds – it would be a gas at RTP – like ammonia. Why?
- Explain how water vapour and clouds influence global temperatures and could influence human induced climate change? Explain why it stays warm on a cloudy night but cools down very quickly when we can see the stars?
Links and Resources

- https://www.bbc.co.uk/bitesize/guides/z94xsbk/revision/3
- https://www.thoughtco.com/some-examples-of-covalent-compounds-603981
- https://www.youtube.com/watch?v=08kGgrqaZXA
- https://www.bbc.co.uk/bitesize/guides/z373h39/revision/1
- https://www.thoughtco.com/definition-of-lone-pair-605314
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