Chem Factsheet

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AS Chemical bonding: Intermolecular bonds

This Fact sheet is designed to help develop your understanding of intermolecular bonding – bonds that form **between** particles. After a brief word about terminology, the areas covered are:-

- Check your understanding about intermolecular bonds
- Hydrogen bonds
- Permanent dipole- permanent dipole (PDPD) bonds
- Instantaneous dipole – induced dipole bonds (IDID) bonds ("van der Waals forces")
- Exam questions and answers on intermolecular bonds

Exam questions and answers are included. Don't forget to complete your knowledge of chemical bonding by reading Chem Factsheet 107 on intramolecular bonds.

A word about terminology – what are "they" called?

Chemists are inconsistent about the names for bonds between particles. The terms "forces", "attractions" and "forces of attraction" are used to describe them. Some are given specific names - you may (or may not) have heard of "van der Waals forces", "London forces" and "dipole-dipole attractions". To be consistent, this FactSheet calls them "bonds" and uses names that say exactly what they are. Our view is that this is most helpful for you, as these names make the origins of the bond types clear and so are easier to remember. The names we have used will also help you realise that all bonds involve attractions between positively and negatively charged particles – its just the particles and the origins of the positive and negative charges that differ. Examiners, as chemists, are aware of alternative names and credit accordingly.

"Intermolecular" bonds are found between atoms and molecules. To start, check your understanding by answering these two questions.

Check your understanding about intermolecular bonds

Boiling	**Chlorides**
When water boils, bubbles appear in the liquid. What is in the bubbles?	The bonding in magnesium chloride ($MgCl_2$) is ionic. The bonding in titanium(IV) chloride is covalent. A mixture of the two chlorides is heated to 1000°C. Explain why the vapour above the heated mixture consists only of titanium(IV) chloride.

Full answers are given at the end of the fact sheet.

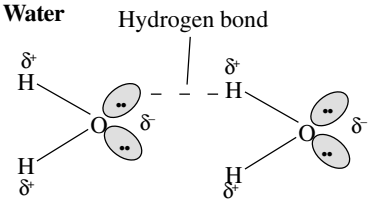
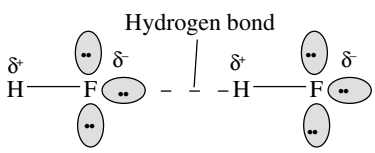
Intermolecular bonds are responsible for many physical properties we observe. In water (see the "*Boiling*" question above), intermolecular bonds break when water boils, creating water vapour. The molecules themselves stay as H_2O. In "*Chlorides*" intermolecular bonds between titanium(IV) chloride molecules break, creating the vapour. Again the molecules stay intact as $TiCl_4$. The strong ionic lattice of magnesium chloride does not break up at this temperature.

Hydrogen bonds

Hydrogen bonds arise when *hydrogen atoms are covalently bonded to a highly electronegative atom, namely nitrogen, oxygen or fluorine.* For similar size molecules they are the strongest of all intermolecular bonds. The strength arises because the hydrogen atom has no other electrons to shield the nucleus, so when distortion of the electron cloud occurs the nucleus is left very exposed, creating a large permanent dipole. The other, negatively charged atom always has one or more lone pairs of electrons. When opposite ends of two molecules approach each other a bond is formed *between the hydrogen atom on one molecule and the nitrogen, oxygen or fluorine atom on the other molecule* that is 90% ionic and 10% covalent. In water, this requires typically about 25 $kJmol^{-1}$ to break.

Simple molecular compounds with hydrogen bonds: Ammonia, NH_3; water, H_2O; hydrogen fluoride, HF.
Giant molecular compounds with hydrogen bonds: the polymers DNA, nylon and Kevlar®, also proteins

Drawing hydrogen bonds between particles is a common exam question. Here are two examples.

What the diagram shows	Hydrogen bonding in…	What to do in an exam
Permanent dipoles exist in water molecules due to the large difference in electronegativity between hydrogen and oxygen. The hydrogen bond forms between the hydrogen atom on one molecule and an oxygen atom in another.	**Water** 	Show at least two water molecules Draw 2 lone pairs on each oxygen atom Show the dipoles clearly Show the hydrogen bond clearly
A permanent dipole exists in hydrogen fluoride molecules due to the large difference in electronegativity between hydrogen and fluorine. The hydrogen bond forms between the hydrogen atom on one molecule and the fluorine atom in another.	**Hydrogen Fluoride** 	Show at least two hydrogen fluoride molecules. Draw 3 lone pairs on each fluorine atom. Show the dipoles clearly! Show the hydrogen bond.

Permanent dipole – permanent dipole bonds (PDPD bonds)
PDPD bonds arise between molecules with permanent dipoles. When "opposite" ends of two molecules meet, a bond forms between them. These bonds require about $5kJmol^{-1}$ to break.

- Simple molecular compounds with PDPD bonds: hydrogen chloride, HCl; chloromethane, CH_3Cl; hydrogen sulphide, H_2S
- Giant molecular compounds with PDPD bonds: polyvinylchloride (PVC); some proteins

Instantaneous dipole – induced dipole bonds (IDID bonds)
These are often rather confusingly called "Van der Waals forces" after the chemist who proposed their existence. IDID bonds arise because *the electron cloud* around, for example, an atom is not always evenly distributed. At any instant, a dipole may exist across the two sides of the atom. If a second atom gets close enough, its electron cloud will be distorted by the dipole on the first atom, creating an "induced" dipole.

The opposites attract, creating a short-lived IDID bond. When the electron clouds rearrange, an IDID bond will form between two other atoms. IDID bonds also form between molecules. Although any one IDID bond has a very small dissociation enthalpy, when there are millions of IDID bonds their effects can be extreme.

- Typical examples of simple compounds or elements with IDID bonds: liquified inert gas atoms; halogen molecules; low carbon alkanes
- Giant structures with IDID bonds: all polymers; long chain fat molecules; high carbon alkanes; iodine; graphite (between layers)

Remember: IDID bonds are found in every substance – they are universal. Instantaneous dipoles arise around any atom and can induce a dipole in any neighbouring atom or molecule.

Exam questions and answers on intermolecular bonds
These are questions examiners have asked specifically about intermolecular bonding in recent AS exams. Make the most of this section by covering up the "Answer" column and writing your own answers, taking note of the number of marks available. All the answers can be found in this Factsheet.

Question	Marks	Answer
Iodine and diamond are both crystalline solids at room temperature. Identify one similarity in the bonding. Explain why they have very different melting points. (part question)	4	Both have covalent bonding.(1) IDID bonds exist between iodine molecules requiring relatively little energy to break (1) Covalent bonds exist between carbon atoms in diamond (1) requiring much more energy to break (1)
Name the strongest type of intermolecular "force" between hydrogen fluoride molecules. Suggest why these bonds are not present between HI molecules. (part question)	3	Hydrogen bonding (1) Fluorine is more electronegative than iodine (1) So the dipole is weaker in HI creating less strong intermolecular bonds (1)
The halogens all have van der Waals forces. Explain how van der Waals forces are formed. (part question)	3	Uneven distribution of electrons around an atom/molecule creates an instantaneous dipole. (1) This induces a dipole (1) to form on a neighbouring atom/molecule. (1)
H_2O, HCl, and Ar all have van der Waals forces. Outline how these arise between molecules	2	An uneven distribution of electrons around an atom creates an instantaneous dipole. (1) This induces a dipole to form on a neighbouring molecule. (1)
Describe the nature of hydrogen bonding in water. (part question)	3	An oxygen atom of one molecule bonds to the hydrogen atom (can be a diagram) (1) Dipole exists in the H-O bond: $^{\delta+}H - O^{\delta-}$ (1)
Explain with the aid of a diagram how hydrogen bonds arise between molecules of $H_2O(l)$	5	H_2O molecules are polar (1) Dipole in water molecule shown correctly (1) H-bond between hydrogen and oxygen in another H_2O molecule (1) Oxygen is very electronegative (1) Oxygen has lone pairs (1) (see diagram on page 1)
Draw a diagram to show how two molecules of HF are attracted to each other.	3	At least one $^{\delta+}$ H and at least one $^{\delta-}$F shown (1) 3 lone pairs shown on at least one fluorine atom (1) H bond shown between H and a lone pair on F in a different molecule (1)

Answers to introductory questions

Boiling
Boiling is a change of state. Water molecules change from the liquid state to the gaseous state. Hydrogen bonds between molecules are broken in the process. Gaseous water is called "steam". The bubbles contain steam, since the hydrogen bonds between water molecules break when water boils.

Correct answers: Steam, water vapour, gaseous water

Possible incorrect answers: Oxygen; dissolved gas; Heat, energy; Carbon dioxide; Hydrogen; Oxygen; and /or hydrogen; Nothing / vacuum

Chlorides
Small induced dipole- dipole bonds between covalent molecules require much less energy to break than the bonds present in an ionic lattice. Intermolecular bonds between $TiCl_4$ molecules require relatively little energy to break them compared to that required to break up the ionic lattice.

Correct answer: Intermolecular bonds between $TiCl_4$ molecules break. Intermolecular bonds in ionic solids are much stronger.

Possible incorrect answers: Covalent substances have lower boiling points; Ionic bonds can't be broken by heating; $MgCl_2$ ionises; Covalent bonds are weaker than ionic ones so break; Covalent bonds are stronger than ionic ones of $MgCl_2$

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