Metallic bonds/Ionic bonds/and Molecular bonds, A First Year Blog
(for the week commencing the 9th February 2020)

- **Bonds** : **If any two entities remain bound together as one entity, then there MUST be some sort of force of attraction that binds them together**!

- Please could I stress that while you will see, in every Chemistry textbook, diagrams of atoms held together by bonds (depicted as lines between the bonded atoms), there is no such thing as a bond in the sense of a physical piece of metal/piece of string/or whatever holding things together. **Bonds are merely the forces of attraction that hold different things together.** That is all that they are. Don't look for a bond because you will not see it – but if two different species remain together and it requires energy to force them apart, then the force of attraction that was holding the species together was a **bond**.

- The examiners sometimes ask questions about "bonds" and about "bonding", and we have covered bonds/ bonding when we talked about *ionic* and *molecular* substances. However, let us cover the ground again – and then you cannot be caught off your guard in the exam.

- For a reaction to take place between two atoms, then the atoms
  a) must collide
  b) with *enough* force
  c) to break any existing bonds, and to
  d) form new bonds

  and **each one of these factors** is a necessary condition for a reaction to take place. For example if the two atoms collide, but not with enough force, then no reaction will take place. When we get to "How Far, How Fast" (HFHF) or "Thermodynamics and Kinetics" we will talk about this in much greater detail, and when we get to HFHF you will find that I like to use the following analogy – you bump into literally hundreds of attractive boys/girls every year of your life but you do not fall in love with every one of them because there is not enough chemistry between you. To fall in love with someone, there has to be a sufficient amount of physical/emotional/and psychological attraction or *energy* in the contact – and the same is true in Chemistry (except that there is no psychological and emotional energy involved in Chemistry)!

- There are five sorts of bonds[1] that we need to be aware of for 'A' Level Chemistry viz.
  A) Metallic bonds
  B) Ionic bonds (or "*electrovalent*" bonds)
  C) Molecular bonds, and these take two forms
  C1) **Intra-**molecular bonds (which are one form of "*covalent*" bond), and
  C2) **Inter-**molecular "bonds" viz.
    a) Hydrogen bonds (which are a *very* weak form of a "bond"), and
    b) van der Waals'/Fritz London/Peter Debye forces of attraction (which I call vdW forces of attraction) – and, strictly speaking, these are not really bonds at all because no ***bonding pairs of electrons*** are involved. vdW bonds are really just **forces of attraction** rather than bonds. The entities involved are very good friends rather than partners.

[1] Let me also remind you that for a "bond" to be formed, then strictly speaking at least two "bonding" electrons must be involved. If that is the case, then perhaps one ought to make a distinction between "**bonds**" and very weak quasi-bonds which are not really "bonds" at all but are just "**forces of attraction**". Johannes Diderik van der Waals and Fritz London and Peter Debye were all Nobel Laureates i.e. they were awarded Nobel prizes for their contributions to science.

A) **Metallic Bonds**

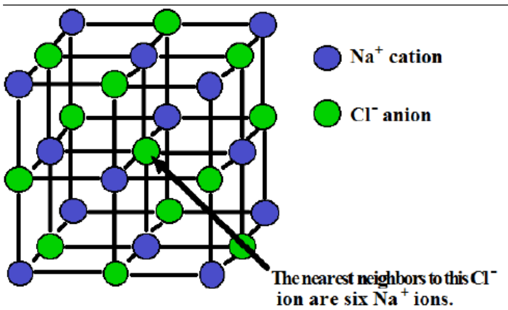
- **Metallic bonds are (or they result from) the omni-directional electrostatic forces of attraction that positively charged metal ions in a piece of metal exert upon the negatively charged sea of delocalised electrons surrounding the positive ions in a piece of metal.**

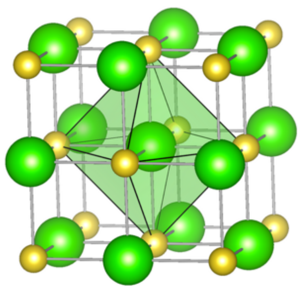
- An *ionic substance* is created when the atoms of a metallic element give up one or more electrons to the atoms of a non-metallic element thus creating positively charged metal cations and negatively charged non-metal anions, and then *every single ion in the ionic substance exerts a force of attraction upon every other oppositely charged ion* ***no matter how near or how far away that oppositely charged ion may be!*** Therefore the force of attraction is not exerted in any one specific direction – and the bond is thus said to be **non-directional** (or, because the force of attraction is exerted in every direction it is more accurately said to be **omni-directional**).

- A similar sort of thing happens in a piece of metal. A piece of a metal element (such as lead/zinc/copper/etc) consists of a large number of atoms of the element whose electrons have been delocalised thus creating positively charged ions of the metal, and every single positively charged metal ion exerts a force of attraction upon every single negatively charged delocalised electron in the piece of metal (and vice versa – and thus metallic bonds are also **non-directional** or **omni-directional** bonds. *[The force of attraction that is exerted is inversely proportional to the square of the distance between the two oppositely charged species.]*

B) **Ionic bonds**

- **An Electrovalent or Ionic bond results from (or is) the omni-directional electrostatic force of attraction between oppositely charged ions** (normally in a giant ionic lattice structure). An ionic bond is what binds together just one positively charged ion and one negatively charged ion in just one ionic unit e.g. between the ions Na^+ and Cl^- in one ionic unit of NaCl – but the definition also applies to whatever number of ionic units that there are in an ionic structure.





If one ion (e.g. Cl^-) is at the centre of an octahedron, then six of the opposite units (e.g. Na^+) will occupy the corners of that octahedron. Different ionic substances have differing layering structures.

Source : Chemistry LibreTextx and https://minerva.mlib.cnr.it/mod/book/view.php?id=269&chapterid=101

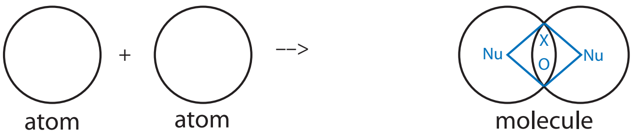
C) **Molecular substances**

- When two (or more) atoms get together and ***SHARE*** one or more **PAIRS** of electrons, then a molecular substance is formed, and an electrostatic force of attraction then binds the atoms together – because what is happening is that both sets of protons in the bonded nuclei of the atoms in the molecule are holding onto the *shared* pairs of electrons which lie "trapped" between them.

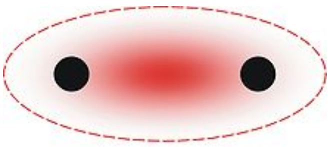
- I have mentioned it before, but I will mention again that the electrons in atoms occupy *atomic* orbitals, but when two (or more) atoms get together to form a molecule, they then occupy σ and π **molecular** orbitals and no longer s/p/d/f/etc atomic orbitals. We talked about the shape of 's' and 'p' orbitals in earlier Chapters, and I showed you the shape of a σ orbital in Chapter 11 (and it is repeated on the next page), and we will talk about the shape of π orbitals when we get to Organic Chemistry.

C1) A Covalent or **intra**-molecular bond is a bond **<u>inside</u> a molecule** and it results from the electrostatic force of attraction that two positively charged nuclei exert upon one or more pairs of **shared** negatively charged electrons. The diagrams below show a molecular σ (sigma) bond where a pair of bonded atoms are sharing the bonded electrons located between them.

- The first diagram below is my attempt to show two atoms locked together in a σ bond, and the one below mine is that by Professor Stephen Lower.



In the diagram above, the positively charged protons in the nuclei ("Nu") of the two bonded atoms are exerting an electrostatic force of attraction (shown here as "<>") on the pair of negatively charged bonding electrons "xo".



Source : Stephen Lower, Simon Fraser University

- Please remember that
  - *Bonds **INSIDE** or within a molecule are called **"INTRA**-molecular**"** bonds, and they hold the atoms inside a molecule together, and*
  - *Bonds **BETWEEN** molecules are called **"INTER-molecular"** bonds and they are what hold molecules together.*[2]

C2) There are four sorts of inter-molecular bonds/forces of attraction viz.
   a) Hydrogen bonds, and
   b) three forces of attraction known collectively as Van der Waals/London/Debye forces of attraction viz.
      b1) Permanent dipole to Permanent dipole bonds[3]
      b2) Permanent dipole to Induced dipole bonds, and
      b3) Instantaneous or Momentary dipole to Induced dipole bonds.

<u>The border between different types of bonds</u>

- We have elsewhere talked about the fact that it would be wrong to regard the difference between molecular and ionic bonding in stark black and white terms. For example, if the two elements participating in a covalent bond have differing electronegativity values, then the more electronegative atom will pull or distort some of the electron density or some of the electron cloud of the less electronegative atom towards itself, and the resulting *partial separation of charge*[4] will create an element of polarity inside the covalent molecule – and **the existence of a dipole (i.e. the existence of a partial separation of charge) in the molecule will thus confer an *ionic* character on the "molecule"** (even though molecules are **<u>not</u>** made up of ions).

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[2] A good way of remembering what an **INTER**-molecular bond is, is to remember that an Inter-City train is the train that runs BETWEEN cities, and an **INTER**-molecular bond is thus the bond BETWEEN molecules!
[3] We will talk about "dipoles" in a different Blog, but basically a dipole exists whenever there is a separation of charge **(no matter how small that separation of charge may be)**. A total separation of charge would result in **ions** in an ionic substance but a total separation of charge cannot occur in a molecular substance.
[4] i.e. the electron cloud has not separated completely into positive and negative areas – but the hitherto **evenly** distributed electron cloud on a species is now distributed **unevenly** with a slightly larger amount of the electron cloud in one area than in another area thus giving ∂– and ∂+ areas. We will talk about this in greater depth in the next Chapter.

- Similarly, in an ionic substance such as Na^+Cl^-, the *positively charged* metal cation (Na^+) will attract the electron cloud of its neighbouring *negatively charged (non-metal)* anions (Cl^-), and will pull or will distort the density distribution of those electrons towards itself. To a certain degree therefore, where there was theoretically a total separation of charge (i.e. the entity was totally polarised into positive and negative entities), the transferred electrons now become partly "*shared*", and since one of the distinguishing features of a covalent bond is the "sharing" of electrons, then **there will be an element of covalency in ALL ionic bonds** (even though ions **DO NOT** form covalent bonds).

- Thus, whilst it is possible for some molecular substances to have **no ionic character whatsoever** (e.g. a *diatomic molecule cannot have ANY ionic character whatsoever*), nevertheless it is unusual for an ionic substance to be *totally* free of ALL covalent characteristics.

- Let me finish this Blog with the words with which I started this Chapter viz. **if any two entities remain bound together as one entity, then there MUST be some sort of force of attraction that binds them together**!

- Please remember this fact for the next two years while you are doing 'A' Level Chemistry.

<u>**Footnote on "Dangling Bonds"**</u>

- When I was an 'A' Level student I was puzzled as to what happened to substances at the edges of their surfaces. After all, at the surface of a piece of say Carbon, the atoms on the surface must have four bond and yet they cannot have 4 bonds precisely because they are on the surface and not attached to any other atoms. However, let me offer you the following explanation (from a Prof of Physical Chemistry and an FRS).

  The atoms at the edges of solid structures cope with being surface atoms in a number of ways. One is that the surface atoms reconstruct so that they have slightly different bonding arrangements to the atoms in the bulk of the solid. They can perhaps satisfy their preferred valencies in this way. Another is that they simply have unbonded electrons sticking out from the surface (lone pairs or single electrons). Physicists refer to these as "dangling bonds". Even at a molecular level, Carbon doesn't have to form 4 bonds all the time; there are free radicals and also carbenes in which C only forms three or two bonds, and you can think of the unfilled valency therein as a dangling bond.

  Alternatively atoms at a surface can avoid these dangling bonds by forming terminating bonds to other atoms such as hydrogen or oxygen. The number of atoms at the surface is tiny compared to those in the bulk, so this doesn't much change the properties of the solid.

- You are not going to need that sort of knowledge at 'A' Level, but if the question about what happens at the surface of substances ever troubles you, then you now know the answer.