

[A First Year blog on Melting and Boiling Points: Part 2, 9th February 2019](#)

(This is a **revision** blog. It is merely a *summary* of some of the things that you need to know. *Everything in this blog can be found in the First Year, Foundation Book.*)

This blog is divided into the following Sections

Part 1 An examination of what happens when things Melt and Boil.

Part 2 An explanation of the forces that hold (i) solid substances and (ii) liquid substances together viz. Hydrogen bonds, and the three forces of attraction known collectively as van der Waals'/and London (after Fritz London) forces of attraction. In general these are

A Hydrogen bonds, and

B1 Permanent dipole to Permanent dipole forces of attraction

B2 Permanent Dipole to Induced dipole forces of attraction, and

B3 Temporary/Momentary/Instantaneous dipole to Induced dipole forces of attraction.

Part 3 An explanation of the above forces.

Part 4 An examination of the forces required to break these bonds (including the sort of questions that are asked in the 'A' Level exams requiring candidates to explain the Melting and Boiling temperatures of different substances).

Last week I drew your attention to the fact that there is a difference between very strong **IntRA-Molecular Forces** of attraction that hold atoms together inside a molecule, and the mainly weak **IntER-Molecular Forces** of attraction that exist between molecules and hold them together. These latter are van der Waals/London/Debye (WLD) forces of attraction¹, and this week I am going to tell you about these **IntER-Molecular Forces** of attraction viz.

a) Hydrogen bonds, and

b) the three forces of attraction known collectively as WLD forces of attraction viz.

b1) Permanent dipole to Permanent dipole forces of attraction²

b2) Permanent dipole to Induced dipole forces of attraction, and

b3) Temporary or Momentary or Instantaneous dipole to Induced dipole forces of attraction.

In the Introduction to this website I told you that I was not going to treat you like children and teach you Chemistry in an "are-you-sitting-comfortably-children" fashion. Instead I am going to treat you like adults and challenge you to use your brains. Well, this is a blog where I am going to do just that.

¹ At the border between Inter- and Intra- molecular forces, it is possible for an Inter-molecular force to be stronger than an Intra-molecular force, but I am going to ignore such fine distinctions for now.

² 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 rather than a molecular substance.

The explanations in this blog are going to be slightly complicated, but if ever you start to feel that you are getting lost, then please come back and read the following statements (in blue), and that will put you back on the right road.

- In an ionic substance there is always a **FULL** separation of charge into “+” and “-” species (*because that is precisely what defines an ionic substance*).
- In a molecular substance there can never be a full separation of charge (because it would then cease to be a molecular substance and it would become an ionic substance).
- What **is** possible in a molecular substance is for there to be a **PARTIAL** separation of charge into “ $\partial+$ ” and “ $\partial-$ ” areas in any one species, and
 - on some occasions the separation of charge will be **permanent**,
 - whilst on other occasions the separation will be **temporary** or **momentary** or **instantaneous** (the three terms being interchangeable).

Another set of distinctions that you must keep in mind in this blog is that

A **dipole** is created when there is a separation of charge, and there are three sorts of dipole that were discovered by and written about by Nobel Laureates such as Johannes Diderik van der Waals, Fritz London and Peter Debye (amongst other great scientists) viz.

- Permanent Dipoles to Permanent Dipoles
 - Permanent Dipoles to Induced Dipoles, and
 - Momentary or Temporary or Instantaneous Dipoles to Induced Dipoles,
- and please keep in mind that we are talking about the intER-molecular forces of attraction that hold molecules together.**

The following diagram shows (on the left) a molecule where there is no separation of charge, and on the right is a molecule where a separation of charge has occurred *for whatever reason*. In the way that I have drawn it, in the right hand molecule there is slightly more electronegativity on the right hand side (on the right it is “ $\partial-$ ”) than on the left hand side (where it is “ $\partial+$ ”).



The possible reasons for there to be a Separation of Charge include factors such as

- i) there is a difference in electronegativity between the atoms inside a molecule
- ii) an Induced Separation of Charge has been caused by a neighbouring molecule, and
- iii) a Momentary Separation of Charge has occurred *spontaneously* inside the molecule.

As you read this week’s blog, please come back to this page again and again. The statements in blue will guide you through a set of fairly complicated explanations.

This is one of those blogs where when you grasp what is going on, you will have a huge grin all over your face and you will say to yourself “My God, I am a **GENIUS!**”

There are four concepts to which I must now introduce you viz.

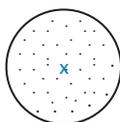
- A) Electron Density Distribution
- B) Uniformity
- C) Randomness, and
- D) The Separation of Charge.

A) Electron Density Distribution³

If you were to get a map of the bit of London (or whichever town/city in which you live), and then draw a cross on the map where your house is, and then for one week/or for one month/or for one year draw a dot for where you were at the end of every minute during the day, then you would have a map of all the places where you were for one week/one month/one year/or whatever. In the same way, if you were to draw a map of where the electron in a Hydrogen atom is during the course of every second, then you would get a map which I am going to call the “Electron Density Distribution” (the “edd”) for an atom of Hydrogen.⁴ Similarly, if you did the same for the two electrons in a Helium atom, then you would get the electron density distribution (the edd) pattern for the 2 electrons in Helium. *NB In both Hydrogen and Helium, the electron/electrons occupy the ‘1s’ orbital for **most** of the time but **not** for all of the time (cf. Prof Lower’s diagram below).*

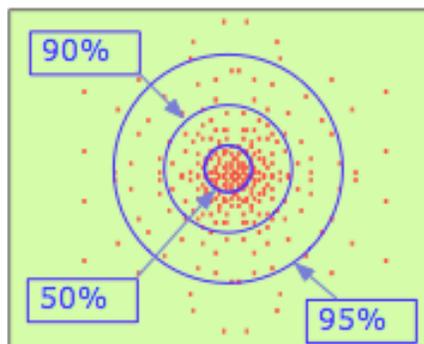
An “orbital” is a volume of space in which an electron is highly likely to be found, and the maps below are meant to show the particular region of space that electrons in an ‘s’ orbital and in a ‘p’ orbital occupy most of the time, i.e. the maps that follow are the **electron density distribution (edd)** patterns for an ‘s’ orbital and a ‘p’ orbital, and they therefore show the shape of each orbital.

This is the electron density distribution of a ‘1s’ orbital⁵ (e.g. that of the electron in the Hydrogen atom).



The edd pattern is *random* and *uniform*. [The blue cross represents the nucleus of the atom.]

However, it would be more informative if I were to use the edd map of Professor Stephen Lower (of Simon Fraser University).



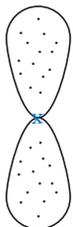
In Prof Lower’s diagram, the outermost circle defines the region of space in which one is likely to find the electron of Hydrogen 95% of the time.

³ Please note that I am **NOT** using the term “edd” in the way that crystallographers would use it. You may like to know that I met the great crystallographer (and Noble Laureate) Sir Lawrence Bragg in 1955 when I was just fifteen years old, and I still remember that meeting! Cf. http://nobelprize.org/nobel_prizes/physics/laureates/1915/wl-bragg-bio.html .

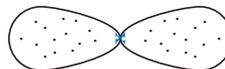
⁴ I repeat again, that this is not how crystallographers would use the phrase – but I am using it in this particular way for convenience. Strictly speaking, “edd” is defined as “the square of the electron wavefunction”, but there is no reason why that phrase should mean anything at all to you at this stage.

⁵ An “orbital” is a volume of space in which an electron is highly likely to be found.

The electron density distribution of electron(s) in a 'p' orbital (where the 'p' orbital is in the y-axis, p_y)



The electron density distribution of electron(s) in a 'p' orbital where the 'p' orbital is in the x-axis, p_x

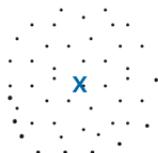


The blue cross represents the nucleus of the atom.

The edd for a 'p' orbital in the z-axis would come straight out of the paper at you!

NB

- 1 Please remember that the edd pattern is normally *random* and *uniform*! That is conceptually rather important.
- 2 Please also note that although there are many dots in the edd patterns of the 's' and 'p' orbitals that I have drawn, there may be only one electron and there can never ever be more than TWO electrons in any one orbital.
- 3 I have drawn my diagrams with hard/defined boundaries, but it is more accurate to draw the orbitals without hard boundaries thus.



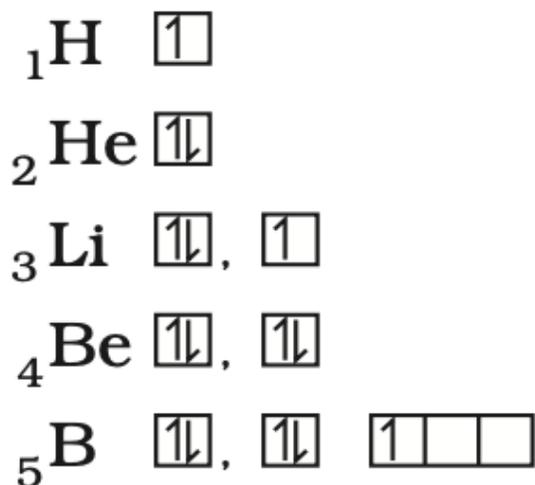
The electron density distribution (edd) patterns that I have drawn are in two dimensions because I cannot draw them **as they are in reality** i.e. in three dimensions. In reality therefore, the electron density distribution for a '1s' orbital would replicate that of a **shell of a football**⁶, and the electron density distribution for a 'p' orbital would replicate that of the shell of a **dumbbell** or an **hourglass**.⁷

It is very important to understand that the electron density distribution for the 's' orbital *is the map which shows where the electron in an 's' orbital is most likely to be found for most* (e.g. say 95% of the time). However, just as you might go to the Alps for your summer holidays and this would not show up on the day-by-day density distribution pattern which you did for yourself – so also, the electron in the Hydrogen atom might also occasionally be anywhere outside its density distribution pattern. The same is true for the electrons in the density distribution pattern of a 'p' orbital (and for every other orbital).

In fact, although the electron density distribution patterns for an 's' and for a 'p' orbital are as shown above, it would take far too long to draw these shapes each time – so for the sake of simplicity, orbitals are drawn as little boxes, and the electrons in them are drawn as single-headed arrows.

⁶ If you want to know where you can find out more about the 3D shapes of all the different orbitals, then you can do so on the excellent Chemistry Department website of Sheffield University presented by Professor Mark Winter (the UK's Royal Society of Chemistry HE Teaching Award winner for 1998) <http://winter.group.shef.ac.uk/orbitron/>, but Professor Winter's orbitron is far too advanced for you just as yet.

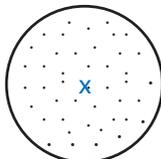
⁷ You will remember that there are three orbitals in a 'p' sub-shell, and the alignment of a 'p' orbital on the x-axis gives the edd for a p_x orbital, the alignment of a 'p' orbital on the y-axis gives the edd for a p_y orbital, and the alignment of a 'p' orbital on the z-axis gives the edd for a p_z orbital (and the 'z' axis is the axis that is perpendicular to or is at right angles to this piece of paper).



It will be remembered that entities possessing the same charge will repel each other, and it is thus not possible for two electrons to occupy the same orbital unless they possess counter-rotating spin – and for this reason, it is conventional to draw the two arrows in one orbital as pointing in opposite directions.

B) Uniformity

If something is ‘uniform’ then it means that it is the same everywhere, as in the normal distribution of an electron.



The edd pattern is *random* and *uniform*. [The blue cross represents the nucleus of the atom.]

C) Randomness

If something is random, then it is not predictable and it does not obey any rules.

Now, this next bit is the secret to understanding **intER**-molecular forces of attraction.

If the edd of an electron is random, then at any one moment in time it will be uniform, but at the next moment in time it will not be uniform. Every split-second of every nano-second, the edd of an electron will move from being uniform to being not uniform!

What then is the consequence of such behaviour? The answer to that question is “the separation of charge”.

D) The Separation of Charge

Where a **full separation of charge** occurs (i.e. where electrons are actually physically **TRANSFERRED** between atoms) then this results in the formation of an **ionic substance** with separate positive and negative species (i.e. cations and anions) in the substance held together by omni-directional electrovalent bonds.

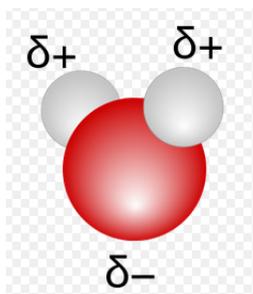
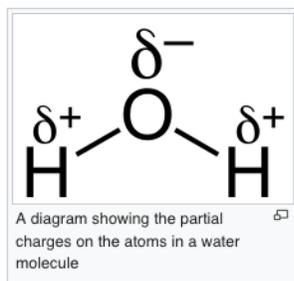
However, when talking about **intER**-molecular forces of attraction **we are not talking about ionic substances and their electrovalent bonds**. We are talking about molecular substances – and **we are trying to understand what holds the molecules in a molecular substance together**.

For **intER**-molecular forces of attraction we are talking about a partial separation of charge, and partial separations of charge can be either

- i) permanent or
- ii) temporary/momentary/instantaneous.

From the definition of a **molecular substance**, electrons are never transferred but they are instead **SHARED**, therefore a full separation of charge CANNOT occur in a molecular substance. However, a **partial separation of charge** can occur and it **does occur all the time** in molecular substances where there does not exist a full separation of charge.

Indeed, the edd of every single molecule of some substances will be distorted by the presence of an electronegative species inside each of these molecules and thus a **permanent partial** separation of charge will take place.⁸ For example, **in every single molecule of Water there exists a permanent partial separation of charge because Oxygen atoms are more electronegative than Hydrogen atoms, and the Oxygen atom in a molecule of Water will create a permanent partial separation of charge inside every molecule of Water.**



Source: Wikipedia

OK, I hope that it is now very clear to you that

- a) where there is a FULL separation of charge the resulting species **MUST** be an **ionic substance**, but that nevertheless
- b) even in a molecular substance there can be (and there very often is) a **partial separation of charge** – and there is a **permanent** partial separation of charge in molecules where the atoms of one element are more electronegative than the atoms of another element in that molecule e.g. as in H₂O or in H₂S.

It is however possible to have a **momentary/temporary/instantaneous** partial separation of charge, and we will talk about that very soon.

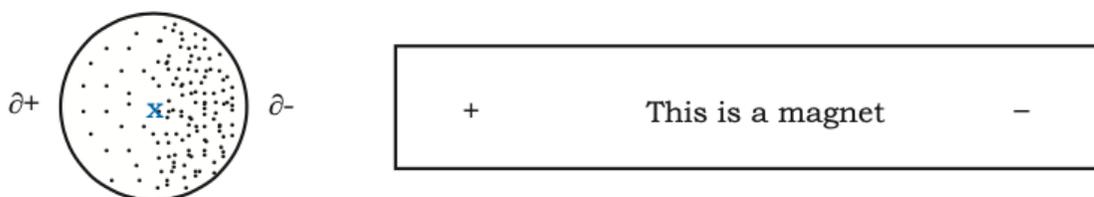
⁸ You will of course not have forgotten that inside a molecule, the **atoms** that make up the molecule are held together by very strong **intra**-molecular covalent bonds.

D1) A partial separation of charge

The whereabouts (or the approximate location) of the electron cloud in any of the orbitals of an atom is determined by the shape of the orbital (i.e. by whether it is an 's' orbital/or a 'p' orbital/or a 'd' orbital/etc, but within the region defined by that shape, the electron density is distributed in a *random* and in a *uniform* manner – and thus there is no *permanent* separation of charge within the atom (but there will always be momentary separations of charge because the very definition of randomness means that the edd does **not** have to be uniform).

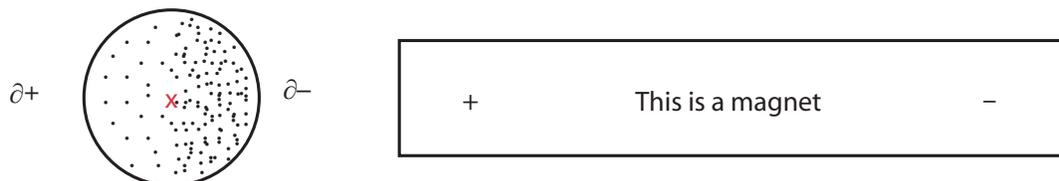
A partial separation of charge will occur **in all the orbitals of an atom** if a charged entity (such as a magnet) is placed near the atom because a *positively* charged entity will attract the electron cloud, while a *negatively* charged entity will repel the electron cloud. One side of the atom will thus become “ δ^- ” and the opposite side will become “ δ^+ ”, and a partial separation of charge will thus occur e.g.

This represents an atom



A magnet will also cause a separation of charge to occur in a molecule in which the *atoms* have exactly the same electronegativity (e.g. $O_2/H_2/N_2/F_2/Cl_2$ /etc).

This now represents a molecule



Please imagine that in this example the species on the left above (*not the magnet*) is a molecule.

It really is very important that you should be able to recognise where separation of charge occurs, because separation of charge (whether partial or complete, and whether temporary or permanent) is a major cause of reactivity in Chemistry – and it is very easy to recognise which of two elements is the more electronegative simply by remembering the two rules for electronegativity viz.

- the electronegativity of elements increases as you go from left to right ACROSS each *Period* in the Periodic Table, and
- the electronegativity of elements increases as you go UP each *Group* in the Periodic Table.

D2) A FULL separation of charge

When talking about molecular substances, we do not need to spend any time in discussing a full separation of charge, because **when a full separation of charge (or complete polarisation) occurs, then an ionic substance is created.**

However, please note **VERY** carefully that the words “partial” and “full” do NOT mean the same as any of the three terms (i) “permanent” (ii) “induced” and (iii) “temporary / instantaneous / momentary”!

A dipole

We are now going to start talking about dipoles, so let us define a dipole. In Physics, a “dipole” is a word that strictly speaking *should* indicate that a full separation of charge into a positive pole and a negative pole has occurred in a given species, but it does not have that meaning when *chemists choose to use it to indicate that a partial separation of charge has occurred.*⁹

A **dipole moment** consists of the product (i.e. the result of the multiplication) of the size of a **charge** and the **distance** that separates the two poles. In ‘A’ Level Chemistry, you are NOT required to know how to calculate the size of a dipole moment, **but you are required to know that in a symmetrical molecule, dipole moments can cancel each other out.** They do not always do so, but they CAN cancel each other out. If you are doing the Trigonometry of ‘A’ Level Applied Maths, then you will understand that statement, but if not, then do not worry about it – just take my word for it.

Permanent, Induced, and Instantaneous or Momentary Dipoles

We are now in a position to talk about dipoles because chemists talk about **a dipole whenever there is either a PARTIAL (“ δ^- ” and “ δ^+ ”) or a FULL (“ $-$ ” and “ $+$ ”) separation of charge inside an entity.**

B1) PERMANENT Dipoles

A **permanent dipole** will exist where there is a **permanent separation of charge** i.e. there will be a permanent dipole in any substance where there are permanent regions of “ δ^- ” and “ δ^+ ” in a molecular substance, or of “ $-$ ” and “ $+$ ” in an ionic substance. Just now we talked about the permanent partial separation of charge in H₂O and H₂S, but literally trillions of molecular substances have a permanent partial separation of charge in them. **A permanent partial separation of charge will occur in every molecule where there is a difference in electronegativity in the constituent atoms of the molecule.**

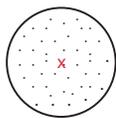
B2) INDUCED vs. Permanent Dipoles

We are now going to talk about **INDUCED** dipoles.

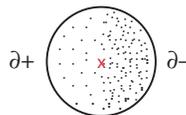
If we were to place a magnet “A” against or near an unpolarised molecule “B”, then “B” would become partially polarised for as long as we kept the magnet against it or near it – and when we took the magnet away, then “B” would no longer be partially polarised. In other words, “B” would have an **induced polarity** (and it would have an *Induced Dipole*) for so long as the magnet were next to it. However, the inducing agent does not have to be a magnet. It can be any entity that has a dipole.

⁹ For a long time in England, grammar and syntax were not taught in schools and thus subsequent generations of **teachers** did not themselves know correct grammar and syntax. I would urge you to learn how to speak and write English correctly. We scientists do not like it when lay people do not know and obey the rules of science (e.g. in a debate on climate change) – and why then should we think that we are not obliged to know and to follow the rules of grammar and syntax?

Normal edd of a given molecule
Entity “B”



Edd of the same molecule when an entity with a dipole is placed next to it



A separation of charge in a molecular substance can therefore be either **PERMANENT** (where its polarity is independent of any other entity) or it can be **INDUCED** (i.e. where its polarity is dependent entirely upon the influence of a polarised species or of a polarising field that is nearby¹⁰).

We can sum up the situation with regard to Induced Dipoles by saying that, **if any entity “A” that has either a full or a partial dipole, or an entity with a permanent/induced/or momentary dipole were to come near to an unpolarised species “B”, then “A” would distort the electron cloud on “B” and would create a partial separation of charge in “B”, and “B” would then have an “Induced Dipole”.**

B3) Instantaneous / or Momentary or Temporary vs Permanent Dipoles

The exact location of an electron at any point in time is purely a random matter. This situation is *exactly the opposite of* (for instance) your daily curriculum where you can look up a timetable to see where you will be at any point in time during the day. Scientists know **roughly** where any electron is (e.g. in an Hydrogen atom there is one electron and it resides in the orbital of the ‘1s’ sub-shell) – *but scientists cannot say with certainty where any particular electron will be at any given point in time!*¹¹

The electrons in any atom and in any molecule are **randomly** orbiting their nuclei which is why *scientists cannot say where any particular electron will be at any given point in time.* It can thus be seen that **at any one point in time there could be more of the electron cloud on one side (say on the Right Hand Side, RHS) of the atom (or of the molecule) than there is on the other side of it (i.e. on the LHS).**

If this were to happen, then the RHS of the atom or molecule (as shown in the diagram overleaf) would be slightly more negative than the LHS (and this situation is indicated by the use of the signs “ δ^- ” and “ δ^+ ”), and the atom or molecule would **temporarily** or **momentarily** or “**instantaneously**” be partially polarised i.e. it would then possess a **Temporary** or **Momentary** or **Instantaneous dipole!**

*NB There could be more electron density or more of the electron cloud on **any one** side (i.e. the top/bottom/ back/front/RHS/LHS) of the atom (or the molecule) than there is on any other side of it.*

However, please note that this **TEMPORARY** or **MOMENTARY** or **INSTANTANEOUS DIPOLE** would NOT have been induced by anything at all! **It would have occurred randomly/by chance.**

¹⁰ Either a magnetic field (from a magnet) or an electric field (from say a battery) will create the induced polarity.

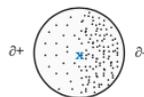
¹¹ I know that my youngest adopted son treats patients in a hospital on a Monday, but I cannot tell you where in the hospital he will be at any point during the day, and if there had been an emergency, then he might have had to fly off to a hospital in Sussex/China/America/Boston/Africa/or (for all I know) Mars or the Andromeda Galaxy. At University you may find that concept helpful in understanding Heisenberg. *I know roughly where my son is, but I do not know exactly where he is! Heisenberg works on a different principle, but the concept of uncertainty is similar.*

Normal edd of a given atom/molecule at any ONE point in time.



A randomly and evenly distributed edd

Edd of the same atom/molecule when for one brief moment in time there is **MOMENTARILY or **INSTANTANEOUSLY** more electron density on one side of it than there is on the other side of it.**



*An **unevenly** distributed edd*

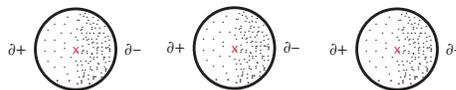
For the brief space of time in which the atom or the molecule above has a partial separation of charge or a dipole, then just for that brief moment in time there is no difference between it and an entity that has a permanent dipole.

For that brief space of time in which an entity possessing an Instantaneous or Momentary Dipole has such a dipole, then it is able to do all the things that a Permanent Dipole can do. For example, it can temporarily induce polarity into another entity. In the diagram below, the middle molecule briefly takes on an Instantaneous dipole, and thus **INDUCES** polarity into its immediate neighbours.

The middle molecule in that brief moment of time in which it takes on a **Momentary or an **Instantaneous** dipole**



The same molecule in the next brief moment of time in which it has induced a dipole into its immediate neighbours



However, as soon as the momentary or instantaneous polarity of the first atom or molecule is lost, then it would cease to induce polarity into its neighbours.

Let me now point out something very interesting to you. In the diagram above, I have shown what happens to the two molecules that are positioned one on each side of the middle molecule; but, could **YOU** work out what would happen at precisely the same point in time to the molecules that were the immediate neighbours of those two molecules, and to the immediate neighbours of those molecules, and to the immediate neighbours of those molecules, and to the immediate neighbours of those molecules, and so on!

Please do not carry on reading until you have worked out the answer for yourself.

The answer is that

- **if just one single molecule in a group of molecules becomes momentarily polarised**, then
- **in a flash all the other molecules in the whole group of molecules will immediately have polarity induced into them!**

Let me put it this way (*and if this does not blow your mind, then nothing ever will*), I do not know how many molecules of water there are in the Pacific Ocean but the number must be colossal¹², but if we were to imagine that the whole of the Pacific Ocean were comprised of molecules of liquid Oxygen (or liquid Nitrogen, or of whatever liquid) and **if just one molecule in the whole of the Pacific Ocean were for one brief moment of time to take on Momentary or Instantaneous polarity and no other molecule in the ocean were to be momentarily or instantaneously polarised at that point in time (a situation that is statistically impossible), then every other molecule in the whole of the Pacific Ocean would automatically acquire Induced polarity!**¹³

Isn't that fantastic! Actually, it is even more fantastic than that, because it is not a question of one molecule in a group of molecules *possibly* acquiring Instantaneous polarity. The edd of an unpolarised molecule is *random* and *uniform*, therefore every single unpolarised molecule is constantly and continuously experiencing edd reversals from uniform to non-uniform, and to all intents and purposes therefore, over a period of a split-second, every molecule always has a separation of charge in it – and **this is the secret of why the molecules in any group of non-polarised molecules stay together instead of flying off in different directions!**

Please could you stop there and read those two paragraphs again because that is the secret of vdW/London/Debye forces of attraction. The sequence of the logic is this

1. The edd of atoms/molecules is random, therefore even where there is not permanent separation of charge in an atom or a molecule, then
2. at every split-second of every nano-second there will be a different temporary separation of charge, and
3. During that split-second the atom or the molecule will have a dipole in it, and **it is the attraction between all the different “ δ^+ ”s and the “ δ^- ”s that holds the molecules together.**

THAT is what inter-molecular forces of attraction are all about.

This part of this blog has been about

A) **The separation of charge** i.e.

A1 The permanent or the temporary **Partial** separation of charge (in a molecular substance), and

A2 The permanent **Full** separation of charge (in an ionic substance),

and whenever there is a separation of charge there will exist something that is called a dipole, and it has therefore also been about the different sorts of

B) **Dipoles** i.e.

B1 **Permanent** dipoles

B2 **Induced** dipoles, and

B3 **Momentary**, or **Temporary**, or **Instantaneous** dipoles

and these affect **Hydrogen bonds**, and **van der Waals/London/Debye forces of attraction**, and I will talk about those in next week's blog.

¹² “colossal” but NOT “infinite”. There are only as many molecules in the Pacific Ocean as there are. Man may not be able to count how many there are, but that is not the same as there being **no limit** to the number of molecules of water in the Pacific Ocean! The word “infinite” should be used only where it is appropriate. The word “infinite” does not mean “a very large number”. It means “the number has no end”, “it has no boundary”, “it has no limit”. I am of the opinion that ALL material things are finite and only non-material things are infinite. I am therefore not happy with the use of the word “infinite” as it is used by astronomers. Just because human beings do not know the answer to something, that does NOT mean that the answer is unknowable.

¹³ In fact, the idea of one molecule inducing polarity into the whole of the Pacific Ocean is an unrealistic concept; but, it is a nice little theoretical concept to play with just to illustrate the idea of Induced polarity!

Could you now close your eyes and pretend that I am sitting in front of you, and please now tell me the difference between a full and a partial separation of charge, and then tell me the difference between a Permanent dipole, an Instantaneous dipole, and an Induced dipole and how these dipoles occur.

If you cannot (and I strongly suspect that you will not as yet be able to do so as yet) then please would you re-read this blog *again and again and again until you can do so*, and I promise you that you WILL have to read this blog again and again and again before you really and truly understand the concepts herein – but, I also promise you that once you HAVE mastered the concepts herein, then you will make a very good chemist, or if you are going on to do something in the medical field, then you will understand things like DNA and double helices *without much difficulty at all*.

Think about what I have just said “If you understand all the different bonds and forces of attraction clearly, you will pick up DNA in a flash – because genes/chromosomes/etc are nothing more than *big* entities. They are complex entities but they are not in themselves complicated ones. Once you understand what a polymer is and how (if you like) the head of one molecule can hold onto the tail of another molecule, and what holds one strand of a double helix onto the other strand – then that’s it, you’ve cracked DNA. OK, that won’t make you into Francis Crick/Maurice Wilkins/James Watson or Sir John Sulston¹⁴, but you will then be able to *understand* what those great scientists discovered.

When we get to Organic Chemistry/Chains & Rings, I will tell you how the head of one molecule holds onto the tail of another molecule (and that will allow you to understand polymers/proteins/peptides/etc) – *and it is all to do with the elementary stuff in this Chapter*. That is the beauty of Chemistry. **If you take the trouble to master the simple stuff, then later on you can just sail through the complicated stuff.**

NB If you do want to do something in the field of medicine, then please do try to understand what you are doing. The idea of someone who has the power of life and death in his/her hands only half understanding what he/she is doing is a terrifying one.¹⁵

¹⁴ and they had to stand on the shoulders of Rosalind Franklin (actually Watson quite possibly *stole* knowledge from Franklin and I believe he has never fully acknowledged his debt of gratitude to her). Franklin stood on the shoulders of Dorothy Crowfoot Hodgkin, who stood on the shoulders of Lawrence Bragg, and so on. In Science, we all depend on the people who have paved the way for us to do whatever we do.

¹⁵ A junior doctor once almost killed my wife when he injected a drug straight into one of her veins instead of putting it into a bag of saline solution and then dripping it into her over the next few hours. She was such a lovely human being that she forgave him, but I am such an awful human being that a quarter of a century later I still find it difficult to do so.