

Year 2, Organic Chemistry, Chapter 24: Zwitter¹ ions and Polymers

Zwitterions

- In Chemistry an “Ionic unit” such as NaCl is composed of both a positively charged cation (e.g. Na^+) and a negatively charged “anion” (e.g. Cl^-), but an “ion” *by itself* is a species that has either a positive or a negative charge, but not both. This is **not the case with a zwitterion which can have both a positive and a negative charge in it** (but each one would be at a different location in the species), and **a zwitterion can not only have both a positive and a negative charge within it, but it can have multiple sets of positive and negative charges within it.**
- At AS Level Chemistry² I started by telling you about simple/standard ions such as Na^+ and Cl^- , and then when we came to Organic Chemistry, I pointed out to you that the salts of organic Acids are in essence no different from the salts of inorganic species except that physically they could be **very much larger** than Na^+ and Cl^- .
- For the purposes of this Chapter, I shall use the definition of an Acid as a proton donor and a base as a proton acceptor, and the example that is most frequently used to illustrate a zwitterion is a molecule that has a “-COOH” species in it and an “-NH₂” species in it (which gives the classic “Amide” link in Biology). Imagine, if you would, how large the species RCOO^- might be if “R” were a huge Acid (or a fatty Acid with *three* lots of Acids attached to the glycerol species³). The beauty of the label “R” is that it is limited only by the size of your imagination! In the diagram at the top of the next page, it is entirely up to you as to how big you want your “R” to be. In the diagram, the H atom is still attached to the “-COO-” part of the molecule, but it *can be* dissociated as a proton. When it becomes dissociated **INTERNALLY**⁴, then the molecule will have both a positive and a negative charge **within the molecule**. This I have shown at the top of page 2 where the proton has as yet **NOT** been dissociated, and there are no charges internally in the molecule. The negative and positive charges that are shown are there merely to draw attention to the **delocalisation of the unhybridised π electron** caused by the mesomerism involved in having two O atoms attached to the C atom.

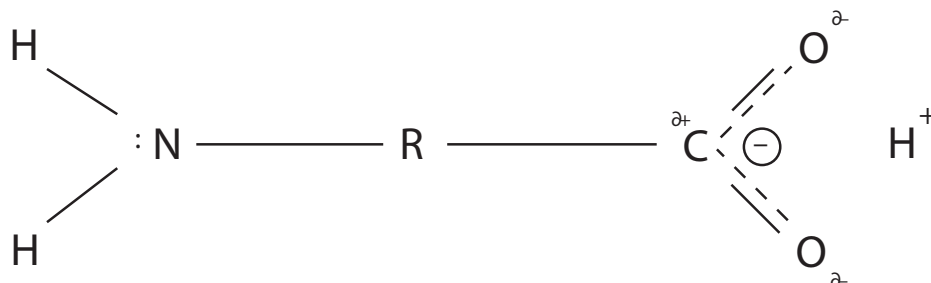
¹ I do not know much German, but apparently “zwitter” in German means an *hermaphrodite*. In Biology hermaphroditism exists in a species **when the members of the species have the sexual organs of both a male and a female and can thus act as either when mating**. In Biology ‘hemaphrodites’ thus use **either** their male or their female reproductive organs when mating, whereas in Chemistry ‘zwitterions’ have both male and female reproductive organs and in a sense **they mate with themselves**. “zwitter” is thus a misnomer. It is just that we do not have an adequate word to describe the activities of a “zwitter” ion.

² This year I will teach you the Chemistry of zwitterions and Polymers, and if you go on and do something in Medicine, then you will be able to understand the mechanics of peptides/proteins/chromosome/genes/DNA/etc very easily.

³ If you are not doing Biology, then please see the Appendix.

⁴ Depending on the pH of the environment in which it is situated. The more acidic the environment (i.e. the lower the pH of the environment), the more likely it is that the “-NH₂” base will have accepted a proton from the environment rather than internally, and the more alkaline the environment the more likely it is that the “-COOH” will have donated its proton to the environment.

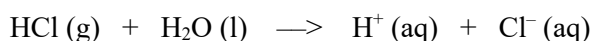
- When talking about the “Acid” and the “base” elements of zwitterions, I shall first confine myself to using “–NH₂” as the exemplar for my base⁵. The reason that, when talking about zwitterions, chemists tend to use species that contain “–COOH” and “–NH₂” regions is to give students who are doing Biology a good grounding in amino-Acids (and thus to give them good strong foundations for studying peptides/proteins/genes/chromosomes/DNA/etc).



The lone pair on the N atom will allow it to accept a proton. It is a base.

The dashed line indicates the delocalisation of the electron in the acid part of the zwitterion.

- Please note that, at this stage, the positive and negative charges shown to the right of the diagram above **do not exist in reality**. **There is no total separation of charge in the molecule** in the “–COOH” (Acid part of the molecule). The C atom and the H atom exist purely as C^{δ-} and H^{δ+} species and **not as ionic entities**.
- Just as HCl as a gas is a molecular substance and cannot become an Acid/an ionic substance until it is in an environment in which the H atom can be dissociated as a proton [normally as H₃O⁺ in Water giving HCl (aq)] thus giving



so also a ‘zwitterion’ is a **molecular** substance and not an ion until it is in an environment in which it can either (i) dissociate its proton from the Acid part of the molecule, here the “–COOH” region, or (ii) accept a proton in the base part of its molecule (here the “–NH₂” region)⁶.

- In essence we need to consider three different situations/three different environments in which the zwitterion can find itself – and now I must introduce you to something called the Isoelectric point.

The Isoelectric point

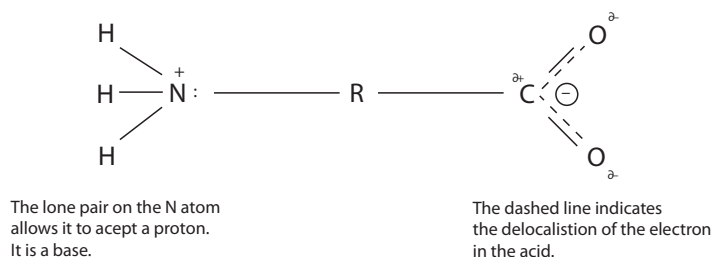
- Dr Ian Hunt of the University of Calgary (in his excellent Organic Chemistry web book⁷: <http://www.chem.ucalgary.ca/courses/350/Carey5th/Carey.html>) describes the isoelectric point as “The **isoelectronic point** or **isoionic point** is the pH at which the Amino Acid does not migrate in an electric field”. However, I prefer the use of the old term “isoelectric” point – and the isoelectric point has a much wider usage other than for just amino-Acids.

⁵ In Organic Chemistry, an Amine is a species that has an “R.CH₂(NH₂)” configuration.

⁶ However, please remember that the “R” species in the zwitterion can themselves contain any number of Acid and base regions.

⁷ In conjunction with Francis Carey who, until he retired, was Prof of Chemistry at the University of Virginia (USA).

- Could I now ask you to study the diagram below for a few moments before you read on. What is the difference between this diagram and the one at the top of page 2?



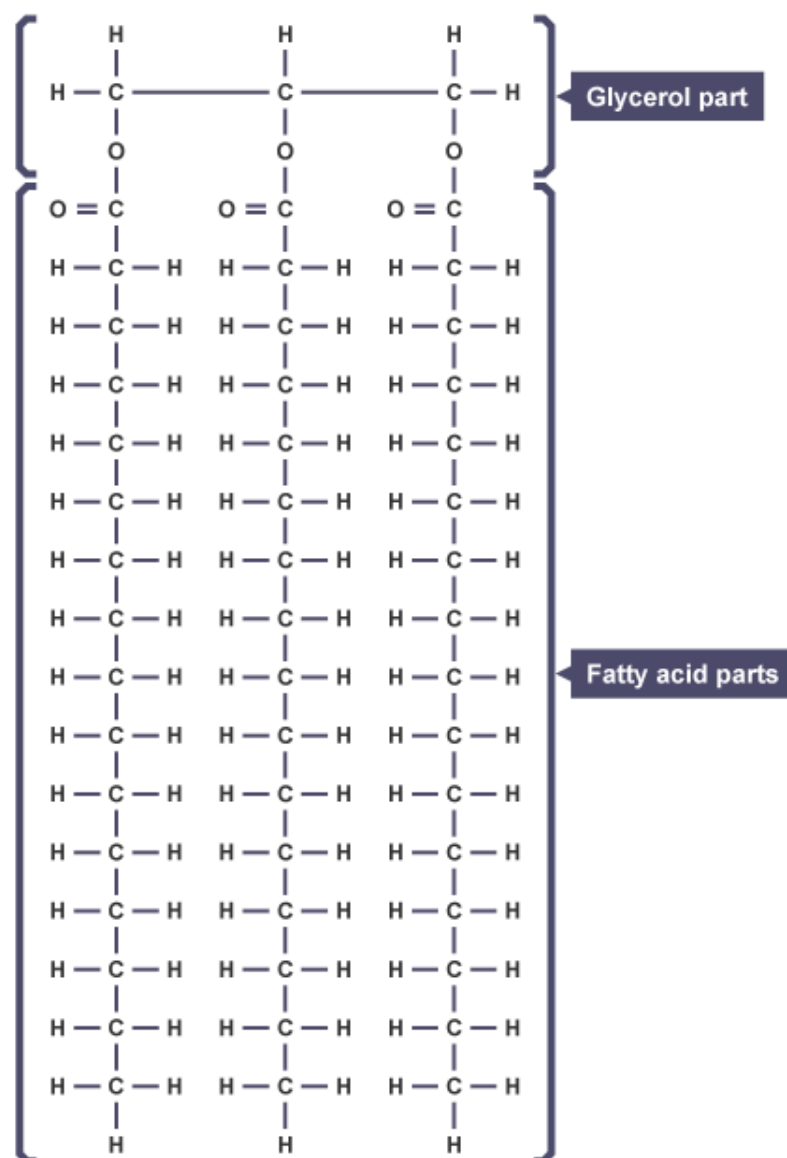
- I am sure that you noticed that **the molecule has now dissociated its proton to itself**. For the moment I do not care how it did so, all that I want you to notice is that it has done so.
- Here the Acid part of the molecule has donated a proton **INTERNALLY** to the base part of the molecule. The “–COOH” part has now become “–COO[–]”, and the “–NH₂” part has become “–NH₃⁺”. The molecule has behaved in the manner of both an Acid and a base, but it has done so **INTERNALLY**. Now can you see why in the olden days these species were designated as *dipolar* – but please note that at this point, **externally the species has no charge. It is ionic internally, but externally it is not ionic.** It has stopped being *potentially* a zwitterion and it has now **actualised its potential to be a zwitterion (and you can therefore see why chemists could not use the normal terminology of ionic and molecular, and instead had to invent the term “zwitterion”.** **At this stage of its existence a zwitterion is externally not an ionic substance, and internally it is no longer a traditional molecular substance.**
- OK, let us go back to our consideration of isoelectric points – and, essentially, the zwitterion in its current state is in the middle position of three different situations. However, at this point it would be helpful for you to remember that pure Water is neutral at a pH of 7 at a temperature of 25° C and it is neutral **at different pH values** which are determined by different temperatures⁸. For example,

at 0°C	pH ≈ 7.47 therefore at 273K Water is neutral at a pH of 7.47, and
at 18°C	pH ≈ 7.11 therefore at 291K Water is neutral at a pH of 7.11, and
at 25°C	pH ≈ 7.00 therefore at 298K Water is neutral at a pH of 7.0, and
at 50°C	pH ≈ 6.61 therefore at 323K Water is neutral at a pH of 6.61, and
at 100°C	pH ≈ 6.12 therefore at 373K Water is neutral at a pH of 6.12.
- The message that you will have taken away from the above is that the pH value of neutral Water depends on the temperature. You will therefore then easily see that the position of neutrality for a zwitterion can depend on the pH of the environment in which it finds itself – and, in fact, that is precisely what it depends on.
- In an **acidic environment** the *base part* of a zwitterion will accept a proton from the acidic solution in which it is immersed and become “–NH₃⁺”, and in a base environment the acidic part of a zwitterion will donate a proton to its surrounding base solution and become “–COO[–]”, and the isoelectric point will lie somewhere in between those two situations.
- At its isoelectric point a zwitterion will be **neutrally charged externally** but it will be **ionically separated internally** viz. it will have a full separation of charge (rather than merely a partial separation of charge with δ⁺ and δ[–] parts) internally – and, overall, externally it will **not** have a charge.

⁸ You will find a detailed discussion of this in the Second Year Chapters on Equilibrium Constants in Inorganic Chemistry.

- I do not intend to go into a pK_a analysis of zwitterions in Organic Chemistry (because it can get rather complicated when we start talking about the differing acidic and base regions in the “R” offshoots in an organic molecule, and I will discuss it separately in Inorganic Chemistry – but when I do talk about it elsewhere, please remember that differing pK_a values can have very important ramifications in the production of drugs for medical purposes.
- In Biology, there can be more than one “R” region, and (ignoring the “R” bits for the moment), the acidic and base parts can be very close to each other physically while the “R” bits can be very long chains. A vegetable oil (as opposed to crude oil that comes out of the ground) is basically an Ester i.e. an Acid and Alcohol joined together. Just look at the oil below and see how big “R” is.

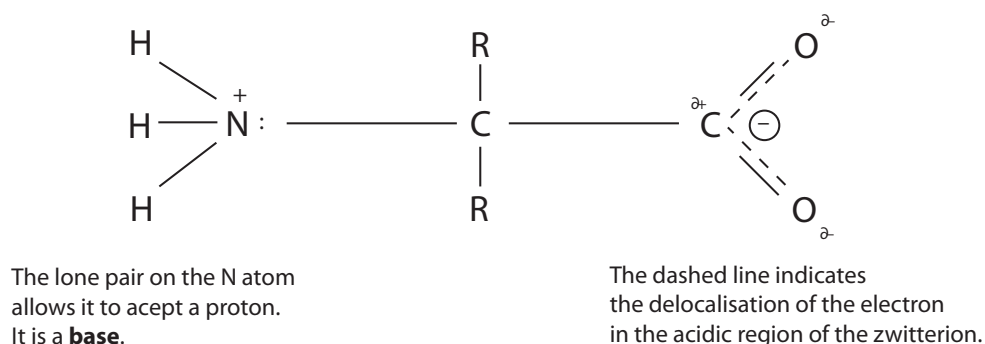
The diagram shows how three long chains of carbon atoms are attached to a glycerol molecule to make one molecule of vegetable oil.



The structure of a vegetable oil molecule

Source: BBC Bitesize

As you can imagine, depending on the size of your “R”s, you could be dealing with a very large molecule (as would be the case in Biology, and less so in Chemistry) but once you have grasped the principles involved, the application of those principles will solve any problem no matter how complicated the problem may be.



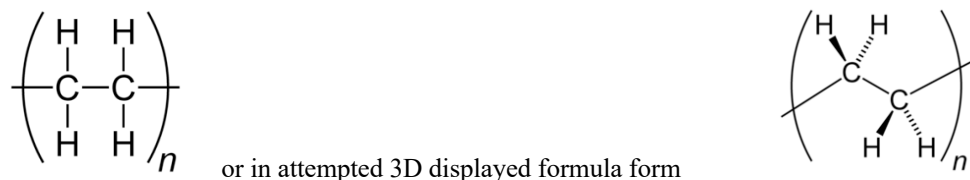
- There is a lot more to zwitterions than I have covered here, and when we get to Electrochemistry (and Methods of Analysis) I will talk about the ability to exploit the fact that there are charges inside these molecules (and therefore charges inside species such as proteins/genes/chromosomes/DNA/etc).
- Please note that, so far, I have simplified the situation. Not only have I not discussed the composition of “R”, but I have confined my discussion of the base part of the molecule to the “–NH₂” species. However, there is absolutely no reason why one should do so. **Any molecule that has both an Acid component and a base component inside it can behave as a zwitterion.** In fact, were it not for the fact that ‘A’ Level Chemistry acknowledges the fact that a large number of students also do Biology, then discussions about zwitterions would actually start with the **normal** Acid base examination and talk about species that have “–COOH” and “–OH” components rather than “–COOH” and “–NH₂” components.
- As it happens, this Chapter is about Polymers as well as zwitterions (and I have started with zwitterions merely to facilitate an understanding of Polymers), so let us now start discussing Polymers.
- In order to understand about Polymers, we need to talk about (A) Addition Polymers, and then (B) Condensation Polymers. Therefore now let us talk about these two forms of Polymers.

A) Addition Polymers

- Carbon Polymers are long-chained molecules that are created by linking up a huge number of basic “*repeating units*” (“RU”) into long chains.



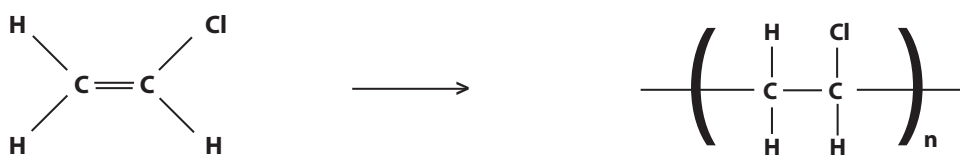
- For instance, probably the most used plastic in the world is “polythene” (or to give it its correct chemical name, “polyethene” or “polyethylene”) which Wikipedia shows as



- The two examples that are often quoted in the Syllabus are where the Repeating Unit is
 - CH_2CHCl , and
 - CF_2CF_2 .
- The progenitor⁹ of a basic *repeating unit* is an alkene – and it is called a “*monomer*”. If the double bond in a monomer is broken, then the monomer will form a repeat unit and it will now need to form one new bond on EACH of its two Carbon atoms, and what happens is that **the new bonds that form become links to other repeat units** – and this gives a long chain of repeat units!
- This sounds more complicated than it is in reality, and we can see what happens in the formation of a Polymer by examining each of the two cases above i.e. CH_2CHCl , and CF_2CF_2 .

ai) This monomer is the alkene
Chloroethene, $\text{CH}_2=\text{CHCl}$ ¹⁰

(aii) The resulting Polymer
(is called polyvinylchloride, or PVC)



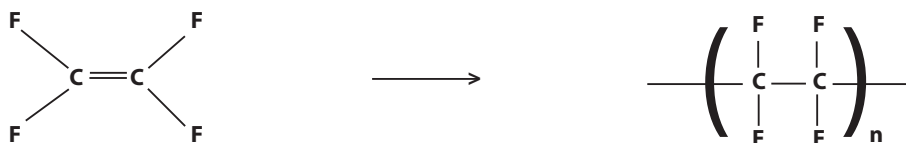
- On a number of occasions, I have asked you to go to the Web and look things up (e.g. petrol / fractional distillation / etc), and I have done this for a number of reasons. For a start, I want you to learn how to use the Web to find things – but much more importantly, the way that I have been drawing the bond line diagrams in this book is NOT the way that Carbon molecules are drawn at a more advanced level (e.g. at University). However, the skeletal diagrams that are used at University can be much more difficult to comprehend (and to use) when you are first learning ‘A’ Level Chemistry, and that is why I have not used such diagrams. I want you to get a good grasp of the Chemistry involved in what you are learning (rather than in spending time trying to interpret diagrams) – and then later on you can learn the more advanced stuff. However, as I tell you about some of the following monomers and Polymers, I am going to show you how they are drawn in Wikipedia (and that is the conventional way of drawing them at University).

⁹ “Progenitor” = that which goes before or is prior in the line of descent.

¹⁰ The “=” here is a double bond. It is **NOT** an equals sign!

bi) This monomer is the alkene
Tetrafluoroethene, $\text{F}_2\text{C}=\text{CF}_2$

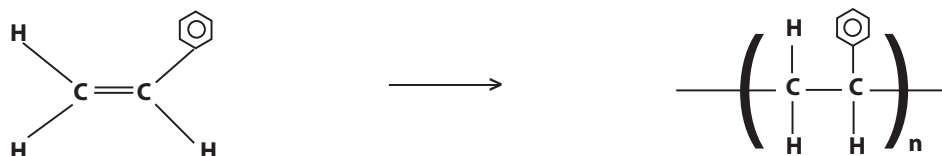
(bii) The resulting Polymer is Polytetrafluoroethene
(and it is also called PTFE, or Teflon)



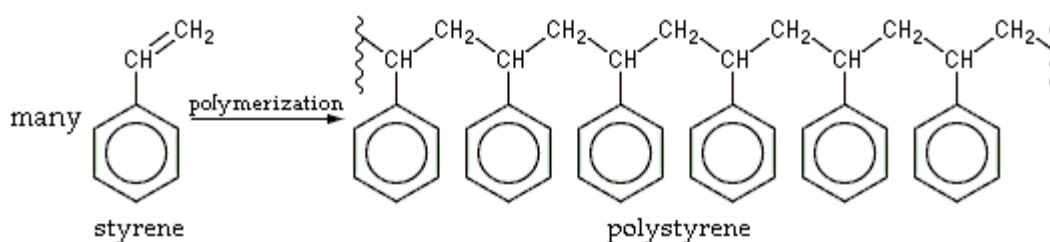
- There is however nothing particularly special about the two monomers on pages 17/18, and there are many other well-known Polymers. The following are monomers and Polymers of some substances that you encounter all the time in your everyday life, and you can of course type the names of any of these substances into your search engine and read about them for yourself – *but please do not waste too much time on the Web*. The greatest asset that **you** have is **your personality**, but after that your greatest asset is **TIME**. Use it wisely. When you come to the end of your life, you cannot go back and alter anything – and, as the saying goes, “Life is not a dress rehearsal, it is your one and only performance”!

ci) This monomer is the alkene styrene
(or phenylethene), $\text{CH}(\text{C}_6\text{H}_5)=\text{CH}_2$

(cii) The resulting Polymer is polyphenylethene
(and it is also called Polystyrene)

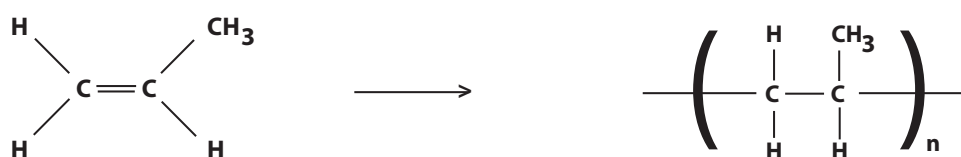


Do you remember that when we talked about the different sorts of formulae that there are (i.e. structural/skeletal/etc) we talked about the difficulty of depicting a three-dimensional object on a two-dimensional piece of paper. Well, here is a real life example of that. Can you see that the two diagrams (mine above and Wikipedia's below) are depictions of exactly the same molecules! (*The diagrams that I have drawn are easier to follow than the more advanced skeletal diagrams – but I will leave you to use whichever set of diagrams you prefer.*) The species on the left below is the monomer, styrene.

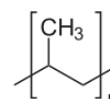


di) This monomer is the alkene
Propene, $\text{CH}(\text{CH}_3)=\text{CH}_2$

(dii) The resulting Polymer Polypropylene
(and it is also called Polypropene)

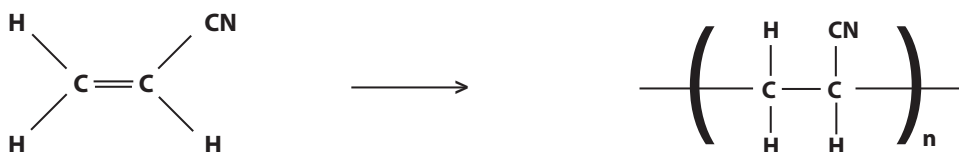


This molecule can also be depicted thus



ei) This monomer is the alkene $\text{CH}(\text{CN})=\text{CH}_2$
Propenenitrile

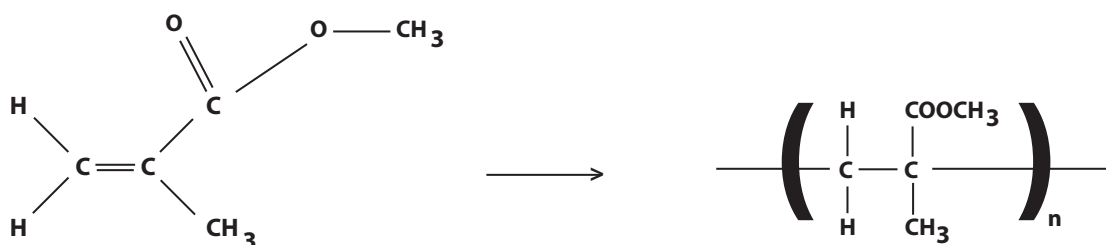
(eii) The resulting Polymer is poly(propenenitrile)
(and its Monsanto trade name is 'Acrilan')



fi) This monomer is the alkene
 $\text{CH}_2=\text{C}(\text{CH}_3)(\text{COOCH}_3)$
i.e. Methyl methacrylate

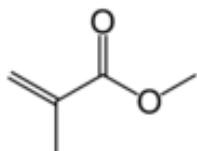
(fii) The resulting Polymer is called
Poly(methyl-2-methyl-propenoate)
or Polymethyl methacrylate
(but it is better known as 'Perspex')

or it could be drawn

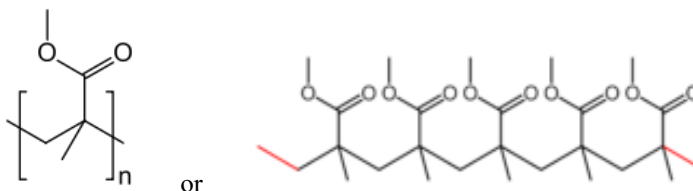


and below are the same molecules depicted as skeletal diagrams.

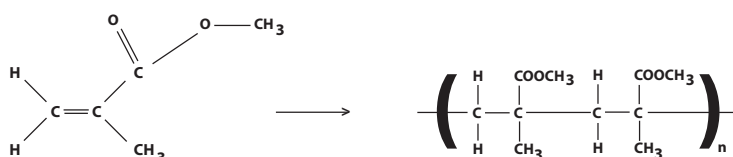
The Perspex monomer



The Perspex Polymer



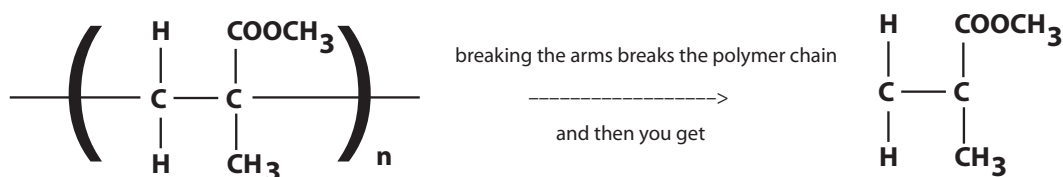
- I have drawn my Polymers with *one* Repeat Unit, with an "n" outside the bracket to indicate that it is possible to draw as many Repeat Units as are required or desired! However, in the exam you may be asked to draw TWO Repeat Units in your Polymer, and **if you are asked to do so, then you MUST draw TWO repeat units in your answer!** (Please do not draw just one repeat unit, otherwise you will *needlessly* lose one precious mark!)
- The diagram below shows the monomer and the Polymer for Perspex – but this time with **TWO** repeat units for the Polymer.



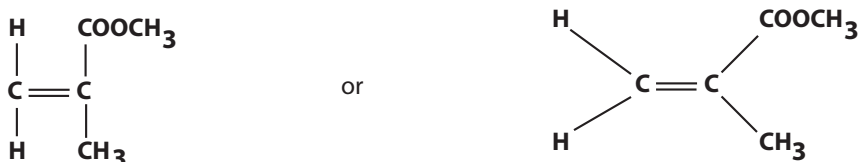
- $$\begin{array}{c} \text{O} \\ || \\ -\text{C}-\text{O}- \end{array}$$
- As you can see, the $-\text{C}-\text{O}-$ bit is very much like the ester that I drew for you on page 16 of Chapter 1 in the First Year book.
 - Strictly speaking, it is **incorrect** to bracket the DOUBLE repeating unit with an “n” since this implies that the unit repeats only as a “Siamese twin” – but the examiners are not concerned with such refinements.
 - In fact, Polymers can be more complicated than this – but luckily the First Year ‘A’ Level Syllabus does not require you to know the slightly more complicated Condensation Polymers! However, **if you are also studying Biology, then please do read about Condensation Polymers in Chemistry textbooks (or in my Second Year book) because that will help you to understand DNA/Polypeptides/etc.**

F Deducing the Repeat Unit from the Polymer

- In the exam you could be asked to state the Alkene monomer from which a given Polymer was derived – and it is not at all difficult to do so. The technique is
 - to isolate a repeating pattern in the Polymer (viz. the Repeat Unit)
 - remove the **two** arms that link the Repeat Unit to the adjoining Repeat Units, and
 - then place a double bond in between the two C atoms in the Repeat Unit.
- This technique can be demonstrated on the most difficult example above, and then you can see how easy it is to deduce the monomer from the Polymer.



- Now re-create the double bond and you get the monomer!

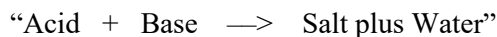


- It is so easy to do that it is almost like stealing sweets from a child (**and they even give you marks for doing this in the exam**)!
- Could you now try it for yourself with ALL the other Polymers that I have drawn for you.

NB Just in case you are asked a question that contains a reference to LDPE (low density poly ethylene) and HDPE (high density poly ethylene), LDPE is a Polymer made by **free radical polymerisation** of the appropriate repeat unit into C_2H_4 at **HIGH temperature and pressure** whereas HDPE is created by **catalytic conversion** at **LOW temperature and pressure**. LDPE was the only ‘polythene’ available until the 1950s when Karl Ziegler working with Giulio Natta came up with a way of producing polythene at low temperatures (100°C) and atmospheric pressure using titanium/organoaluminium/and triethylaluminium as the catalyst. (Why on earth the examiners think that questions involving LDPE and HDPE are suitable for ‘A’ Level is way beyond my comprehension. Ziegler **admitted that he** did not understand how the catalyst performed its function, and Natta was never quite sure. Sometimes I suspect that examiners get a bit too carried away with enthusiasm. *I believe that the modern injunction to them would be, “Get a life”!*)

B) Condensation Polymers

- The English verb to condense has at least two meanings: it can mean “the act of making smaller” (i.e. to condense something), and it can also refer to the Condensation of Water vapour in the air into liquid Water. I am not sure where the phrase “Condensation” comes from with regard to Polymers because small molecules join together to make **larger** molecules. The name should thus be expansion or magnification Polymers rather than Condensation Polymers, but it may be that the name derives from the fact that the most common Acid base reaction is the one that produces Water. At GCSE Level you learnt it back-to-front and memorised the reaction as



but as you now know, the salts are just spectator ions and of not much importance. The real reaction is



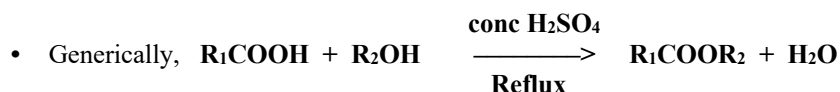
- The spectator ions merely carry the important reactants to the reaction, and thus you get



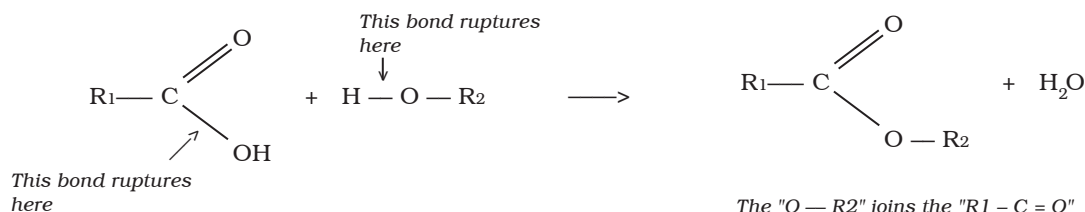
- OK, I shall now spend the rest of this Chapter talking about Condensation Polymers, but I do not want you to think that Condensation Polymers spit out only Water as their by-product. **That would be totally incorrect.** Any small molecule (such as H₂O/HCl/HBr/whatever) could be ejected in the reaction. **Do not let the name mislead you.**

Reacting an Alcohol with a Carboxylic Acid to form an Ester (and very often, but not always, Water)

- For the Esterification of an Alcohol, the Syllabus requires you to know that
 - “an **Alcohol** and a **Carboxylic Acid** must be **REFLUXED** in the presence of concentrated H₂SO₄ until Esterification takes place”, and then
 - you must draw the diagram (for example) of Ethanol and Butanoic Acid (cf. overleaf).



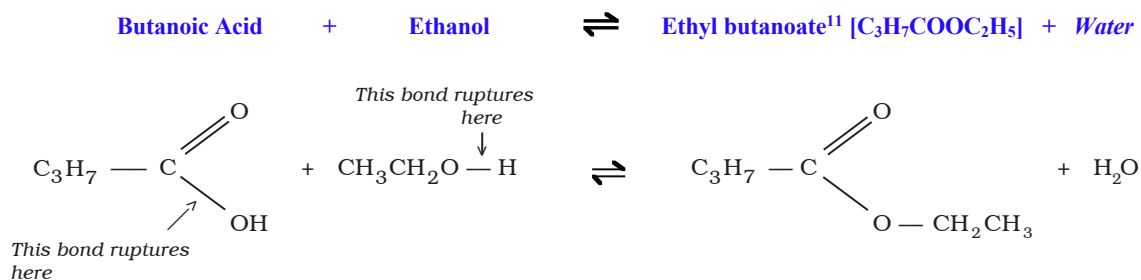
- The “OH” from the **ACID** and the “H” from the **ALCOHOL** join together to form a molecule of Water.
- Please note that R₂COOR₁ is not formed! R₂COOR₁ and R₁COOR₂ are DIFFERENT Esters, and R₂COOR₁ IS NOT FORMED,** therefore please note carefully in the diagram the exact place at which each one of the two bonds breaks.



A double bond is stronger than a single bond, therefore the single bond in the Acid is the one that ruptures.

NB In Organic Chemistry, it is not important to show the non-organic products of a reaction therefore it is NOT *necessary* to show the Water (or the HCl/HBr/or whatever) that is formed in this reaction. I however like to show it because I can then check that my equations are stoichiometrically correct (i.e. the moles in the equation are in the right proportions).

- When the reaction is completed, the resulting solution can be distilled and the Ester thus separated from the unreacted reactants/catalyst.



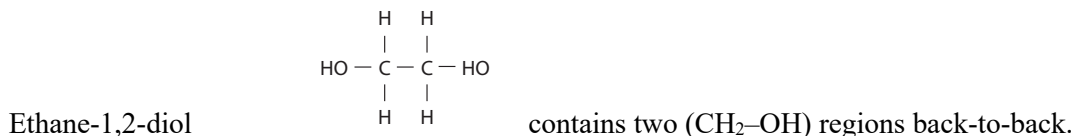
- Please note that just as a Carboxylic Acid will react with an Alcohol in the presence of a strong Acid to form an Ester, so also an Ester can be hydrolysed in the presence of a strong Acid into a Carboxylic Acid and an Alcohol. **The reaction is thus a reversible one.** It is better therefore to hydrolyse an Ester into a Carboxylic Acid in the presence of a strong base (rather than a strong Acid) **because this is not a reversible reaction.** The resulting ion can be reacted with an Acid to form the Ester.
- The reaction would take place enormously slowly because the reversible reaction of Water breaking down into its ionic components reaches dynamic equilibrium very quickly (therefore there are hardly any H⁺ and OH⁻ ions present in Water), but the reaction can be speeded up by increasing the number of OH⁻ ions in the reaction by the addition of NaOH or KOH to the reaction mixture (i.e. alkaline hydrolysis) or by increasing the number of H⁺ ions by adding an Acid to the reaction mixture (i.e. Acid hydrolysis).

A-B-A-B Structured Polymers

- Let us also distinguish between (i) **one** molecule making the Condensation Polymer with other members of exactly the same species viz. an A-A-A-A Condensation Polymer, and (ii) two differing molecules getting together to make the Polymer, to give an A-B-A-B structure (and this is why last year the examiners asked you to draw **two** monomer repeat units from which to create your Polymer).
- If a molecule contains both an acidic and a base region, then it can create a Polymer without the help of any other molecule, but if it does not contain both, then it will need the help of another (complementary) molecule that contains two of the opposite regions that it itself possesses. Let us take a very simple Acid and see how this works.
- Ethanedioic Acid (“ethane” because there are two C atoms in the molecules, and “dioic” because there are two “-COOH” regions), contains two acidic regions joined back-to-back viz.

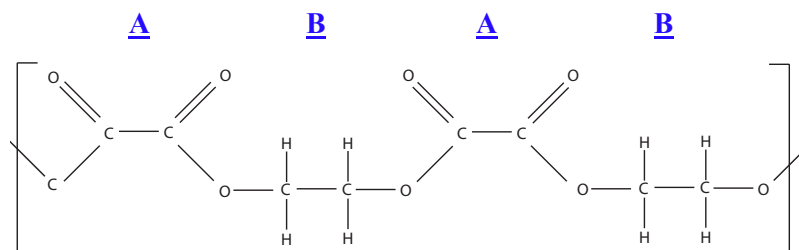


whilst



¹¹ Remember to ask yourself what the “-oate” molecule is (here it is a butanoate), and then ask what sort of butanoate it is (here it is an ethyl butanoate).

- In a Polyester reaction between (Ethanedioic Acid + Ethane-1,2-diol), the **“OH” from the Acid and the “H” from the Alcohol join together** and are ejected as a Condensation reaction. The remaining bits of the molecule then join together to create an ester. If multiple units of Ethanedioic Acid and Ethane-1,2-diol join together in a Condensation reaction, then a Polyester is formed.
- Not surprisingly, this structure for Condensation Polymers is given the label “A-B-A-B” structure (and in a few moments I will describe “A-A-A-A” structures).

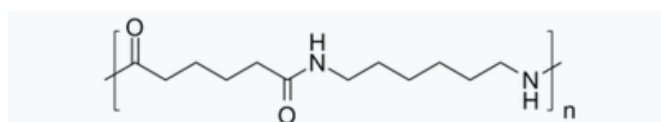
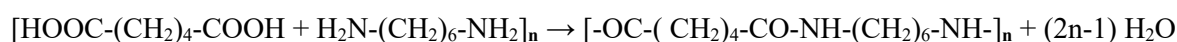
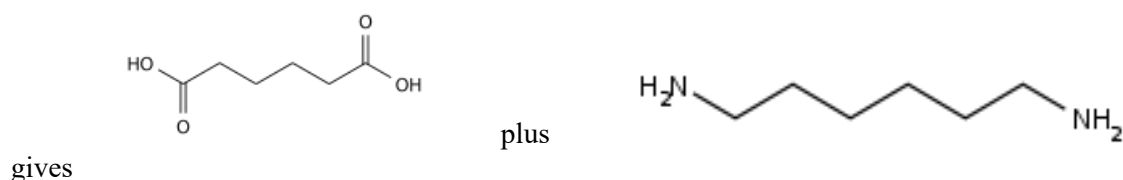


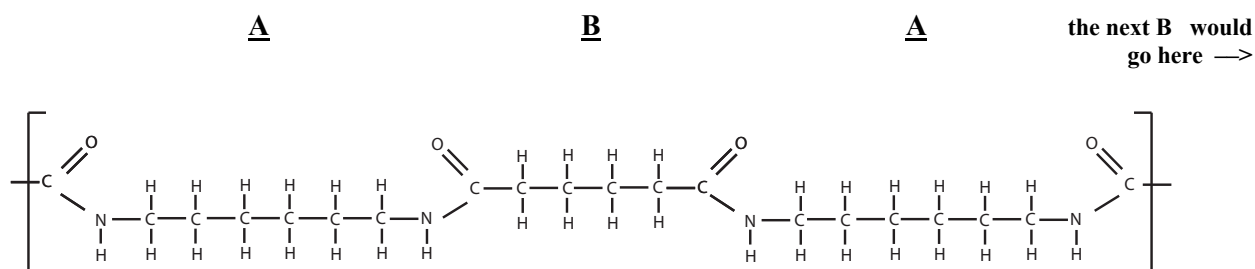
NB Normally the function of an Acid is to dissociate a Proton, but please remember that in Esterification, the Acid loses its **“OH”** bit while the Alcohol loses its **“H”** bit.

- In an exam, this might be shown as



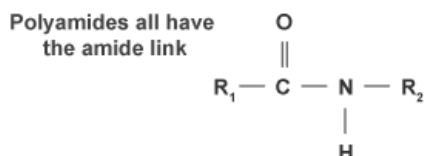
- However, before I talk about “A-A-A-A” structures let me show you another example of molecules that need a complimentary molecule in order to form a Condensation Polymer – and I shall show you the one that the ‘A’ Level examiners often ask about in examinations i.e. “Nylon” (and please remember that Nylon does not have an “-OH” type base but an “-NH₂” type base).
- There are different sorts of “Nylon” but the two most famous ones were developed by William Carothers of DuPont (Nylon-6,6) and by Paul Schlack of IG Farben (Nylon-6). I shall not talk about Nylon-6 here.
- Nylon-6,6 is made from two monomers viz. Hexanedioic Acid COOH-(CH₂)₄-COOH or [CH₂]₄(COOH)₂ and hexamethylenediamine viz. NH₂-(CH₂)₆-NH₂ and it is called Nylon-6,6 because there are 6 C central atoms in each molecule).



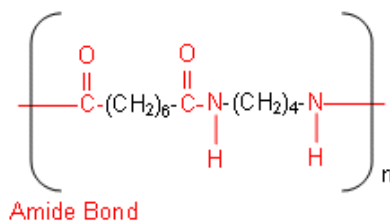


Please note that each N atom must have three bonds, and each C atom must have four bonds. I have not drawn two repeat units because that would make the diagram too large to fit the page.

- In this esterification process, each time that two complementary molecules get together, one molecule of Water is ejected. There are therefore $(2n-1)$ molecules for 'n' molecules of Hexamethylenediamine and 'n' molecules of Hexanedioic Acid.
- The link between an Amine and an Acid is called the “amide link” and is commonly shown as

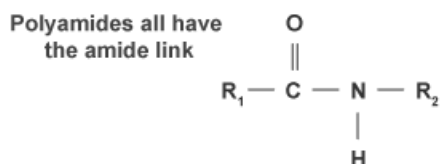


- There are many different sorts of “Nylon”. For example there is another sort of Nylon called Nylon-4,8 (made from 1,4-diaminobutane and Octanedioic Acid) and if you count the number of C atoms in the complementary molecules in the diagram below you will see why it is called that.

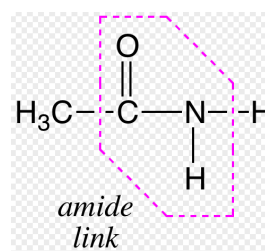


Source: <http://www.4college.co.uk/a/dp/Condensation.php>

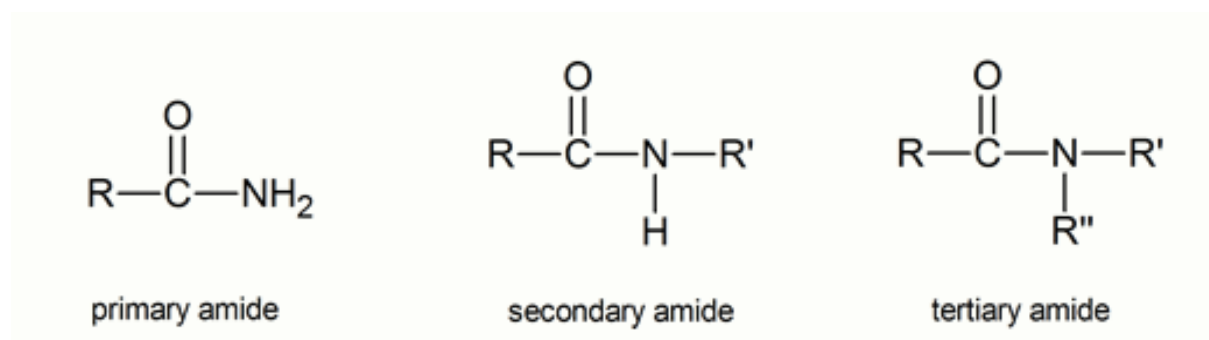
- Sometimes in an exam you may be faced with what looks like a complicated Polymer, but if you keep calm and examine the molecule closely, then you should be able to see how it was put together. The examiners very often use an Amide link



as in

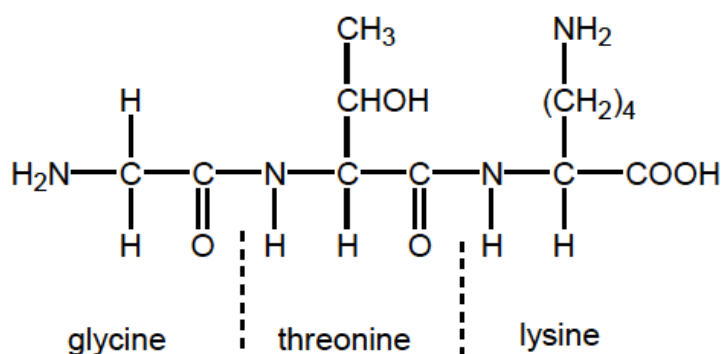


but the Amide link could be a 1° or a 2° or a 3° with regard to the N atom viz.



Source: Chemistry LibreTexts

- A 1° Amine has one C atom attached to it.
A 2° Amine has two C atoms attached to it.
A 3° Amine has three C atoms attached to it.
- The main thing is to use your brain and make sure that you keep calm in an exam (in any exam).
- On the subject of Polymers, I think it is rather unfair (because not every student who does 'A' Level Chemistry does Biology) but the examiners can and do use Polymers from Biology in the examinations e.g.



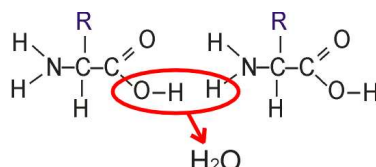
and it can be any sort of dioic Acid e.g. they could put a C_6H_4 part of a Benzene ring between the two “-COOH” bits.

- My advice therefore is to just keep cool and apply the principles that we have covered in this Chapter. If you look at the junctions of the ‘Acid end’ of one molecule with the ‘base end’ of its adjoining molecule (e.g. glycine with threonine) you will see that these are just bog-standard Polypeptides [$\text{>C=O}(\text{NH})$] linkages.

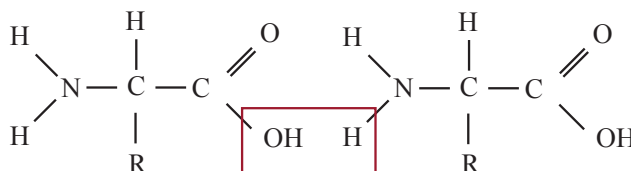
A-A-A-A Structured Polymers

Aminoacids

- Earlier, I said that there are “A-B-A-B” structured Polymers and that there are “A-A-A-A” structured Polymers. Well, let us now talk about the latter.
- An Aminoacid is a Carboxylic Acid that has both a “-COOH” **Acid** region and an “-NH₂” **base** region in itself, and such Acids are often written as “H₂N-R-COOH” to indicate that the composition of the interior of the Acid is not known and can consist of any legitimate species.
- Because an Aminoacid has both an Acid and a base region it is “self-complementary” in terms of polymerisation. An Aminoacid can make a Polymer with members of its own species and thus form an “A-A-A-A” structured Polymers, but it does not need to do so. It can form a Polymer with another Aminoacid. *Revisionworld.com* points out that two Amino Acids can be linked by a Condensation reaction and that this creates a **Peptide** bond between the Carbon atom in the Acid group and the Nitrogen atom in the Amine group, and that the resulting molecule is called a dipeptide.



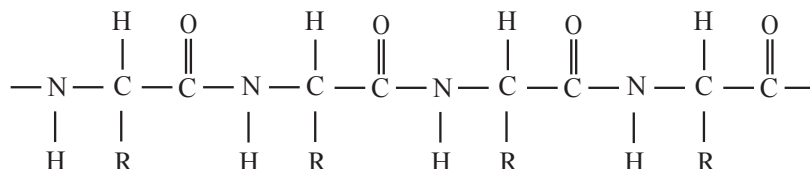
and *revisionworld* says that a chain of Amino Acids can be built up in this way and it would be called a **Polypeptide**. A **Protein** may contain just one sort of Polypeptide or it may have two or more chains that interact.



The “H” and the “OH” are ejected/eliminated as a molecule of Water in a condensation reaction.

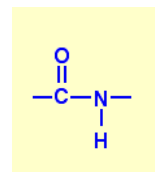
A series of amino acids link up in this fashion to form a protein.

Each protein could be built up out of any of 22 amino acids.



- Two Amino Acids thus linked form a “dipeptide”. More than two makes a “Polypeptides”. As is customary, “R” is any appropriate species.
- Carboxylic Acids and Amines link to form peptide bonds known in Chemistry as Amide groups. **Proteins are Condensation Polymers made from one or more Amino Acid monomers.**

The ejection of the H₂O molecule allows the Peptide bond to form viz.



Source: chemguide

The O atom can be written below the C atom and the H atom above the N atom.

- **Carbohydrates** are also Condensation Polymers made from sugar monomers such as glucose (i.e. cellulose or glycogen) and galactose. Jim Clark has a webpage entitled “Aminoacids and Other Biology menu” at <http://www.chemguide.co.uk/organicprops/aminoacidmenu.html> , and if you are doing ‘A’ Level Biology, then I would strongly advise you to visit that webpage.
- The only thing that I will add here is to remind you that in Organic Chemistry the term “ α ” is used to refer to the first C atom that is attached to a functional group, and that the location of “R” may therefore be identified by such a usage when it is appropriate to do so.
- An Amino Acid has an Acid ‘ $-\text{COOH}$ ’ end and a base ‘ $\text{H}_2\text{N}-$ ’ end, and Proteins consist of long strands of joined up Amino Acids where the Acid end of one molecule of an Amino Acid has joined up with the base end of a molecule of an Amino Acid and thus formed a long Polypeptide/Protein Polymer.¹² The permutations/combinations that there can be from 20 different Amino Acids¹³ gives a very large number of possible Proteins to exist in the animal kingdom, and in Chemistry Electrophoresis provides a quick and easy method of distinguishing one Protein from another.

Hydrolysis of Esters

- Water (H_2O) breaks down in a reversible reaction into H^+ and OH^- ions,



and “hydrolysis” occurs when a molecule of something is broken into different components by Water. For example, an Ester is *formed* by reacting a Carboxylic Acid and an Alcohol together in the presence of conc. Sulphuric Acid, and an Ester can be hydrolysed back into a Carboxylic Acid and an Alcohol by the action of Water.



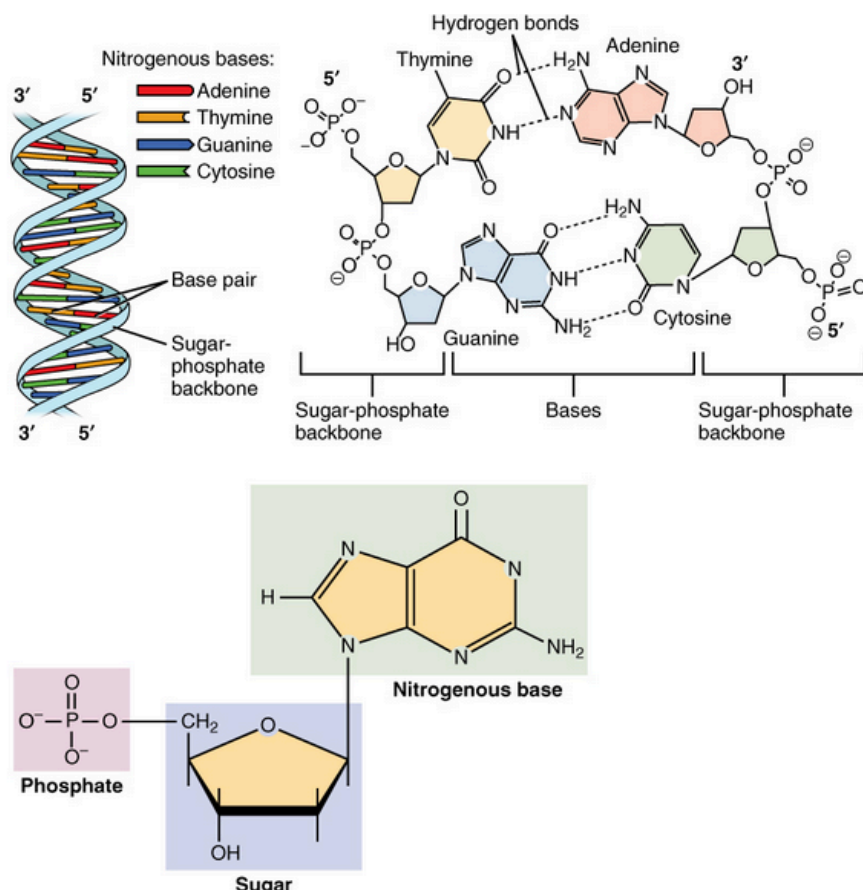
- The reaction would take place enormously slowly because the reversible reaction of Water breaking down into its ionic components reaches dynamic equilibrium very quickly (therefore there are hardly any H^+ and OH^- ions present in Water), but the reaction can be speeded up by increasing the number of OH^- ions in the reaction by the addition of NaOH or KOH to the reaction mixture (i.e. alkaline hydrolysis) or by increasing the number of H^+ ions by adding an Acid to the reaction mixture (i.e. Acid hydrolysis).
- Some Condensation Polymers (such as Polyesters) eject molecules of Water as the complementary monomers bind together, and some textbooks say that Polyesters can be turned back into their monomers by “hydrolysis” (i.e. replacing molecules of Water where they were ejected), but Jim Clark of Chemguide makes a powerful point. He says “*Simple esters* are easily hydrolysed by reaction with dilute Acids or alkalis. *Polyesters* are attacked readily by alkalis, but much more slowly by dilute Acids. [Hydrolysis by Water alone is so slow as to be completely unimportant.](#) (You wouldn't expect your Polyester fleece to fall to pieces if you went out in the rain!).”

¹² The bond is called a ‘peptide’ bond (or an ‘amide bond’). Arbitrarily, a ‘Polypeptides’ consists of fewer than 50 consecutive linked Acid molecules (more than 50, and it mysteriously becomes a ‘Protein’).

¹³ There were 20 recognised amino Acids that make up Proteins. A 21st was discovered in the 1980s and then in this century a 22nd was discovered. However, there is an argument about stop coda regarding Selenocysteine (Sec) and Pyrrolysine (Pyl), and I am not qualified to make any worthwhile comment on this subject.

¹⁴ You will remember that the name of an Ester is determined by the “R.C=O” part of the Ester and the adjectival part of the name is determined by the “(OR)” part. Therefore $\text{C}_4\text{H}_9\text{C=O(O.C}_2\text{H}_5\text{)}$ is called “Ethyl-pentanoate” because the “R.C=O” part has 5 C atoms in it, and the “(OR)” part has two C atoms in it.

- I mentioned earlier that the examiners can and do (unfairly in my opinion) use stuff from Biology to test your knowledge of Chemistry. You may therefore like to know the following
 - Every human body consists of some 50,000,000,000,000 (or 5×10^{13}) **cells**
 - In every cell there is a **nucleus**
 - In cells can also be found **mitochondria**
 - In both nuclei and in mitochondria there can be found **DNA and RNA**
 - DNA (DeoxyriboNucleic Acid) consists of the famous **double helix**
 - Each strand of a double helix consists of a “backbone” of **nucleotides** (the ‘backbones’ are the outside edges of the helices and are coloured in light blue below)
 - A nucleotide is composed of three distinctive chemical sub-units each of which is identified in the diagram below: a five-carbon **sugar molecule** (on the purple background below), a nitrogenous base on the green background below (“base” as in lone pair donor) *and the two together are called a nucleoside*, and a **phosphate group** (on the dirty-pink background below). *Please look carefully at the diagram until you have recognised each of the three.* The Phosphate groups are very easy to recognise and are on the two outside edges of the diagram below.



Source: Wikimedia

The US National Library of Medicine says the following.

What is DNA?

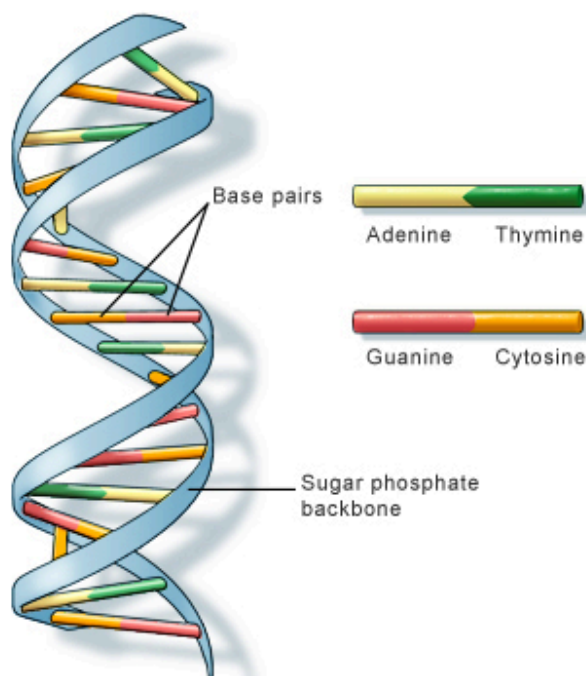
DNA, or deoxyribonucleic acid, is the hereditary material in humans and almost all other organisms. Nearly every cell in a person's body has the same DNA. Most DNA is located in the cell nucleus (where it is called nuclear DNA), but a small amount of DNA can also be found in the mitochondria (where it is called [mitochondrial DNA](#) or mtDNA). [Mitochondria](#) are structures within cells that convert the energy from food into a form that cells can use.

The information in DNA is stored as a code made up of four chemical bases: adenine (A), guanine (G), cytosine (C), and thymine (T). Human DNA consists of about 3 billion bases, and more than 99 percent of those bases are the same in all people. The order, or sequence, of these bases determines the information available for building and maintaining an organism, similar to the way in which letters of the alphabet appear in a certain order to form words and sentences.

DNA bases pair up with each other, A with T and C with G, to form units called base pairs. Each base is also attached to a sugar molecule and a phosphate molecule. Together, a base, sugar, and phosphate are called a nucleotide. Nucleotides are arranged in two long strands that form a spiral called a double helix. The structure of the double helix is somewhat like a ladder, with the base pairs forming the ladder's rungs and the sugar and phosphate molecules forming the vertical sidepieces of the ladder.

An important property of DNA is that it can replicate, or make copies of itself. Each strand of DNA in the double helix can serve as a pattern for duplicating the sequence of bases. This is critical when cells divide because each new cell needs to have an exact copy of the DNA present in the old cell.

DNA is a double helix formed by base pairs attached to a sugar-phosphate backbone.

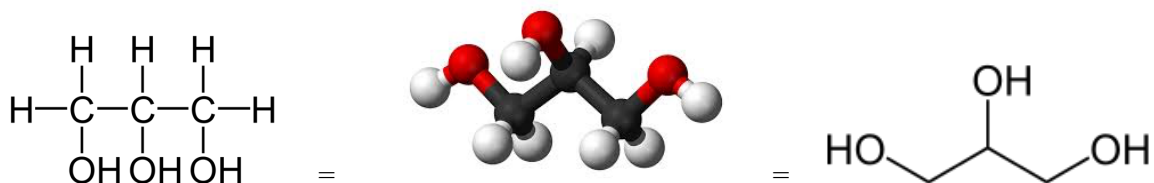


U.S. National Library of Medicine

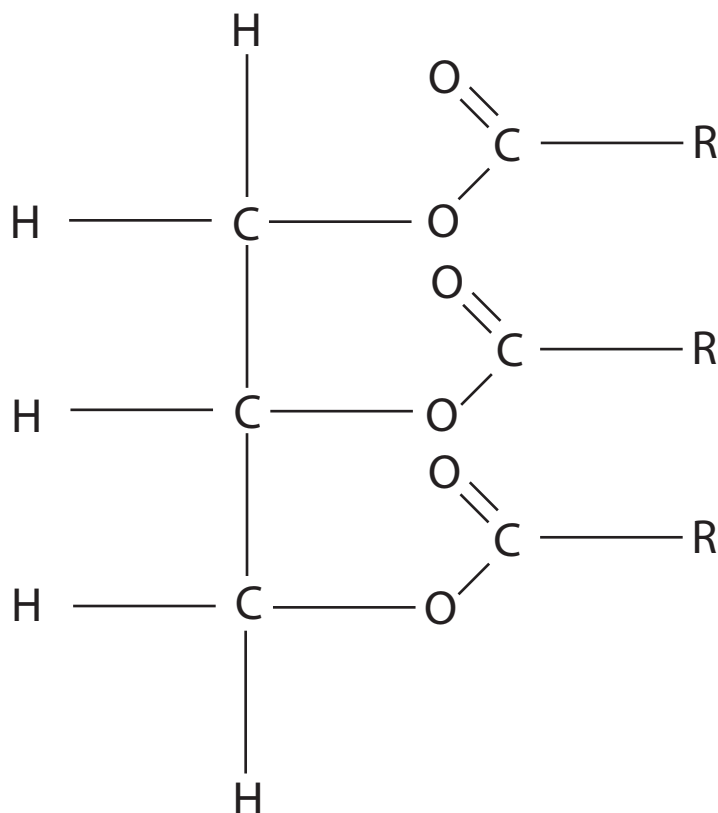
Credit: U.S. National Library of Medicine

APPENDIX: FATTY ACIDS

- Fats/oils (and they are also known as triglycerides) are the Esters of three fatty Acid chains and Glycerol. Glycerol or Glycerin is Propane-1,2,3-triol, and it has 3 C atoms joined together in the following manner



and you are aware that an Ester is formed by reacting a Carboxylic Acid with an Alcohol, therefore if three Carboxylic Acids form an Ester through the three “-OH” alcohol regions of Glycerol, then a fat/oil will be formed as follows.



- As is usual, the size and characteristics of the three “R” components will determine the size of each molecule of the fat/oil, and the molecular mass of the molecules will be one of the factors that determines whether or not it is an oil. I am afraid that that is all the help that I can give you on the Biology front.