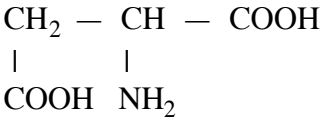
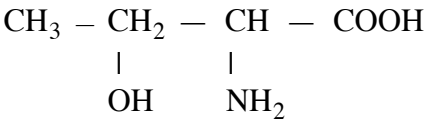
The World of Carbon

Section 8

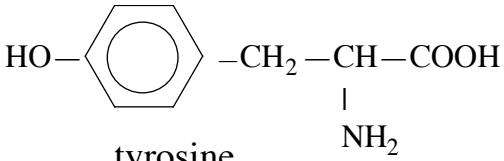
Natural & Synthetic Polymers



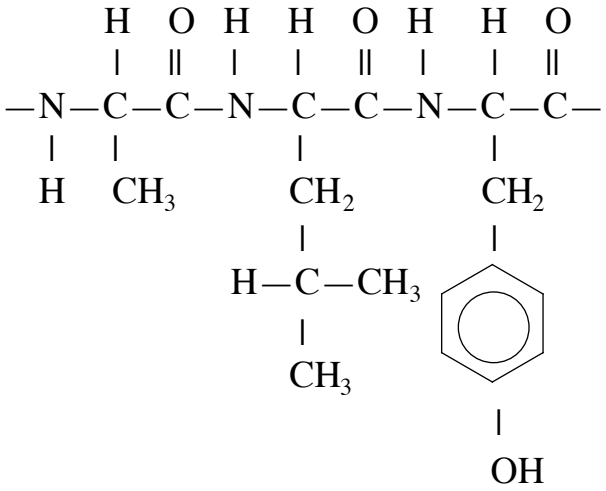
aspartic acid

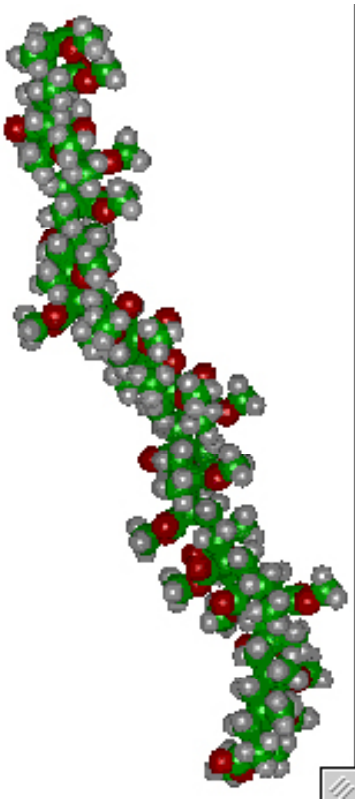


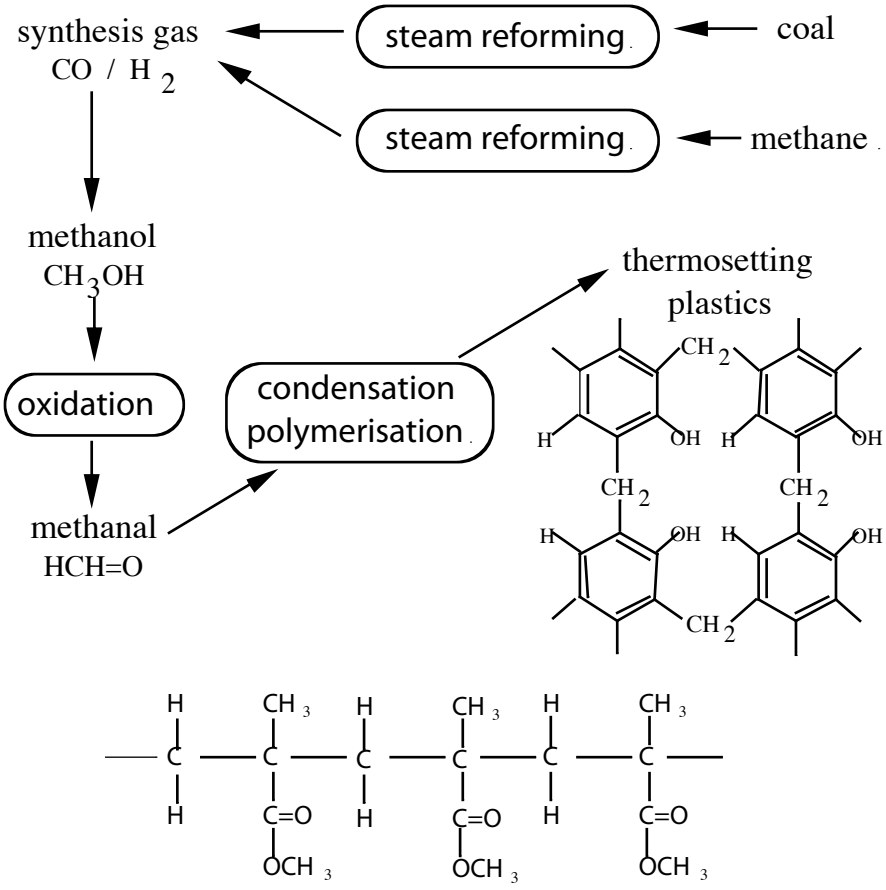
threonine



tyrosine







Unit 2: *The World of Carbon* | Section3: *Natural & Synthetic Polymers*

Topic	*Sub-Topic*	*LO*	*Primary Source*	*Class Problems*	*Homework*	*Activities/Practicals*
				HC = HIGHER CHEMISTRY	***CC*** = CHEMCORD	
Amines & Amides	✍ Amines	**1**	***Salters*** p261	***Salters*** p265 Q1-2		
	✍ Properties of amines	**Unit 1**	p261			
	✍ Reactions of amines	**Unit 1**	p261			
	🕮 What are amides?	**2**	p262			
Amino Acids	✍ Examples of proteins	**3**	***HC*** p114			
	✍ Structure of amino acids		***Salters*** p262		***CC*** 2.18 Q1	
	✍ Essential amino acids	**4**	p264			
	✍ Digestion	**5**	p264			
	✍ Chromatography		***HC*** p115			
Proteins	✍ Forming peptides	**6,7**	***Salters*** p264			
	✍ Forming proteins	**8,9**	***HC*** p116/7	***Salters*** p265 Q3-5	***HC*** p117 Q2	
	✍ Breakdown of proteins	**5,10**	p116	***CC*** 2.18 Q2,3		
Structure of Proteins	✍ α-helix & β-sheet	**12**	p118			
	✍ Fibrous proteins	**13**	p118			
	✍ Globular proteins	**14,15**	p118			
	🕮 Structure of insulin	**14**	***Salters*** p73-76			
Enzymes	✍ Shape	**16**	***HC*** p119			
	✍ Denaturing enzymes	**17-19**	p120	***CC*** 2.18 Q4-6		***PPA*** *Enzyme Activity*
	🕮 The importance of shape	**16**	***Salters*** p77			
Addition Polymerisation	✍ Ethene & propene	**20**	***Salters*** p267			
	✍ LPDE, HDPE & LLDPE		***HC*** p98/99			
	✍ Steam cracking	**21,22**	p99	***CC*** p78/9 Q1-5	***CC*** p78/9 Q6-10	
Condensation Polymerisation	✍ Polyesters	**23,24**	***Salters*** p268			
	✍ Polyamides	**26-28**	p268			
	✍ Fibres & resins	**24**	p268	***CC*** p83 Q4,5,7	***CC*** p83 Q8,9	
Polymer Properties	✍ Elastomers, plastics & fibres	***various***	***Salters*** p268/9			
	✍ What decides properties?	***various***	p269			
	✍ Thermoplastics/thermosets	***various***	p269			

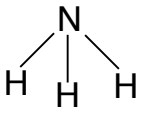
Topic	*Sub-Topic*	*LO*	*Primary Source*	*Class Problems*	*Homework*	*Activities/Practicals*
				HC = HIGHER CHEMISTRY	***CC*** = CHEMCORD	
Nylon	🕮 5.5 The invention of nylon	**29,30**	***Salters*** p63-65			
	✍ Making nylon	**27**	p64			
	✍ Properties & uses	**30**	p65			
	✍ Engineering plastic	**29**	p64	***CC*** p84 Q6		
Bakelite	🕮 Bakelite	**24**	***Salters*** p270			
	✍ Synthesis gas	**31-33**	***HC*** p103			
	✍ Making bakelite		**23**	p103		
	✍ Properties & uses		p103			
	✍ Urea-formaldehyde		p103	***CC*** p81/2 Q1,2,3		
Kevlar	🕮 5.7 Kevlar	**34,35**	***Salters*** p66-68	***Salters*** p66 assignment 3		
	✍ Making Kevlar	**27**	p66			
	✍ Properties & uses	**34,35**	p67		***CC*** p86 Q1	
Poly(ethanol)	🕮 Dissolving plastics	**36-39**	***Salters*** p69	***Salters*** p69 assignment 6		
	✍ Making poly(ethanol)	**37**	***HC*** p104			
	✍ Properties & uses	**36-39**	p104		***CC*** p87 Q4	
Poly(ethyne)	🕮 5.4 Conducting polymers	**40-42**	***Salters*** p61-63			
	✍ Making poly(ethyne)		***HC*** p105			
	✍ Properties & uses	**40-42**	p105	***CC*** p86 Q2		
Poly(vinylcarbazole)	🕮 5.1 Designer polymers	**43**	***Salters*** p57-58			
	✍ Making poly(vinylcarbazole)		***HC*** p105			
	✍ Properties & uses	**43**	p105	***CC*** p86 Q3		
Degradable plastics	🕮 Degradable plastics	**44-45**	***Salters*** p68-69			
	✍ Biopol	**44**	***HC*** p105			
	✍ Carbonyl groups	**45**	p106	***CC*** p87 Q5		

8.1 Amines, Amides & Amino Acids

This first topic introduces the amine functional groups and, in particular, its ability to form a link with other groups - the amide or peptide link.

Amines & Amides

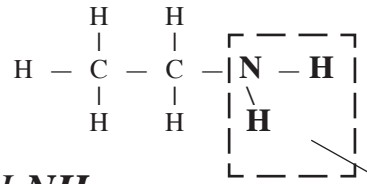
This activity deals with how to recognise and identify amines and introduces a few of their properties.



$N^{\delta-}—H^{\delta+}$

Amines are the ***organic*** relatives of ***ammonia***, NH_3, and like ***ammonia***, their properties are mainly due to the small, highly ***electronegative*** Nitrogen atom. (Unit 1, Section 2).

The simplest amines are called ***primary*** *amines* and will have a ***carbon*** chain (*alkyl group*, R—) in place of *one* of the ***hydrogen*** atoms, R—NH_2

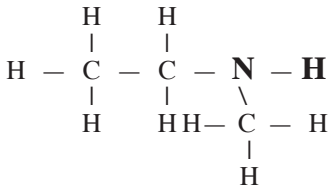


$C_2H_5NH_2$

This amine is usually called simply *ethylamine*, though its more formal name is *aminoethane*.

You do not need to learn the formal systematic naming of amines.

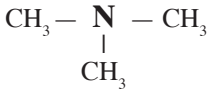
This is the ***amino functional group***



$C_2H_5NHCH_3$

Replacing *two* of the ***hydrogens*** with carbon chains produces what is called a ***secondary*** *amine*.

Simple naming is used whenever possible, so this molecule is called *ethylmethylamine*.



$CH_3\ N(CH_3)CH_3$

Replacing *all* of the ***hydrogens*** with three carbon chains produces what is called a ***tertiary*** *amine*.

Simple naming is used whenever possible, so this molecule is called *trimethylamine*.

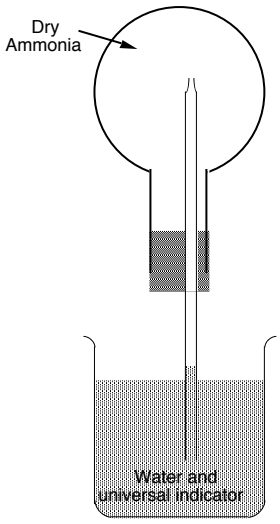
We will concentrate mainly on ***primary*** *amines* and molecules containing the ***amino*** *group*,—NH_2 , though you are expected to at least recognise other amines when you meet them.

Properties of Amines

This activity will remind you of some of the properties that ammonia has and which are shared by the amines

Ammonia is a *gas* with a very *pungent* smell. Similarly the smaller amines are *gases* or ***volatile*** *liquids* with very *unpleasant* smells similar to rotten fish or.....

F P



Last year you were shown that ***ammonia*** is an *extremely soluble* gas - *the* ***fountain*** *experiment*.

This is due to the fact that ***ammonia*** molecules are like ***water*** molecules and have *very strong* ***hydrogen*** *bonding* between them. *Small* ***primary*** *amines* will also have *strong* ***hydrogen*** *bonding* and will also be *very soluble*. ***Secondary*** *amines* are *less soluble* and ***tertiary*** *amines* even *less soluble*.

Ammonia was the *only* ***alkali*** gas met during Standard grade. *Amines* are *organic alkalis* and will ***dissolve*** in water to produce ***hydroxide*** ions, OH^-.

Many ions of ***Transition*** *metals* are ***coloured*** but only when *hydrated* - surrounded by ***water*** molecules. Cu^{2+} ions - or more acuurately $[Cu(H_2O)_4]^{2=}$ ions - are ***blue*** in colour. ***Ammonia*** and the smaller ***amines*** can replace these ***water*** molecules but this will change the ***colour*** of these ions:

$$[Cu(H_2O)_4]^{2+} \rightarrow [Cu(NH_3)_4]^{2+}$$
BLUE VIOLET

Therse colour changes are sometimes used as a *'Test'* for ammonia/amines

Reactions of Amines

This activity introduce you to the reactions of ammonia/ amines

① *Dissolve in water to produce Alkalis-* solutions containing the ***hydroxide*** ion.

$$\underset{\textit{ammonia}}{NH_3} + H^{\delta+}—O^{\delta-}—H \rightarrow \underset{\textit{ammonium ion}}{NH_4^+} + OH^-$$

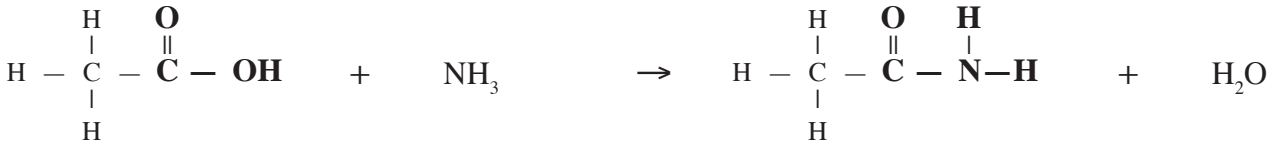
$$\underset{\textit{ethylamine}}{C_2H_5NH_2} + H^{\delta+}—O^{\delta-}—H \rightarrow \underset{\textit{ethylammonium ion}}{C_2H_5NH_3^+} + OH^-$$

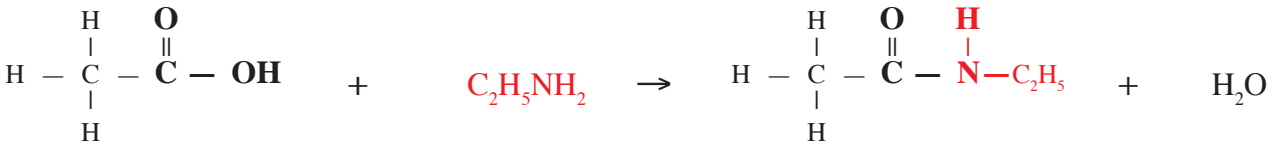
② *React with acids to produce Salts-*

$$\underset{\textit{ammonia}}{NH_3} + H^+\ Cl^- \rightarrow \underset{\textit{ammonium chloride}}{NH_4^+\ Cl^-}$$

$$\underset{\textit{ethylamine}}{C_2H_5NH_2} + H^+\ Cl^- \rightarrow \underset{\textit{ethylammonium chloride}}{C_2H_5NHCl^-}$$

③ *React with organic acids to produce Amides-*

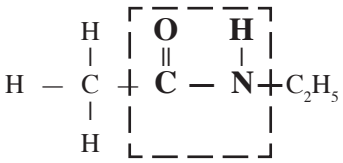




Amides are not an 'important' family and you are not required to learn how to name them.

The reactions above are very similar to *esterification* - ***acid*** groups can react with ***amine*** groups in a ***condensation*** reaction that allows the two molecules to *join together*.

This is an important reaction in nature, and you will need to learn to recognise the ***amide link*** (the ***peptide link***)



Proteins

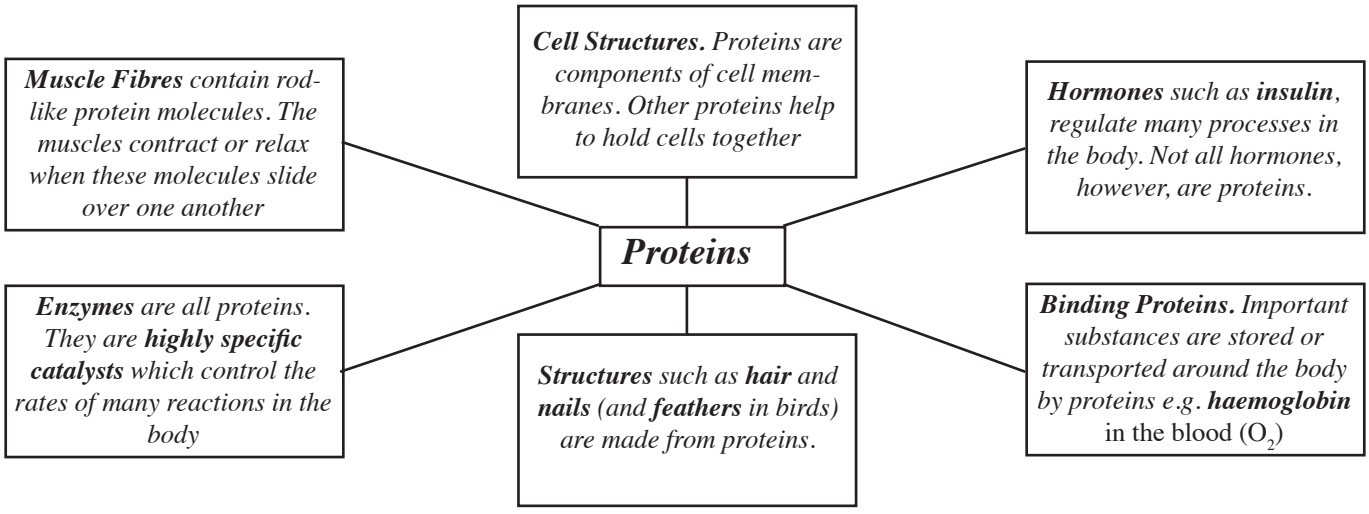
- *peas and* ***beans***
- ***meat***
- ***fish***
- ***cheese***
- ***eggs***
- *hide &* ***skin***
- *wool &* ***silk***

This activity will introduce you to some proteins and the roles played by proteins in living organisms

When ***protein*** is mentioned, most people will think of *foodstuffs* that contain ***protein*** and make up a very important part of our *diet*.

When we eat ***proteins*** they are ***digested*** (*broken down*) into simpler molecules called ***amino acids***.

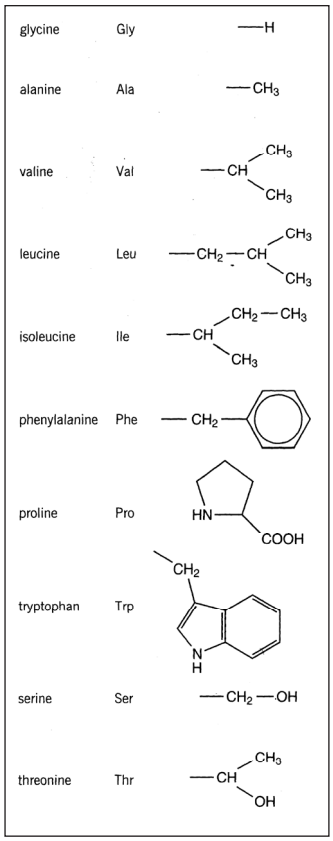
These ***amino acids*** are then reconstituted as ***proteins*** that fulfil a large number of important roles in living organisms.



Amino Acids

This activity will introduce you to the structure of amino acids and explains why some are labelled as essential amino acids

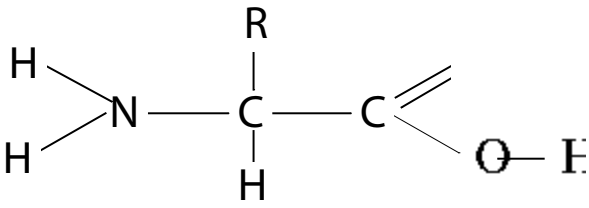
All the ***proteins*** in the world are made from *about* 20 ***amino acids***.

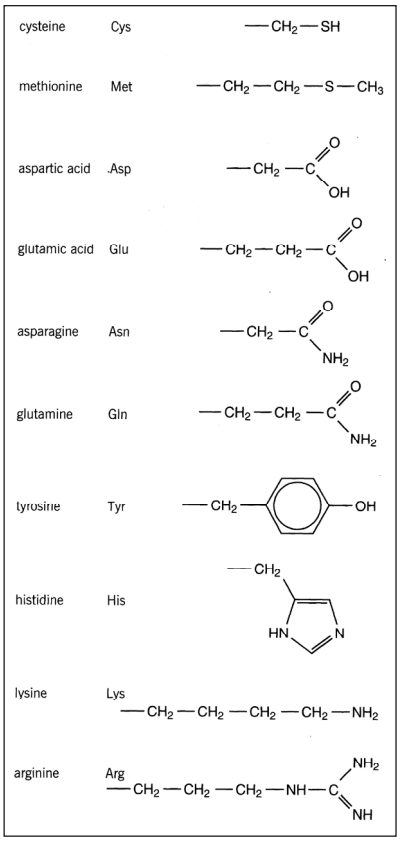


These 20 ***amino acids*** have a common structure. (one exception)

A central ***carbon*** atom has an acid group (***carboxyl***), an ***amino*** group and a ***hydrogen*** atom attached .

The final group attached to the carbon is *different* for each ***amino acid*** and is usually represented by —R.





When we ***digest proteins*** we break them down into ***amino acids*** which we then use to build new ***proteins***. Most ***amino acids*** (12) can be made from *carbohydrates* and other *amino acids* so it is not crucial that we eat ***foods*** containing these amino acids.

The remaining amino acids (8), however, *cannot be made* and therefore must be part of our food intake. These are classified as ***essential amino acids*** (though we need all 20 to remain healthy).

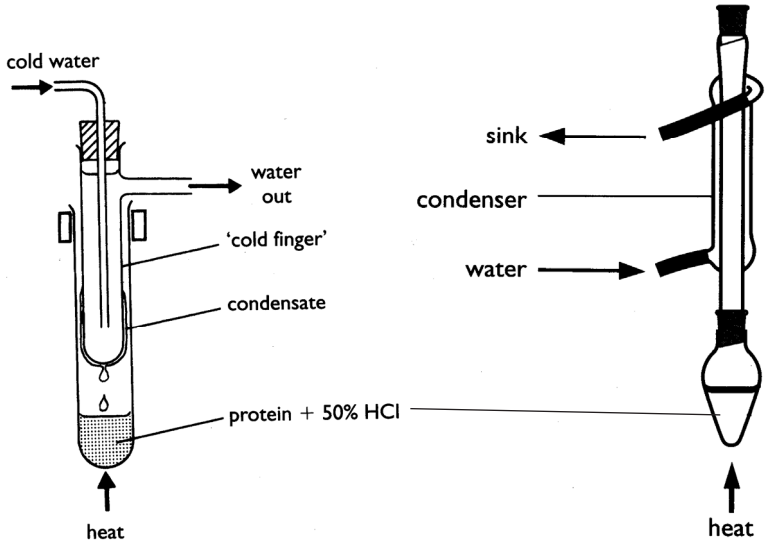
Proteins can be broken down in the lab by ***heating*** them for several hours with dilute acid.

This reaction is called *hydrolysi*

hydro = ***water***

lysis = ***splitting apar***

To prevent the water ***evaporating*** away before the ***reaction*** has finished we can use apparatus like these.

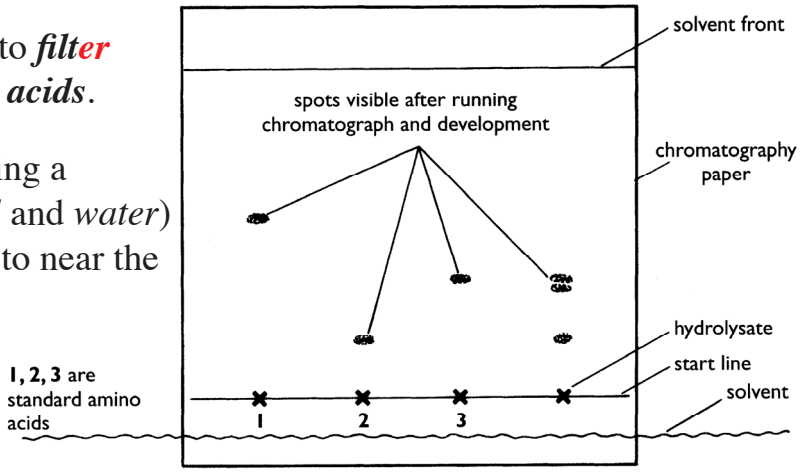


a reflux condenser

Having *hydrolysed* a ***protein***, we will often attempt to ***identify*** the ***amino acids*** that made up the ***protein*** using ***chromatography***.

The ***protein*** *hydrolysate* is *spotted* onto ***filter*** paper with solutions of *known* ***amino acids***.

The *paper* is placed in a *tank* containing a suitable ***solvent*** mixture (eg *propanol* and *water*) and left until the ***solvent*** has climbed to near the top of the paper.



The ***amino acids*** are *colourless*, so a chemical called *ninhydrin* is *sprayed* onto the paper and, after a few minutes in an *oven*, pink, blue or brown spots appear. In the example above, the ***protein*** *hydrolysate* appears to contain amino acids '2' and '3' and some other amino acid which is not '1'.

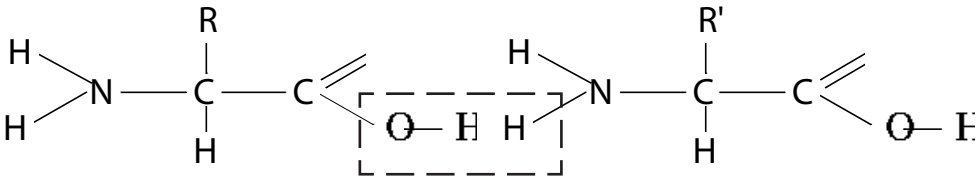
8.2 Proteins

This second topic looks at how proteins are formed and the different structures that proteins can form

Making Peptides

This activity looks at how amino acids can link together to form peptides.

Most ***proteins*** contain more than 40 ***amino acids*** joined together. Firstly, however, the ***amino acids*** tend to join together in twos or threes to make *peptides*.



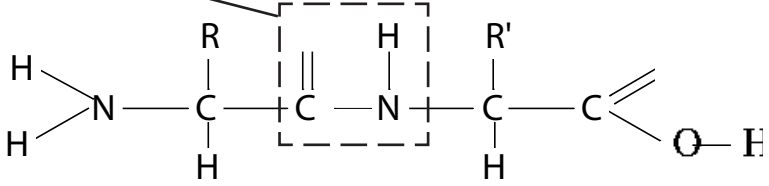
two amino acids
(R and R' represent different side chains)
link together to form a dipeptide

The ***carboxylic*** group from one amino acid links with the ***amino*** group of another amino acid

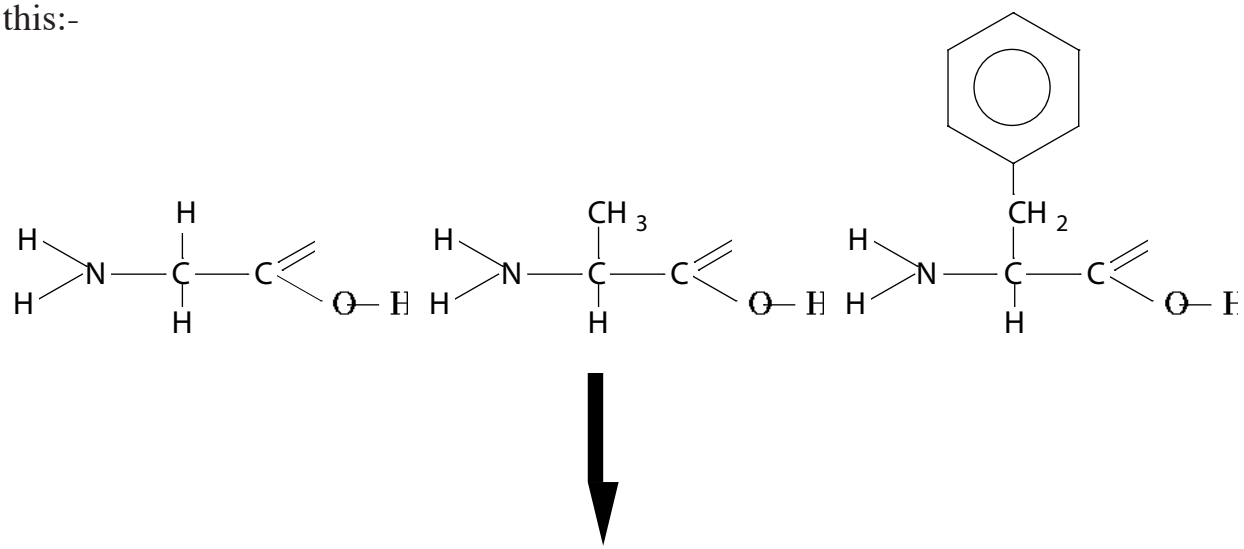
This is known as the ***peptide link*** (or ***amide link***)

H_2O

Water is also produced and this is a ***condensation*** reaction



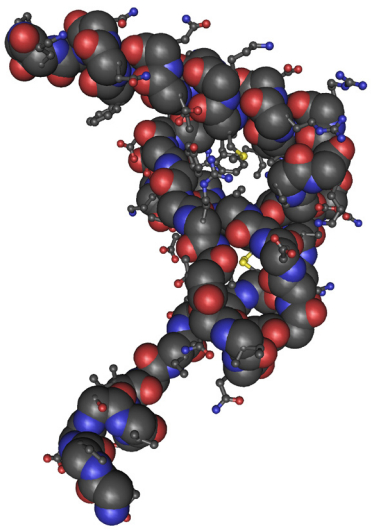
Tripeptides are made by joining ***three*** amino acids together. ***Peptides*** are *'named'* using the accepted abbreviations of the amino acids they contain. For example, the peptide made from *Glycine*, *Alanine* and *Phenylalanine* would be labelled *GlyAlaPhe* and would look like this:-



By convention, the ***amino acids*** are always drawn with their ***amino*** *groups* to the left, in the order they appear in the peptide name - a different peptide would be formed if we'd lined the 3 amino acids up facing the 'wrong way'.

Polypeptides can contain *up to about* 40 amino acids; more than 40 and we tend to call it a protein, though the distinction between a polypeptide and a protein is an *arbitrary* one.

Making Proteins



This activity looks at how proteins are made

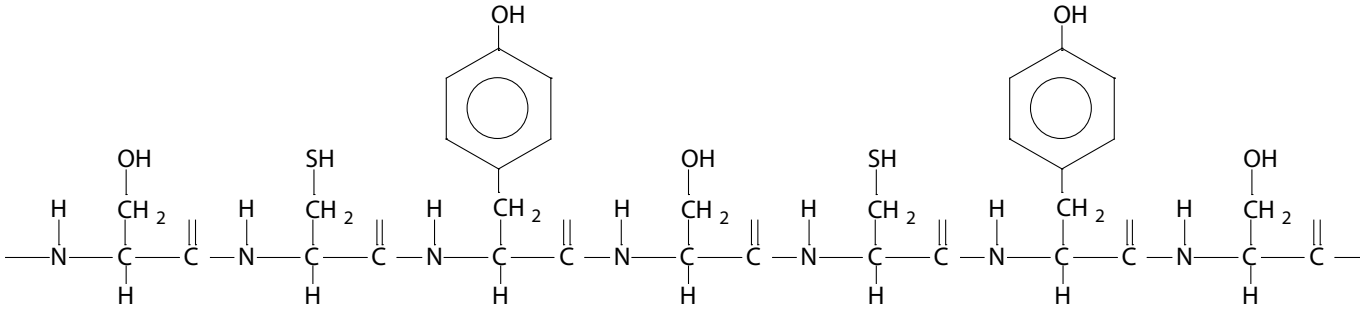
Proteins are ***condensation polymers*** which can contain *several thousand* amino acids. A massive *variety* of ***proteins*** can be made by *arranging* up to 26 ***amino acids*** in *varying numbers* and *varying orders*.

Proteins comprise a large part of an animal's *diet*. During ***digestion*** the ***animal*** and ***vegetable*** *proteins* are ***hydrolysed*** into their component ***amino acids***. Some *amino acids* can be *synthesised* in the body, but others (*the* ***essential amino acids***) have to be present in the diet.

Proteins required for the body's specific needs are built up from amino acids in the body cells according to information supplied by DNA in the cell nuclei.

Breakdown of Proteins

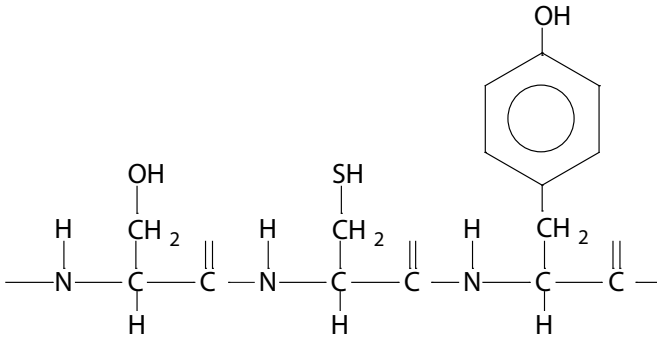
This activity looks at the hydrolysis of proteins to recreate the original amino acids used to form them.



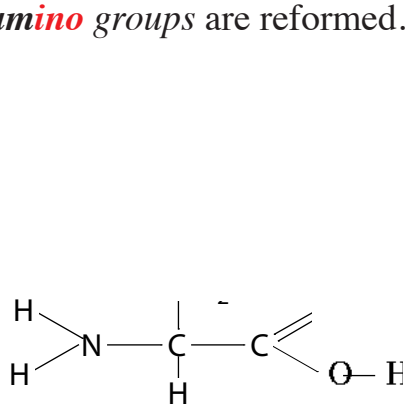
You will only ever see a *fragment* of a ***protein chain*** but it will be enough to allow you to recognise the *"repeating pattern"* and identify how many ***different amino acids*** are being used to make this protein.

In this case there are ***three*** amino acids in the *"repeating pattern"*.

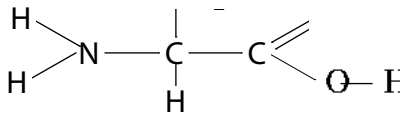
The recognisable ***peptide link*** is used to show where one amino acid ends and the next one begins.



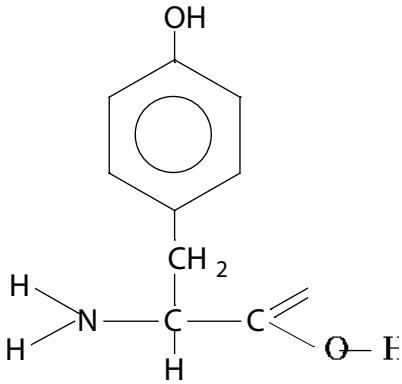
The *original amino acids* can then be drawn - remembering to replace the —H atoms and —OH groups lost when they joined together. In other words, the original ***carboxyl*** and ***amino*** *groups* are reformed.



serine



cysteine



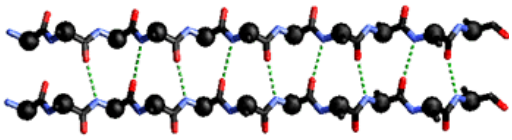
tyrosine

Structure of Proteins

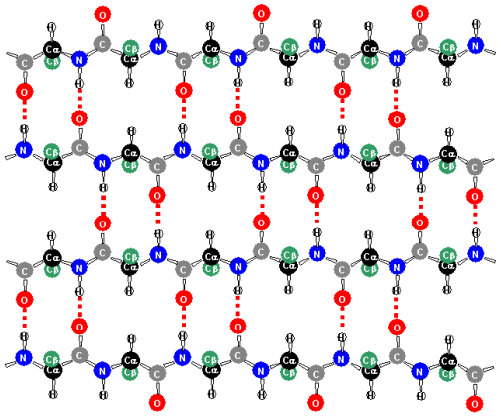
This activity looks at how different structures for proteins depend on their constituent amino acids and affect their role

The *primary structure* of all ***proteins*** is *long chains* of ***amino acids***. However, all along these chains are ***polar*** *groups* such as $—N^{\delta-}—H^{\delta+}$ and $—C=O^{\delta-}$ as well as ***polar*** and ***non-polar*** groups (—R) on each amino acid. A lot of ***attractions*** (and ***repulsions***) are set up *within* and *between* chains, plus some reactions that lead to *permanent* bonds.

As a result of these extra bonds, *secondary structures* will be formed.

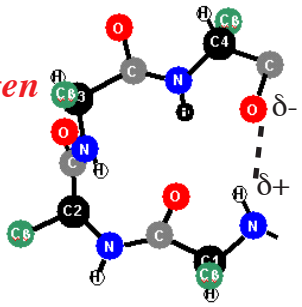


Chains can become linked together by ***strong hydrogen bonds*** *between* the chains.

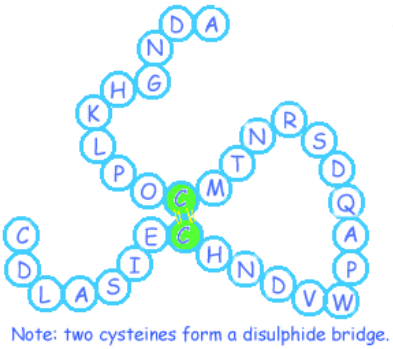


Many *chains* can link in this way to form a ***sheet***.

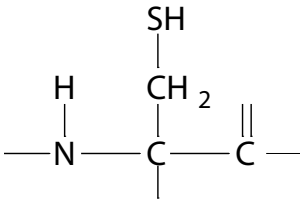
Often the *chains* will ***twist*** around to form ***strong hydrogen bonds*** *within* the chain. The length of ***amino acids*** is usually enough to allow this to happen



As a result of this *twisting* a ***helix*** chain will form.


Note: two cysteines form a disulphide bridge.

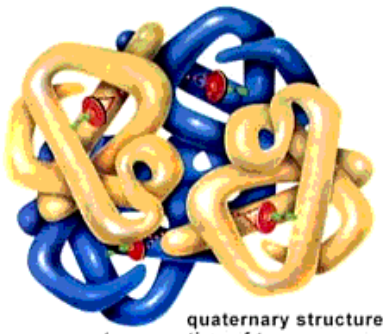
More ***permanent bonds*** can also be formed. For example,two *cysteine* side groups can be oxidised and lose hydrogen atoms to form a *'disulphide bridge'*



The ***folding*** of *chains* and *helixes* is what gives ***proteins*** their individual ***shapes***.

tertiary structure
(folded individual peptide)

Proteins which remain more elongated are referred to as ***FIBROUS*** proteins. These make up most *animal tissue* such as *muscles*. Other examples include *Keratin* found in *horns*,*hoof* and *hair*, and *Collagen* found in *tendons*.


quaternary structure
(aggregation of two or more peptides)

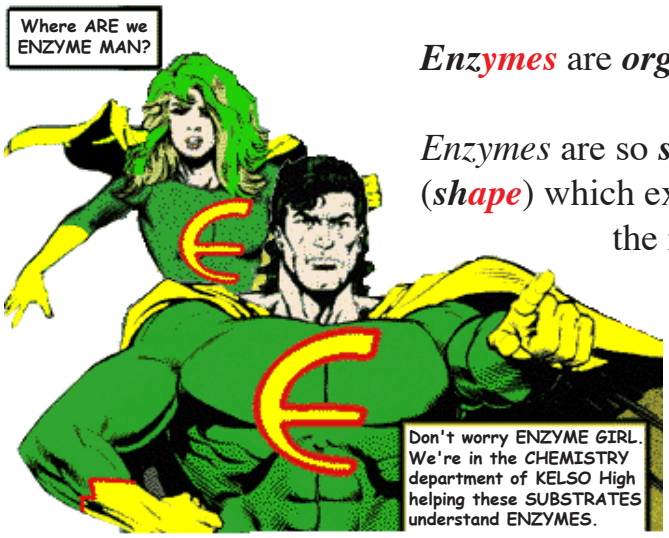
Even more complicated structures called ***GLOBULAR*** proteins can result when a number of ***peptide chains*** join together. These ***Globular*** proteins are involved in the *maintenance and regulation of life processes*.

Examples include ***hormones*** e.g insulin, and ***enzymes***.

Shape, *and their ability to form various types of bonds to bind to other substances, are crucial to a proteins role*.

Enzyme Shape

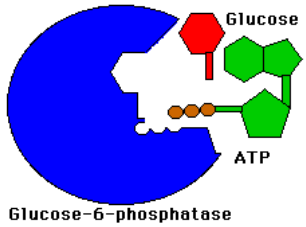
This activity looks at the importance of molecular shape to the way an enzyme functions



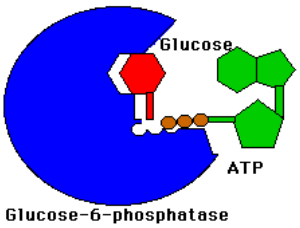
Enzymes are ***organic catalysts*** and all contain ***protein.***

Enzymes are so ***specific*** because they have a precise structure (***shape***) which exactly matches the structure of the ***substrate*** - the molecule(s) which is/are reacting.

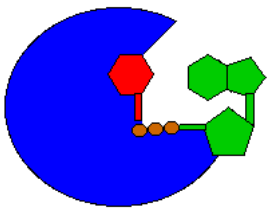
Enzymes will have an *active site* where the reaction takes place. Within the ***active site*** chemical groups (some of the side chains on the ***amino acids***) will form *bonds* with the ***substrate*** molecule



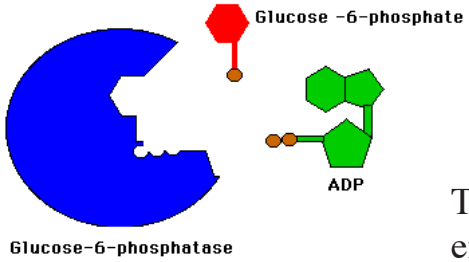
The ***bonds*** which bind the ***substrate*** to the ***active site*** have to be ***weak*** so that the products can easily leave the ***active site*** after the reaction. The bonds are usually ***hydrogen bonds*** or *interactions* between ***ionic*** groups.



While attached to the ***active site***, bonds *within* the ***substrate*** molecule(s) will be *weakened* making it ***easier*** for the ***substrate*** to react - *lowering the* ***activation*** *energy* of the reaction as a ***catalyst*** should.



Sometimes, being attached to the ***active site*** will change the ***shape*** of the substrate bringing atoms or groups that need to react into *closer contact*. This helps overcome awkward *'collision geometry'*.



When talking about ***enzymes*** we often use the phrase *'lock and key'* to cover the importance of *correct* ***shape*** and the fact that each enzyme is likely to only work with one ***specific*** substrate.

The example on the left is a good illustration of how an enzyme works.

Denaturing

This activity looks at the factors which can change the shape of an enzyme and prevent it functioning.

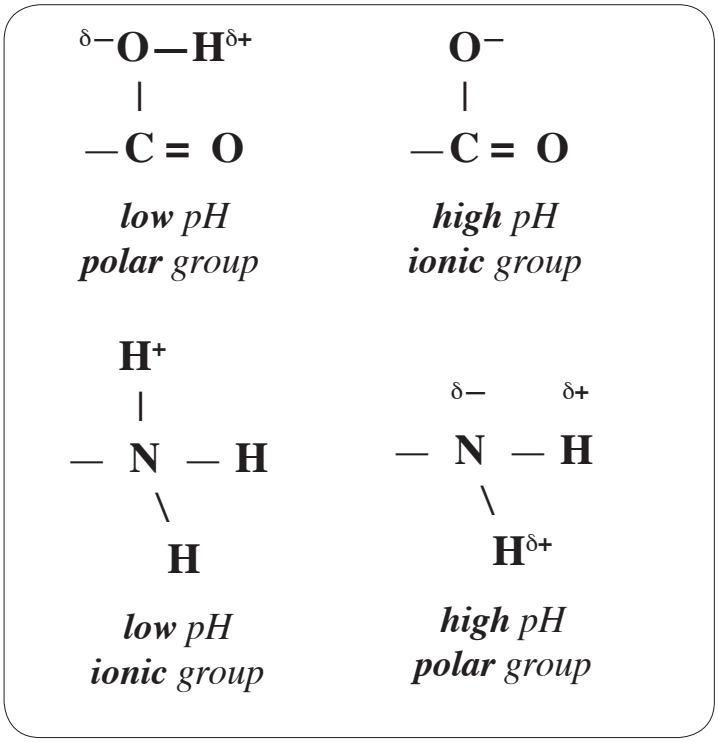
Many of the ***groups*** found on the ***side chains*** of ***amino acids*** (*see page 11*) are *ionisable* and will be affected by a change in ***pH***

Groups such as —COOH and —NH_2 are ***polar*** but can become ***ionic*** as the ***pH*** changes.

This can change the ***active site*** so that the ***substrate*** molecule will be unable to ***bond*** with the ***enzyme***.

Changing the nature of some of these ***groups*** can also change the ***shape*** of the ***enzyme***, as ***folding*** of the ***peptide chain*** may no longer happen at the same points.

If the ***active site*** is destroyed the enzyme is said to be ***DENATURED***.



The structure of an ***enzyme*** is often held together by *weak polar—polar bonds* and *hydrogen bonds*. These can easily be ***broken*** by raising the ***temperature***, which causes them to ***vibrate*** more vigorously. *So enzymes are sensitive to small changes in temperature or pH.*

PPA - *Factors Affecting Enzyme Activity*

Aim:

Labelled diagram:

Procedure: *How was the activity of the enzyme measured?*

Results: *Record your results in tabular form*

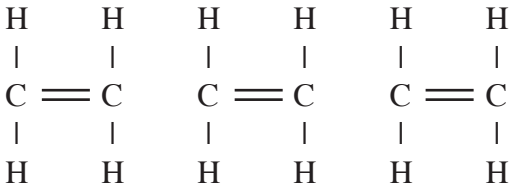
Conclusion: *State the conclusion of the experiment*

8.3 Polymerisation

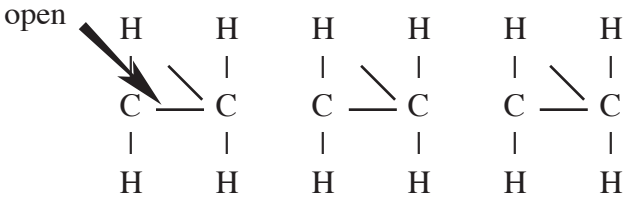
This lesson topic considers the two different methods of polymerisation and looks at the general properties that polymers share

Addition Polymerisation

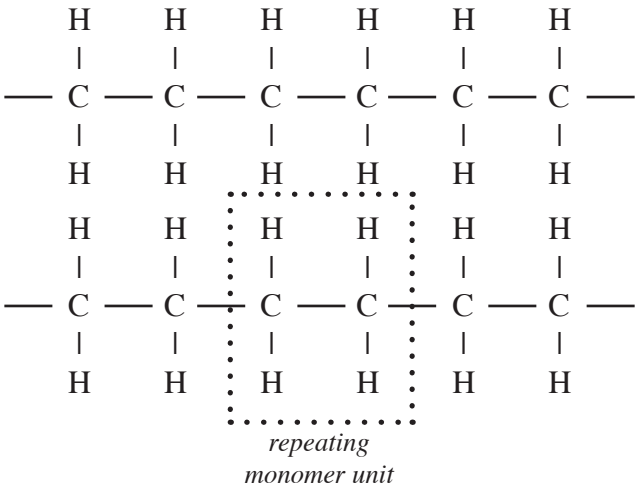
This activity revises the polymerisation reaction met at Standard grade



A ***polymer*** molecule is *a long chained molecule* made up from *lots of small molecules* called ***monomers***. If the ***monomers*** contain *C = C double bonds*, e.g ***ethene*** then the polymers will be formed by the reaction known as ***addition polymerisation***.



An *initiator* will start the reaction by causing the ***double bond*** in some of the ***monomers*** to open up. These moecules react with other molecules to continue the *'chain reaction'*.



A *long chain* made from ***hundreds*** or even ***thousands*** of ***monomers*** will result. It can be identified as an ***addition polymer*** because it will have *only carbon atoms in the chain*.

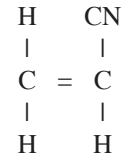
In the chain the same basic unit is ***repeated*** over and over so structure of *poly(ethene)* can be shown as:

$$(-CH_2-CH_2-)_n$$

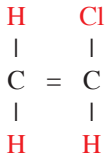
Depending on ***reaction conditions***, *different forms of polythene* can be made with slightly *different properties* and, as a result, different uses.

LDPE (0.92 g cm^{-3}) ***low density poly(ethene)***	**HDPE** (0.96 g cm^{-3}) ***high density poly(ethene)***	**LLDPE** (0.92 g cm^{-3}) ***linear low density poly(ethene)***
very high pressures 150°—300°C initiator	lower pressures lower temperatures Ti/Cr catalyst	lower pressures lower temperatures catalyst
extensive branching more flexible material	fewer branches stronger, more rigid	side chains butene co-polymer
film packaging electrical insulation	pipes, gutters, bottles industrial packaging	film packaging electrical insulation

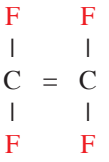
Other ***polymers*** can be made from ***ethene*** by replacing some or all of the ***hydrogen*** atoms with other atoms or groups. Examples include;



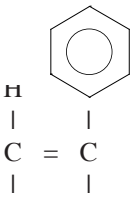
acrylonitrile



chloroethene

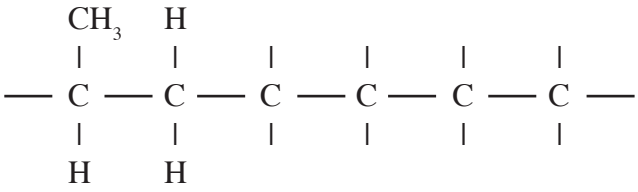


tetrafluoroethene



phenylethene (styrene)

Propene is also a very important ***monomer*** used to make *poly(propene)*.



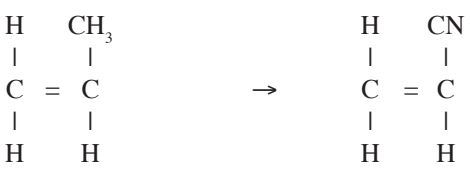
Steam Cracking

This activity looks at the feedstocks used to produce the starting materials for the plastics industry

The *raw material* for most *plastics* is ***crude oil***. After ***distillation*** some of the ***fractions*** obtained will be taken through the process called ***Steam Cracking***. The main ***fraction*** used as a suitable *feedstock* is ***naphtha*** (C_6 to C_{10}). The products of cracking ***naphtha*** only contain about 30% ***ethene*** and 15% ***propene***, but other valuable by-products such as ***gasoline*** (*petrol*) and ***fuel gases*** (*propane* & *butane*) are also produced.

Ethane, separated from the other ***fuel gases*** by further ***distillation***, is the other important ***feedstock*** used. On ***Cracking***, it will yield about 80% ***ethene***. Both types of ***feedstock*** are cracked at *Grangemouth* while *ethane* is cracked at *Mossmorran* in Fife.(photo above).

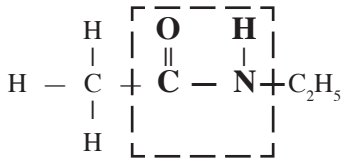
Similarly *propane* can be used as a ***feedstock*** to produce more ***propene*** to add to the ***propene*** produced by ***cracking naphtha***. As well as being used to produce *poly(propene)* it is also the starting material for other ***monomers*** such as *acrylonitrile*



Condensation Polymerisation

This activity shows how the condensation reactions met earlier can be used to make polymers.

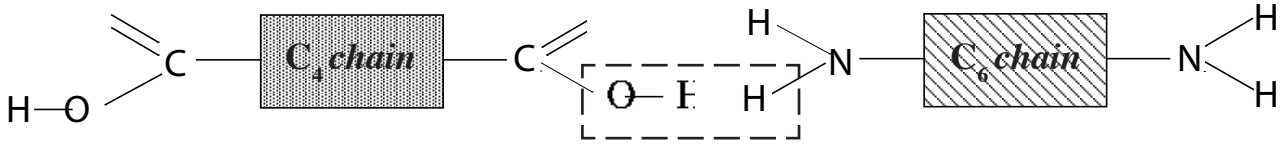
Polyamides



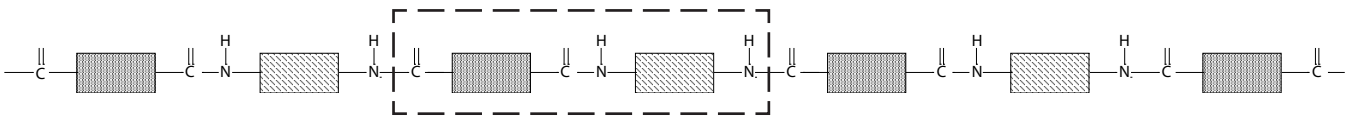
Earlier it was shown how the ***carboxyl*** (*acid*) *group* (—COOH) could take part in a ***condensation*** reaction with the ***amino*** *group* ($—NH_2$) to form an ***amide*** *link*.

Amino *acids* use the ***amide*** (or ***peptide***) *link* to form ***condensation polymers*** called ***proteins***.

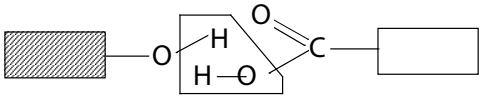
Man-made *polyamides* such as *Nylon* tend to make use of ***two monomers***. One will have an ***acid group*** at both ends (*a diacid*), while the other molecule will have two ***amino groups*** (a *diamine*). For example, when *1,6-diaminohexane* and *hexan-1,6-dioic acid* react the polymer known as ***Nylon 6,6*** is formed.



As usual, *long chains* are formed though the ***repeating unit,*** in these examples, is a *two monomer* unit.

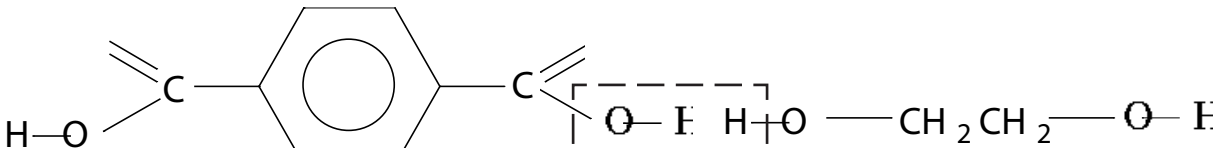


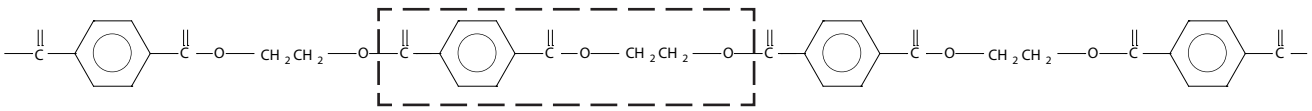
Polyesters



Earlier it was shown how the ***carboxyl*** (*acid*) group could take part in a ***condensation*** reaction with the ***hydroxyl*** group to form an ***ester link***.

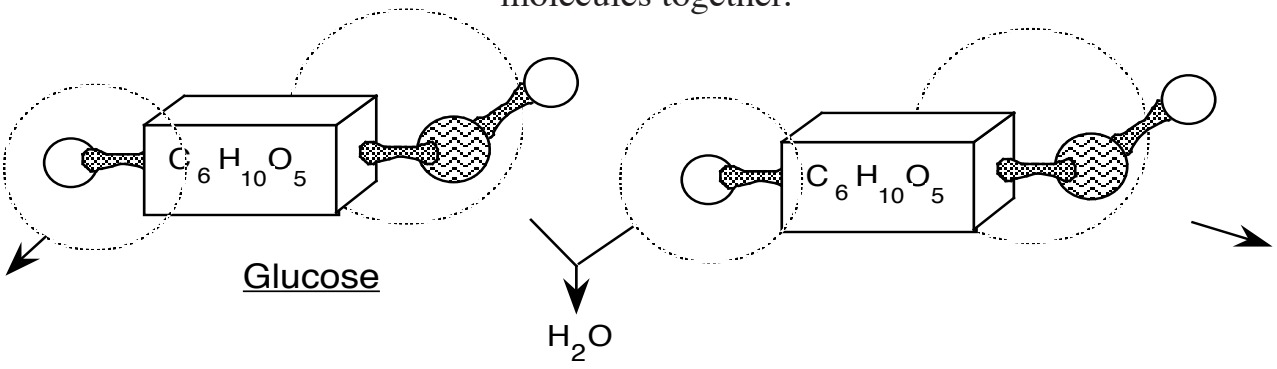
Again man-made *polyesters* tend to make use of ***two monomers***. One will have an ***acid*** group at both ends (*a diacid*), while the other molecule will have two ***hydroxyl*** groups (a *diol*). For example, when *ethan-1,2-diol* and *benzene-1,4-dicarboxylic acid* react the ***polymer*** known as *Terylene* is formed.



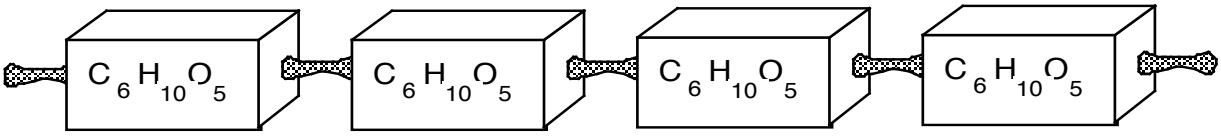


Polysaccharides

It is worth remembering that the first ***condensation polymers*** you ever met were ***starch*** and ***cellulose***, two ***natural polymers*** made by joining ***glucose*** molecules together.



The only thing you needed to learn about the structure of ***glucose***, and the other ***monosaccharides***, was that there were —OH *groups* (***hydroxyl***) and —H *atoms* available. These could react together to form ***water***, allowing the ***glucose*** molecules to *link* together. You don't need to know about this type of *link*, but you should not forget *polysaccharides*.

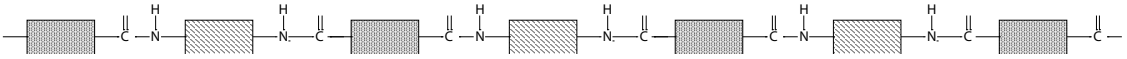


Fibres & Resins

This activity looks at the main two categories of polymers

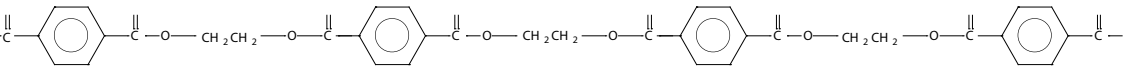
Fibres are formed from *linear* ***polymers*** - individual ***long chained*** molecules which can be *spun* together to make ***fibres***. Examples include:

Nylon



&

Terylene

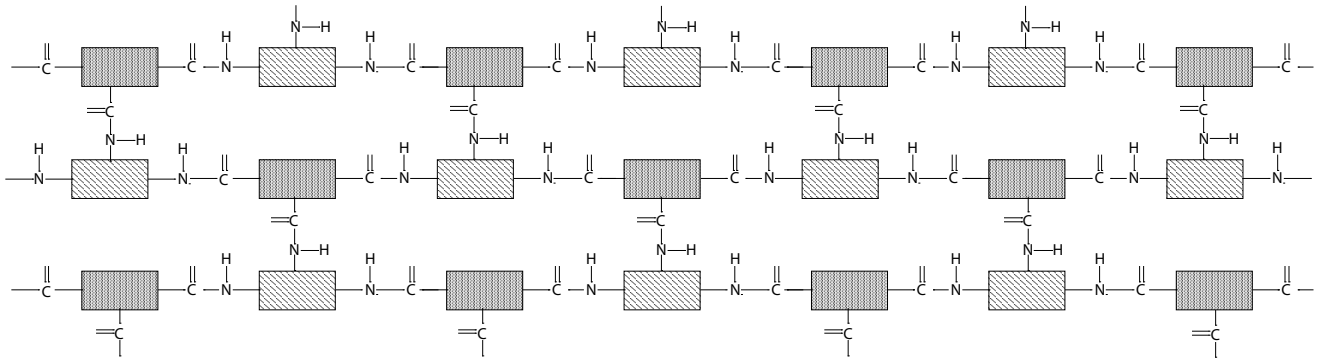


Monomers with *two functional groups* are able to link together to form ***fibres***.

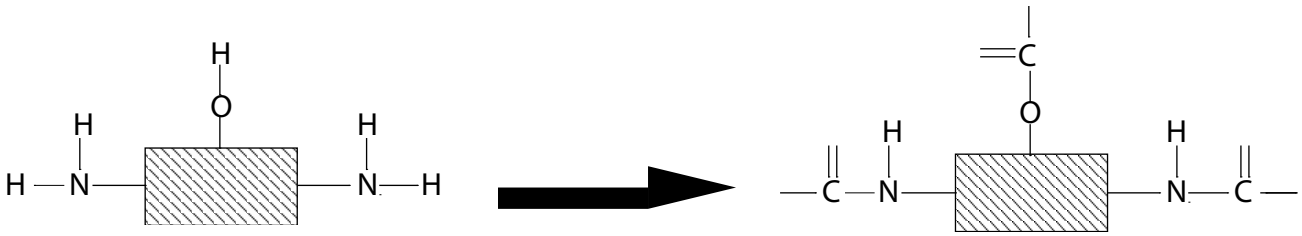
Monomers with *more than two functional groups* are able to form ***cross-links*** between adjacent ***polymer chains*** and, therefore, can form ***resins***.

Resins are usually harder and are used where a rigid polymer structure is required. Resins are also ***thermosetting*** plastics- they will ***not soften*** on ***heating*** and cannot be ***re-shaped*** i.e. they cannot be ***recycled***.

Both ***polyesters*** and ***polyamides*** can exist as ***resins***. In the structure below, the ***third*** *functional group* allows *linking* between the ***polyamide chains*** to occur.



The 3 functional groups do not have to be the same. For example, a *diamine* may have a ***hydroxyl*** *group* branching off. The ***amino*** *groups* might use ***amide links*** with ***acid*** *groups* to form the *chain*, while the ***hydroxyl*** *group* could form an ***ester link*** to *cross-link* the chains.



If you look back at the structures of ***amino acids*** on *page 11*, you will notice that many of them have suitable ***functional groups*** on the side chain. Linking between ***protein chains*** helps make ***protein tissues***.

The ***properties*** of a ***polymer*** are decided by the following *characteristics*:

*	*chain length*	the ***longer*** the *chain* the ***stronger*** the ***polymer***
*	*side groups*	***polar*** side groups give ***stronger attractions*** between ***polymer****chains*, making the polymer ***stronger***
*	*branching*	***straight*** *chains* can *pack* closer than ***branched*** *chains*; this *maximises attractions* between *chains* and makes them ***stronger***
*	*cross-linking*	if ***polymer*** *chains* are *linked* together by ***covalent*** *bonds*, the *polymer* is ***harder*** and *more difficult* to ***melt***. ***Thermosetting*** *polymers* have *extensive cross-linking*.

The rest of this Section will look at various polymers and you will see how some of these characteristics affect the properties and uses of the polymers.

8.4 Polymer Case Studies

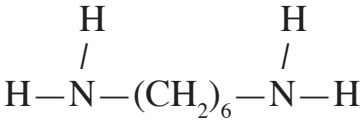
This lesson topic examines various polymers; how they are made, what their properties are and what they are used for.

Nylon

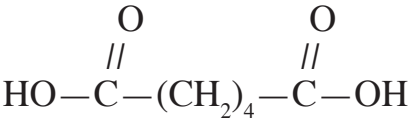
Nylon was first made in 1935 by a scientis called *Carothers*. He used ***silk***, a natural *polyamide*, made from ***amino acids***. *Carothers* decided to use ***diamines*** and ***dicarboxylic acids*** as his ***monomers***.

monomers

1,6-diaminohexane



hexan-1,6-dioic acid



polymer structure

properties

It has an excellent combination of ***strength***, *toughness*, *rigidity* and *abrasion resistance* as well as being *chemically unreactive* in many environments.

The ***polymer*** *chains* in ***nylon*** have the same ***strength*** as chains of *poly(ethene)* and *poly(propene)* that are *twice as long*. The more powerful ***intermolecular*** *forces* which act ***between*** chains (***hydrogen bonding***) are the source of the increased ***strength***.

uses

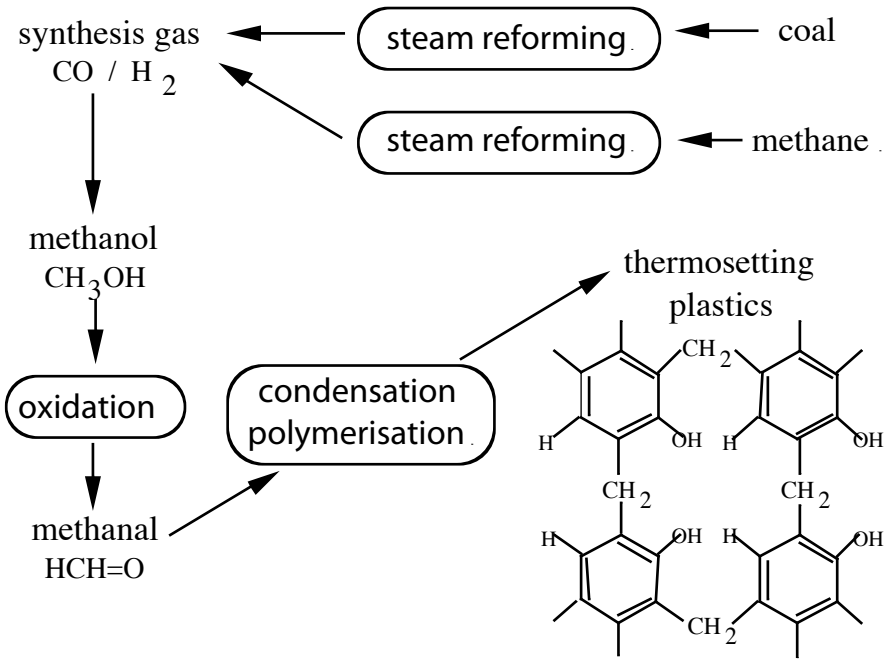
As a ***fibre***, *nylon* started off as a substitite to ***silk*** in first of all parachutes and then in ***stockings***. *Spun nylon fibres* are ***strong*** enough to be used to make ***climbing ropes***. Early *nylon* repelled ***water*** - useful in *cagoules* and ***ropes***, but it meant that *nylon* clothes were very *sweaty*. Modern methods of treating the *nylon* fibres have solved this problem.

Nylon is also a very important ***Engineering Plastic*** -when mixed with fillers and reinforcing materials it can be used to replace ***metal*** in things

Bakelite

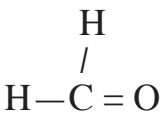
Bakelite was the first ***synthetic polymer*** ever made. It is one of a number of ***polymers*** made from *methanal*, whose old name *formaldehyde*, is often used as a group label for these ***polymers***.

The production of ***methanal*** is an important industrial process that *you are expected to know* (it was first introduced in Unit 2 section 6)

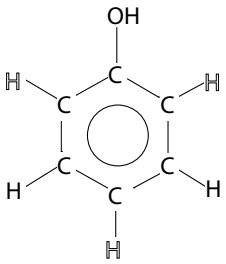


monomers

methanal

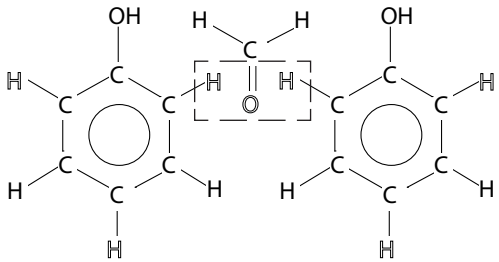


phenol

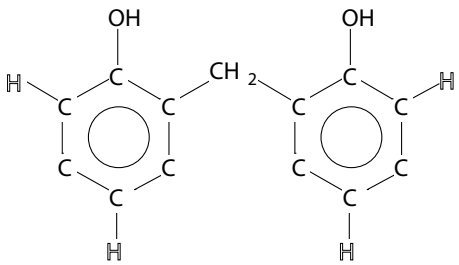


polymer structure

This is a different type of ***condensation*** reaction. Surprisingly, the ***hydroxyl*** *group* attached to the ***benzene*** *ring* seems to play no part in the reaction. *In fact, it is crucial*. It affects the ***hydrogens*** attached to the ***benzene*** ring. The two *adjacent* ***hydrogens***, and the ***hydrogens*** *opposite* are affected.



3 molecules are involved but the end result is the same; ***joining together*** by ***eliminating water***. ***Condensation***.



With three *'functional groups'* (***hydrogens***) a ***thermosetting resin*** will result. Various structures can result, but they are all ***phenol*** molecules linked by —CH_2— 'bridges'.

properties

Bakelite and the other ***formaldehydes*** all have extremely ***strong network*** structures. They do not ***soften*** on ***heating*** (*thermosetting*) and are good ***insulators***, ***heat*** and ***electrical***. They are also *very* ***insoluble***.

uses

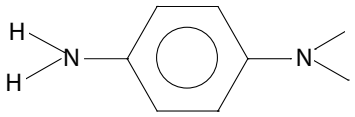
Less popular nowadays as they tend to be *brittle*. Originally, they were widely used as ***electrical insulators*** in *plugs* and *light fittings*. *Bakelite* was the black plastic used for the original ***telephones***. *Bakelite* is still used widely to make ***pan handles***.

Kevlar

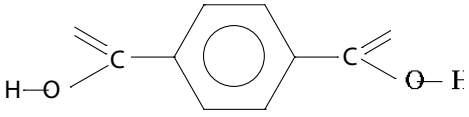
Kevlar belongs to a new group of polymers called *aramids* - ***aromatic polyamides***. It has many applications and is a big earner for the plastics industry.

monomers

1,4-diaminobenzene



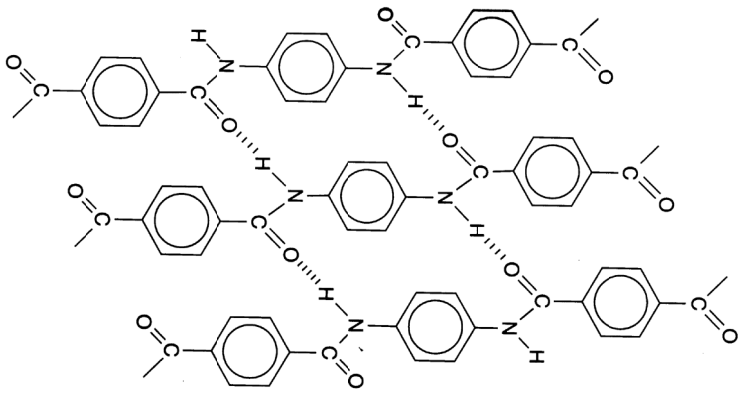
benzen-1,4-dioic acid



polymer structure

The basic structure of *kevlar* has the ***monomers*** using ***amide links*** to form ***CHAINS***.

These ***chains*** then line up parallel to each other and form ***SHEETS*** held together by *many strong* ***hydrogen*** *bonds*



Finally these ***sheets*** can stack up close together, again held by *many strong* ***hydrogen*** *bonds*. This results in *extremely strong* ***FIBRES***.

properties

Kevlar is a ***fibre*** which is ***fire-resistant***, *extremely* ***strong*** and ***flexible.*** It also has a ***low density*** because it is made from light atoms (C , H, O & N). *Weight for weight Kevlar is about five times stronger than steel!*

uses

One of the early uses for *Kevlar* was to replace ***steel*** cords in *car tyres*: *Kevlar* tyres are ***lighter*** and ***last longer*** than *steel-reinforced tyres*.

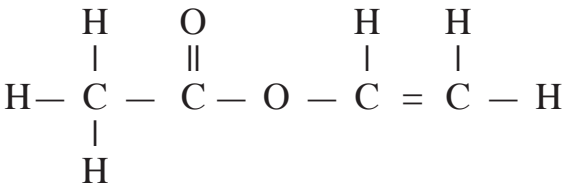
Kevlar ***ropes*** have 20 times the strength of *steel ropes* - and they last longer too. A stiffer form of *Kevlar* is used in *aircraft wings* where the combination of ***strength*** and ***low density*** is important. It's also revolutionised the production of *bullet-proof vests* and ***crash helmets***. It's also a vital component in the production of *space suits*.

Poly(ethenol)

Poly(ethenol) belongs to a new group of ***polymers*** called the '*the dissolving plastics*' that are having a big impact - particularly in the ***medical*** world.

monomers

ethenyl ethanoate

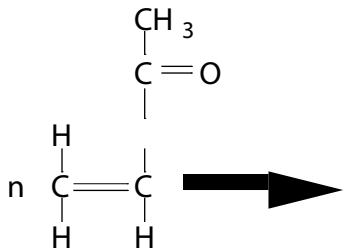


ethenol

polymer structure

Poly(ethenol) cannot easily be produced by simply making *ethenol* molecules undergo ***addition polymerisation***.

Instead, *ethenyl ethanoate* (an ***ester***, but here it is easier to consider the *ethanoate group* as 'branch' coming off an ***ethene*** molecule - *think rugby posts!*) will react to produce the ***addition polymer*** *poly(ethenyl ethanoate)*.



The next step is to *replace* the ***ethanoate*** *group* CH_3COO- with a ***hydroxyl group*** HO—. This is done by reacting the ***polymer*** with some *methanol*. The ***ethanoate*** goes off to form the simple ester ***methyl ethanoate*** and the ***hydroxyl*** takes its place. This is called *ESTER EXCHANGE*.

The final ***polymer***, *poly(ethenol)* looks like this:-

properties

Obviously the main property that makes *poly(ethenol)* useful is its ability to ***dissolve in water***. The ***hydroxyl groups*** $—O^{\delta-}—H^{\delta+}$ with their ability to form ***hydrogen bonds*** *similar in strength* to ***water*** molecules hold the key.

However, if *every single* ***ethanoate group*** is replaced by a ***hydroxyl group*** the *strength* of the ***hydrogen bonds*** set up *between polymer molecules* is ***so strong*** that the polymer will be *unable to* ***dissolve*** at all.

Leaving just 1% of the original ***ethanoate group***s behind helps *disrupt* the ***hydrogen bonding*** and allows the polymer to ***dissolve***, but only in *hot water*. Leaving more ***ethanoates*** behind *increases the solubility*.

% of OH groups	*Solubility in water*
100 - 99	insoluble
99 - 97	soluble in hot water
96 - 90	soluble in warm water
below 90	soluble in cold water

uses

If *soiled laundry* from a ***hospital*** is mishandled, there is a risk of ***infection***. Laundry bags are now made out of a ***dissolving plastic***. The dirty laundry remains in the bag at all times. Once in the washing machine the bag ***dissolves*** in the *hot water* releasing the laundry.

Dissolving polymers are often used as *sutures* (***stitches***) in surgery. This gets rid of the need for ***patients*** to undergo further ***surgery***/ *visit out-patients* to have ***stitches*** removed.

Different *suture threads* are produced which ***dissolve*** at *different rates*; *days*, *weeks* or *months*. The doctor will choose the one most suitable for a particular case.

Poly(ethyne)

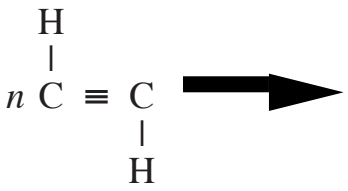
Poly(ethyne) belongs to a new group of ***conducting polymers*** whose properties are exciting a lot of interest.

monomer

ethyne

polymer structure

Poly(ethyne) molecules undergo ***addition polymerisation***.



properties

Obviously the main property that makes *poly(ethyne)* special is its ability to ***conduct electricity***. Forming a chain of *alternating* ***single*** and ***double*** *bonds* turns out to be a *'fluid'* arrangement. The *'spare'* ***electrons*** in the ***double*** *bonds* turn out to be *free to move* along the chain. They are ***delocalised electrons***. (This is not dissimilar to the structure in ***benzene*** rings)

uses

It is early days but already *poly(ethyne)* is used in the *membranes* of *high performance speakers*. There is a lot of research going on and there is speculation that the the next generation of computer monitors will be flexible plastic that can be rolled up or bent to fit any shaped surface.

Poly(vinylcarbazole)

Poly(vinylcarbazole) is another plastic that can ***conduct electricity***, but its *conductivity* depends on the *intensity of light* shining on it.

monomer

vinylcarbazole

polymer structure

Poly(vinylcarbazole) molecules undergo ***addition polymerisation***.

properties

Poly(vinylcarbazole) ***conducts*** *much better* when ***light*** shines on it.

uses

At the heart of a *photocopier* is a metal ***drum*** coated with a very thin layer of *Poly(vinylcarbazole)*. The ***drum*** is ***charged*** (*positively*). Then the sheet to be ***copied*** is placed on a glass sheet and ***illuminated***. ***White*** areas on the paper allow *a lot of light* to shine on the drum and *increase* the ***conductivity*** of the *Poly(vinylcarbazole)* in these areas. This allows the ***charge*** to leak away. ***Black*** areas *do not let enough light through*. A ***charge image*** is formed on the ***drum***. As the ***drum*** rotates, *negatively* charged *ink powder* sticks to the ***drum***, *some areas more than others*. The ink is then transfered to paper where heat is used to fuse it to the paper.

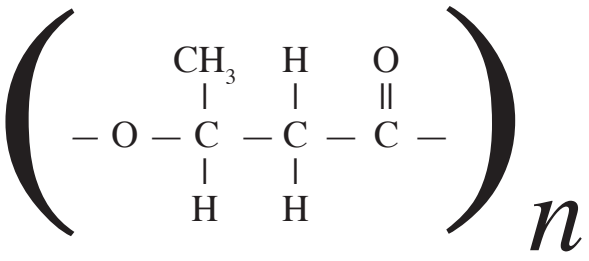
Degradable Plastics

Most plastics are *not degradable* because ***decomposer*** organisms, such as ***bacteria*** and ***fungus***, do not have the ***enzymes*** needed to break them down.

There are 3 main types of degradable plastics:

Biopolymers

These are usually *polyesters* made by ***bacteria*** during a ***fermentation*** process. The best known example is called ***BIOPOL***, *poly(hydroxybutanoate)* or *PHB*. It can also be produced by *genetically modified plants*.



Biopol is a ***thermoplastic*** so it can be processed to make many items such as bottles etc. Once dumped it can be broken down by *micro-organisms* either *aerobically*, to produce CO_2 and H_2O, or *anaerobically* (in land-fill sites), to produce ***methane***, CH_4.

Photodegradable

These are usually existing ***polymers*** which have been modified to include ***carbonyl groups*** (C=O). These groups absorb *UV light* from the ***sun*** and this *extra* ***energy*** causes nearby ***bonds*** to ***break***. Once the chains have broken down into shorter fragments they can be broken down by *micro-organisms*.

Synthetic Biodegradable

Some plastic bags, for example, are made from *poly(ethene)* that has ***starch*** granules encapsulated in it. Once in the soil, the ***starch*** is digested by *micro-organisms* leaving the *poly(ethene)* fragmented and much easier to biodegrade.

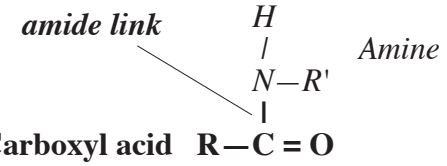
UNIT 2 Section 8 : *Natural & Synthetic Polymers*

Proteins

1. *An amine can be identified from the functional group*

amino group, $-NH_2$ (also —NHR and —NRR')

2. *The **amide link** is formed by the reaction of an **amine** group with a **carboxyl** group*



3. *Nitrogen is essential for protein formation by plants and animals*

Covered in Standard Grade

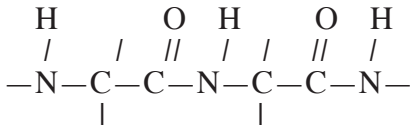
4. *The body cannot make all the amino acids required for body proteins and is dependent on **dietery supply** for certain amino acids known as **essential amino acids***

All amino acids are 'essential' since the inability to make any protein is likely to be harmful. However, only those we cannot make ourselves are **labelled** as ***"essential"***

5. *During **digestion**, the **hydrolysis** of proteins produces amino acids*

A combination of acid hydrolysis and enzymes (***Chromotography*** can be used to identify)

6. ***Condensation** of amino acids produces the **peptide** (amide) link.*



7. *The **peptide link** is formed by the reaction of an **amine** group with a **carboxyl** group*

8. *Proteins are **condensation polymers** made up of many amino acid molecules linked together*

9. *Proteins specific to the body's needs are built up within the body*

10. *The structure of a section of protein is based on the constituent amino acids*

You will be expected to draw part of the protein that would be formed by joining (typically) 3 amino acid units together (to from a tripeptide).....

11. *The structural formulae of amino acids obtained from the hydrolysis of proteins can be identified from the structure of a section of the protein*

..... and, given a section of a protein, draw the original amino acids that formed it

...

12. *Proteins are classified as **fibrous** or **globular***

Fibrous proteins are found in skin, hair and muscle. Examples include the ***keratins*** (in wool, hair and nails), the ***collagens*** (in skin and tissue) and the ***elastins*** (in lungs and arteries)

There is a regular folding of the 'backbone' of the polypeptide chain due to the ***intermolecular*** bonding ***between*** the carboxyl and amino groups

13. *Fibrous proteins are long and thin and are the **major** structural materials of **animal tissue***

In fibrous proteins, a linear ***sheet*** structure is obtained as a result of ***hydrogen*** bonding ***within*** the same chain (intramolecular) or ***between*** different molecules (intermolecular)

14. *Globular proteins have the **spiral chains** folded into compact units*

Intermolecular bonding in globular proteins results in spiral chains which fold to give the globular structure

15. *Globular proteins are involved in the **maintenance** and **regulation** of life processes and include **enzymes**, many **hormones**, eg insulin, and haemoglobin*

16. *Enzyme function is related to the molecular **shape** of proteins*

The idea of 'lock' and 'key' where enzyme and substrate fit each other perfectly and ***exclusively***

17. ***Denaturing** a protein involves physical alteration of the molecules as a result of **temperature** change or **pH** change*

Changes the ***shape*** of the enzyme

18. *The ease with which a protein is denatured is related to the susceptibility of enzymes to change temperature and pH*

19. *Enzymes are most efficient within a **narrow range** of temperature and pH*

The idea of 'optimum' conditions

Early plastics & fibres

20. ***Ethene** is a starting material of major importance in the petrochemical industry, especially for the manufacture of plastics*

Revision of standard grade: monomers, polymers, ***addition polymerisation***.

21. *Ethene can be formed by **cracking** the ethane from the gas fraction or by cracking the naphtha fraction from oil*

$$\text{e.g. } C_2H_6 \rightarrow C_2H_4 + H_2$$
$$C_6H_{14} \rightarrow C_2H_4 + C_4H_{10}$$

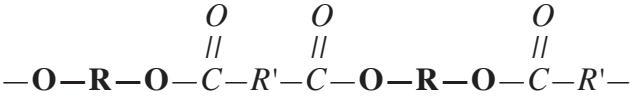
22. *Propene can be formed by **cracking** the propane from the gas fraction or by cracking the naphtha fraction from oil*

$$\text{e.g. } C_3H_8 \rightarrow C_3H_6 + H_2$$
$$C_6H_{14} \rightarrow C_3H_6 + C_3H_8$$

23. ***Condensation polymers** are made from monomers with **two functional groups** per molecule*

HO—R—OH HOOC—R—COOH
H_2N—R—NH_2 H_2N—R—COOH
HO—R—COOH etc

24. ***Polyesters** are examples of condensation polymers*



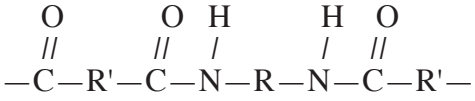
25. *Polyesters used for textile **fibres** have a **linear** structure whereas cured polyester **resins** have a **3-dimensional** structure*

To form a resin, momomers will normally require a ***third functional group*** to allow links between chains

26. *An amine can be identified from the functional group*

amino group, $-NH_2$ (also —NHR and —NRR')

27. *The **amide link** is formed by the reaction of an **amine** group with a **carboxyl** group*



28. ***Polyamides** are examples of condensation polymers*

29. *An example of a polyamide is **nylon** which is a very important **engineering plastic***

An engineering plastic is a plastic which can be used in place of metal for engineering applications

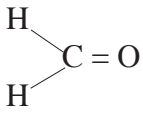
You will be expected to give ***examples*** of uses of nylon as an engineering plastic e.g. for machine parts

30. *The strength of nylon is related to the hydrogen bonding between polymer chains*

Nylon is far superior to poly(ethene) or poly(propene). The polymer chain in nylon need only be about half as long as poly(ethene) chains to show the same strength

The strong hydrogen bonds between nylon chains are the source of this strength. Nylon is also ***chemically unreactive*** in many environments

31. ***Methanal** is an important feedstock in the manufacture of **thermosetting** plastics*



32. *Methanol, a feedstock for methanal, is made industrially from **synthesis gas**, a mixture of carbon monoxide and hydrogen*

$$CO + H_2 \rightarrow CH_3OH \rightarrow CH_2O$$

33. *Synthesis gas can be obtained by **steam reforming** of methane (from natural gas) or by **steam reforming** of coal*

Always been a popular source of questions in the past. (See cover for scheme of reactions).

Recent Developments

New polymers have ranges of properties ***not available*** in traditional materials

A very important theme which runs through this section is the relationship between ***properties*** of a substance and its ***structure & bonding***.

34. ***Kevlar** is an **aromatic polyamide** which is extremely strong because of the way in which the rigid, linear molecules are packed together*

The strength of Kevlar is related to the packing together of ***sheets of molecules*** held together by ***hydrogen bonds***

35. *Kevlar has many important uses*

Kevlar is used to replace steel in the cords of car tyres.

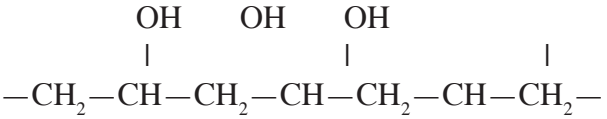
Kevlar ropes have 20 times the strength of steel ropes of the same weight.

Kevlar is used in aircraft wings, where its low density combined with its strength is important.

Kevlar is ideal for bullet-proof vests.

Leading racing motorcyclists wear protective suits containing Kevlar since its abrasion resistance is better than leather.

36. ***Poly(ethenol)*** *is a plastic which readily dissolves in water*



37. *Poly(ethenol) is made from another plastic by a process known as* ***ester exchange***

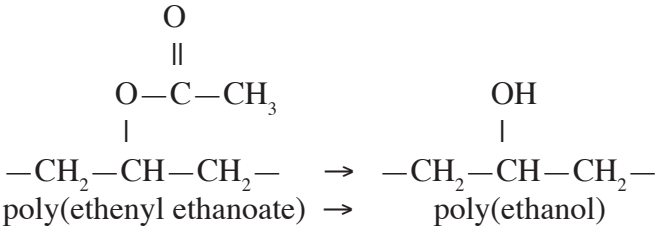
poly(ethenyl ethanoate) → poly(ethanol)

38. *Poly(ethenol) has many important uses*

Hospital laundry bags are designed to dissolve in the washing machine cutting down the risks of infection from handling the washing

Soluble threads are used as sutures or stitches in surgery. A decision is made about how quickly they should dissolve, and the appropriate thread is chosen.

39. *The percentage of acid groups which have been replaced by hydroxyl groups in the production process influences the* ***strengths of the intermolecular forces*** *upon which solubility depends*



poly(ethenyl ethanoate) → poly(ethanol)

The extent of reaction can be controlled by adjusting the ***temperature*** or the ***reaction time***:

% of OH groups	***solubility in water***
100-99	insoluble
98 - 97	soluble in hot water
96 - 90	soluble in warm water
below 90	soluble in cold water

If no ester groups are left, the strength of the intermolecular forces are too strong to allow the polymer to dissolve in water. The closer they get to the strength of forces between water molecules. the more soluble in water they become

40. ***Poly(ethyne)*** *can be treated to make a polymer which conducts electricity*

41. *The conductivity depends on the* ***delocalised electrons*** *along the polymer chain*

42. *Poly(ethyne) is used to make the membrane for high-performance loudspeakers*

43. ***Poly(vinylcarbazole)*** *is a polymer which exhibits photoconductivity and is used in photocopiers*

In many photocopying machines there is a metal drum coated with a very thin layer (about 10^{-5} cm thick) of poly(vinylcarbazole).

It conducts electricity much better when light shines on it than when it is in the dark - photoconductivity.

44. ***Biopol*** *is an example of a* ***biodegradable*** *polymer*

Biopol is a polyester made by living organisms and can be broken down by bacteria.

Biopol is the trade name for a ***family*** of polyesters, mainly poly(hydroxybutaneoate).

45. *The structure of low density polythene can be modified during manufacture to produce a* ***photodegradable*** *polymer*

A photodegradable polymer is broken down by sunlight.

Carbonyl groups (C=O) are introduced into the polymer chain. They absorb U.V. light. This energy causes bonds to break in the neighbourhood of the carbonyl group, and the polymer chain breaks down.