

FOOD CHEMISTRY

- F1 Food groups
- F2 Fats and oils
- F3 Shelf life
- F4 Colour
- F5 Genetically modified foods
- F6 Texture
- F9 Stereo-chemistry in food (HL)

(Note that HL material from F7, F8 and F10 has been integrated)



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Food chemistry is a study of the composition and properties of food, the chemical changes it undergoes during handling, processing and storage, and the principles underlying the improvement of food. The aim of this option is to give students an understanding of the chemistry of important molecules in food and the contribution that chemistry has made (and continues to make) towards maintaining and improving the quality and cost of food, adequacy of food supplies and food safety. Students should be able to recognize some important structures and relevant functional groups and to distinguish between them. It is not necessary to memorize complex formulas, as structures and examples of some food molecules are given in the *Chemistry data booklet*.

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materials required for essential bodily functions, as well as the building blocks for the growth and regeneration of our bodies. A balanced diet is vital for good health, hence the need to study the chemistry of food.

A food may be considered any substance that we deliberately take into our mouths and swallow. That is any natural or artificial material intended for human consumption. Ideally, a food must contain one or more nutrients. Some foods are rich in nutrients, whereas others have very little nutrient value. A **nutrient** is a component of food that is used by the body to provide energy, or for the growth and repair of tissue. The major nutrients are lipids, carbohydrates and proteins. Other nutrients are vitamins and minerals, which are required in much smaller quantities. Water, which is essential for biochemical processes to occur, is also considered a nutrient. A lack of these nutrients in the diet eventually gives rise to **malnourishment**.

Lipids (fats and oils) are esters of a glycerol (propan-1.2.3-triol) and three fatty acids (long chain carboxylic acids) as shown in Figure 1701.

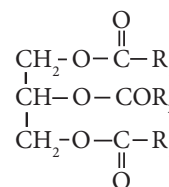


Figure 1701 The chemical structure of lipids

F1 FOOD GROUPS

- F.1.1 Distinguish between a food and a nutrient.
- F.1.2 Describe the chemical composition of lipids (fats and oils), carbohydrates and proteins.

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Like all matter, food is composed of chemicals. These chemicals are particularly important because they provide the fuel from which we gain our energy and the

OPTION

Here R_1 , R_2 and R_3 represent long hydrocarbon chains, which may be the same or may be different. The hydrocarbon chains may also be saturated, unsaturated (containing a carbon-carbon double bond) or poly-unsaturated (containing a number of carbon-carbon double bonds). The nature of the R group determines the physical and chemical properties of the lipid. For example, saturated fats tend to be solids at room temperature whereas unsaturated ones (as in vegetable oils) are liquids. Lipids are a source of energy and are also vital in constructing cell membranes.

Carbohydrates, as their name would imply, have the empirical formula CH_2O . **Monosaccharides** with the general formula $(CH_2O)_n$ ($n > 2$) are the simplest carbohydrates. Each monosaccharide contains one carbonyl group ($C=O$) and at least two hydroxyl groups ($-OH$). Condensation of two monosaccharides forms a **disaccharide**. Carbohydrates comprise sugars and polymers such as starch and cellulose derived from monosaccharides. The main function of carbohydrates is as a source of energy, though they are also used for cell construction. One of the simplest sugars is glucose, shown in Figure 1702.

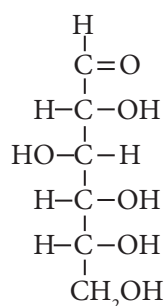


Figure 1702 The chemical structure of carbohydrates

Proteins are polymers of amino acids. All proteins contain C, H, O and N and some also have P and S. A typical section of a protein is shown in Figure 1703.

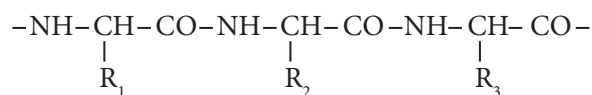


Figure 1703 The chemical structure of proteins

Here R_1 , R_2 and R_3 represent the side chains of the amino acids involved and they may be the same or different.

F2 FATS AND OILS

- F.2.1 Describe the difference in structure between saturated and unsaturated (mono- and poly-unsaturated) fatty acids.
- F.2.2 Predict the degree of crystallization (solidification) and melting point of fats and oils from their structure, and explain the relevance of this property in the home and in industry.
- F.2.3 Deduce the stability of fats and oils from their structure.
- F.2.4 Describe the process of hydrogenation of unsaturated fats.
- F.2.5 Discuss the advantages and disadvantages of hydrogenating fats and oils.

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As stated in the previous section, fats and oils (sometimes referred to collectively as lipids) are esters of glycerol (propan-1.2.3-triol) and fatty acids (long chain carboxylic acids). Refer back to Figure 1701.

The groups R_1 , R_2 and R_3 , which may be the same or different, represent hydrocarbon chains, typically 15-25 carbon atoms long, though in most oils and fats the total number of carbons in the chain (including the $-O-CO-$ one) is even because they are synthesised from two carbon units. These hydrocarbon chains may be saturated (all C-C bonds single), mono-unsaturated (containing one $C=C$) or poly-unsaturated (containing more than one $C=C$). In any given oil there is usually a mixture of chain lengths and degrees of saturation, though the relative proportions of these has an effect on the properties of the lipid.

Chemically oils and fats are similar, the main difference being in their melting point with fats being solid at room temperature and oils being liquid. The melting point of the lipid and hardness (degree of crystallinity) of the solid will depend on a number of factors:

- The mean length of the hydrocarbon chains.
- The degree of unsaturation.
- Whether the hydrocarbon chain is *cis*- or *trans*- around the double bond.

The longer the carbon chain, then the greater the molar mass, the stronger the van der Waals' forces and the higher the melting point. The presence of double bonds means that the hydrocarbon chain is less 'straight', so weakening the van der Waals' forces by reducing the close contact between the chains. As a result the greater the degree of unsaturation, the lower the melting point. The effect of double bonds on the 'straightness' of the hydrocarbon chain is much greater if these are *cis*- (H-atoms on the same side of the carbon chain) than if they are *trans*- (H-atoms on the opposite side of the carbon chain) as shown in Figure 1704.

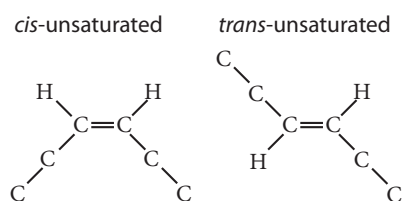


Figure 1704 *Cis and trans forms*

As a result *cis*-unsaturated oils (the sort most commonly found naturally) have lower melting points than the equivalent *trans*-unsaturated oils.

Lipids that are solids at room temperature (such as coconut fat, butter and lard) tend to have saturated hydrocarbon chains and form more crystalline solids which are relatively hard. Oils, which are liquid at room temperature and give less crystalline, softer solids when solidified, are unsaturated. Poly-unsaturated oils (such as sunflower oil, corn oil and fish oil) have lower melting points and form softer solids than mono-unsaturated oils (such as olive oil, canola oil and peanut oil).

As might be expected from the underlying chemistry (unsaturated hydrocarbons are much more reactive than saturated ones) unsaturated oils are less stable and therefore keep less well than saturated fats. The major problem is reaction of the carbon-carbon double bond with oxygen (**auto-oxidation**), especially in the presence of light (**photo-oxidation**), which is why the surface of margarine is often discoloured. Unsaturated lipids are also more prone to hydrogenation and hydrolysis as well as enzyme-catalysed degradation by microbes.

Unsaturated oils are often hydrogenated using hydrogen at high pressure and a temperature of about 200°C in the presence of catalysts such as nickel, to produce products that are more saturated and in some cases fully saturated, as shown in Figure 1705.

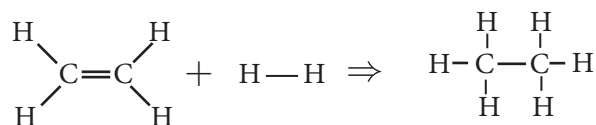


Figure 1705 *Using a catalyst to increase saturation*

Whilst this has some practical advantages, such as:

- the product is a semi-solid or solid, rather than a liquid, which is more convenient for some cooking techniques.
- the product is more stable because the rate of oxidation is decreased.
- the texture (hardness and plasticity) of the product can be controlled.

This comes at a health cost because mono- and poly-unsaturated fats are healthier for the heart than saturated fats. Also partial hydrogenation can lead to the formation of *trans*-fats which, as they do not occur naturally, are difficult to metabolise and hence they accumulate in the fatty tissues of the body. *Trans*-fats also cause an increase in the levels of LDL cholesterol, which can lead to atherosclerosis (narrowing of the arteries) and a resultant increase in the probability of strokes and heart problems.

F3 SHELF LIFE

F.3.1 Explain the meaning of the term shelf life.

F.3.2 Discuss the factors that affect the shelf life and quality of food.

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One problem with all foodstuffs is that they gradually degrade so that because of changes in flavour, smell, texture and appearance, or because of the growth of organisms, they become undesirable and/or unfit for consumption. The length of time a product can be stored without this occurring is known as its **shelf life** and obviously maximising shelf life is desirable.

This degradation can result from a number of different processes.

Change in water content as a result of contact with the air

Loss of water from moist foods can result in them becoming dry and changing in texture. The increased exposure to air of the solid food can result in an increase in the rate of oxidation leading to a decrease in nutrient value, discolouration of the surface and rancidity. Conversely if dry foods absorb water vapour from the air they become moist and more vulnerable to microbial degradation.

Chemical reaction

Chemical changes occurring within the food can result in pH changes (e.g. becoming sour) or the development of other undesirable flavours. Chemical changes can also result in colour changes in the food and a decrease in its nutritional value. The presence of oxygen often leads to oxidative degradation of foodstuffs.

Light

Light provides energy for photochemical reactions to occur leading to rancidity, the fading of the colour of foodstuffs and the oxidation of nutrients, especially vitamins.

Temperature

As with all chemical changes, an increase in temperature leads to an increase in the rate of degradation of foods.

Note that water is an important component of food. It determines its texture, softness and how juicy it is depending on how the water molecules are present. These can either be chemically bonded to carbohydrate and protein polar groups amongst others or be 'free' but linked via hydrogen bonding to protein and polysaccharides. A change in the forces of attraction that hold carbohydrate or protein chains in place will influence how much water it can hold. Thus a change in pH or increased temperature disrupts these forces, changing the amount of water it can hold and thus affecting texture, softness and how juicy it remains.

- F.3.3 Describe the rancidity of fats.
- F.3.4 Compare the processes of hydrolytic and oxidative rancidity in lipids.
- F.3.5 Describe ways to minimize the rate of rancidity and prolong the shelf life of food.
- F.3.6 Describe the traditional methods used by different cultures to extend the shelf life of foods.

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One common form of food degradation is **rancidity** in lipids. Rancidity is the development of unpleasant smells in fats and oils, which are often accompanied by changes in their texture and appearance. There are two distinct ways in which rancidity can develop; **hydrolytic rancidity** and **oxidative rancidity**. In the former, the ester bond is broken down in the presence of lipase, heat and moisture to yield free fatty acids. See Figure 1706.

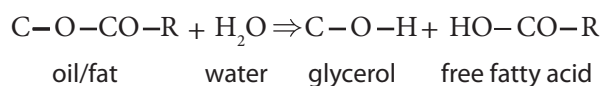


Figure 1706 Rancidity in lipids

The free fatty acids with 4-8 carbon atoms such as butanoic acid, hexanoic acid and octanoic acid have an unpleasant smell giving a rancid smell and taste to milk and butter (which is made from milk) that have been stored too long. Longer chain acids are less volatile, so the smell is less noticeable, but the presence of the free fatty acids such as palmitic, stearic and oleic acids or lauric acid affects the texture to give a fatty or soapy feel to the product, as for example in old samples of chocolate or cocoa butter. The rate of hydrolysis is significantly increased by the presence of enzymes, such as lipase, produced by micro-organisms and deep frying, can produce a hydrolytic reaction between the cooking oil and moisture in the food.

A second way in which rancidity occurs is oxidative rancidity (auto-oxidation) which involves the reaction of the carbon-carbon double bond in unsaturated lipids with oxygen from the air. This results in complex free radical reactions to produce a wide variety of products, many of which have unpleasant odours or tastes. The presence of light (which can produce free radicals leading to photo-oxidation), and of enzymes produced by, for example, micro-organisms, accelerates the rate at which oxidative rancidity occurs. Obviously this is much less of a problem with saturated lipids, but in highly unsaturated lipids, such as fish oils, oxidative rancidity can be a major problem.

HL F.7.1 Describe the steps in the free-radical chain mechanism occurring during oxidative rancidity.

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Auto-oxidation is a free radical process chain reaction that involves the reaction of oxygen molecules with the double bonds of unsaturated lipids. Like other free radical chain reactions there are three stages to the reaction:

Initiation

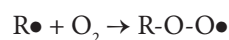
The initial formation of free radicals has a very high activation energy and usually occurs by exposure of unsaturated lipids to light (photo-oxidation) which causes homolytic fission of a carbon-hydrogen bond:



Initiation may also occur as a result of the decomposition of hydroperoxides, a product of the reaction, catalysed by traces of transition metal ions.

Propagation

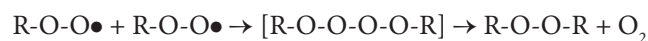
Once formed the hydrocarbon free radicals react rapidly with oxygen molecules to form peroxide radicals, which then abstract hydrogen from other substrate molecules reforming the hydrocarbon radicals:



These propagation reactions continue until a termination reaction destroys the free radicals. As these involve radicals encountering each other they are relatively rare and so one initiation step can produce very many hydroperoxide products.

Termination

This involves the removal of free radicals from the system by reactions between radicals. An inspection of the propagation steps above shows that there are three possible combinations:



The hydroperoxides formed (R-O-O-H) in the propagation step are very reactive molecules and are gradually converted to aldehydes and ketones. These, and the long chain fatty acids that the aldehydes are further oxidised to, have unpleasant smells and tastes and it is these that are responsible for the spoiling of the food.

Increasing the time required for the onset of rancidity is a major factor in increasing the shelf life of products containing high proportions of oils and fats. There are number of ways in which rancidity can be controlled:

Packaging

Using opaque packaging and coloured glass bottles will reduce light induced oxidative rancidity. Gas impermeable wrapping film will reduce the exposure of the product to oxygen and water vapour in the air and the free space in the container should be kept to a minimum to reduce the amounts of these present. Even better is vacuum packaging or filling the package with an inert gas. A good example is potato crisps which are usually packed in thick foil packets filled with nitrogen.

Storage

Refrigeration will reduce the rate of most reactions that produce rancidity and storing fat and oil rich foods in the dark will reduce the rate of photo-oxidation, which is less affected by temperature. Dairy products for example are almost always stored at low temperatures. Reducing the water level, by *drying* or *smoking*, and then storing away from moisture reduces hydrolytic rancidity and discourages the growth of micro-organisms.

Additives

There are many substances that can be added to foodstuffs to reduce the occurrence of rancidity. Some processing, for example **salting** (as in preparing bacon) and having a high sugar content (as in **preserves**), reduces the amount of water in the foodstuff by osmosis. This reduces the rate of hydrolytic rancidity as well as making the environment less suitable for the growth of micro-organisms. Other substances, such as sulfur dioxide and sodium sulfites used

with fruit products, along with sodium and potassium nitrites and nitrates used in curing meats, are reducing agents and prevent the oxidative reactions that for example lead to the browning of many substances when stored too long.

Anti-microbial agents

Many methods of delaying the onset of rancidity depend on preventing the growth of micro-organisms in the foodstuff. Traditionally in **pickling** the use of vinegar creates an environment that is too acidic for micro-organisms. Many other organic acids and their salts (indicating that this is not purely a pH effect) are added to discourage the growth of moulds and bacteria in foods. Specific examples include the addition of benzoic acid and sodium benzoate to fruit juices as well as propanoic acid, along with its sodium and calcium salts, to bread and cheese. **Fermentation** also produces ethanol which limits bacterial growth, so wine keeps much better than fresh fruit juice and distilled spirits, with an even higher alcohol concentration, last longer still.

Quite a few of the methods mentioned above, particularly those in **bold**, have been traditionally used by cultures worldwide for many centuries to preserve foodstuffs.

- F.3.7 Define the term antioxidant.
- F.3.8 List examples of common naturally occurring antioxidants and their sources.
- F.3.9 Compare the structural features of the major synthetic antioxidants in food.
- F.3.10 Discuss the advantages and disadvantages associated with natural and synthetic antioxidants.
- F.3.11 List some antioxidants found in the traditional foods of different cultures that may have health benefits.

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An **antioxidant** is a substance that can be added to food to increase its shelf life by delaying the onset of oxidative degradation. Many of the antioxidants work by reacting with oxygen containing free radicals, so preventing these species degrading food by, for example, oxidative rancidity. There are many naturally occurring antioxidants present in foods, common examples being:

- Vitamin C (ascorbic acid) - found in citrus fruits and most green vegetables.
- Vitamin E (a tocopherol) - found in nuts, seeds, soya beans, whole grains, and some vegetable oils like canola oil.
- β -carotene - found in vegetables such as carrots and broccoli as well as fruits such as tomatoes and peaches.
- Selenium – an important trace element found in fish, shellfish, meat, eggs and grains.

Increasingly, synthetic antioxidants are being added to foodstuffs to increase their shelf life. Some of the most common are BHA (2- and 3-tert-butyl-4-hydroxyanisole), BHT (3,5-di-tert-butyl-4-hydroxytoluene), PG (propyl gallate), THBP (2,4,5-trihydroxybutyrophenone) and TBHQ (tertbutylhydroquinone). Almost all have phenolic type structures, that is they have a hydroxyl group attached to a benzene ring, a structural feature that is not found in naturally occurring antioxidants. The use of synthetic antioxidants is not without controversy as there are many who feel that they can have harmful side effects, but there is no clear evidence on the issue. Studies have however shown that naturally occurring antioxidants, such as vitamin C, vitamin E and β -carotene reduce the risk of cancer and heart disease by reacting with free radicals. There are also other health benefits of these as vitamin C is vital for the production of hormones and collagen, whilst β -carotene can act as a precursor for vitamin A. Even though synthetic antioxidants are more effective than the natural ones. they require strictly enforced codes for their safe use in foods. These may be difficult to police, especially in developing countries and many feel that their safety has yet to be satisfactorily proven.

That being said many substances traditionally used in different cultures as promoting good health are rich in natural antioxidants. Common examples of such foods include green tea, turmeric, oregano, blueberries, cranberries and dark chocolate. Many claims are made for these such as the lowering levels of LDL cholesterol, blood sugar levels and high blood pressure as well as preventing cancerous cell development. In many cases these claims have not been subjected to the stringent tests of modern science.

F.8.1 Explain the differences between the three main types of antioxidants.

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The antioxidants added to foods may interfere with the auto-oxidation process in a number of ways:

FREE RADICAL QUENCHERS

These are species (represented as H-A in the equation below) that react with the free radicals present and produce less reactive free radicals (A• in the mechanism below):



There are also many naturally occurring antioxidants, such as tocopherol (vitamin E) that can be used as free radical quenchers and many people prefer these to synthetic antioxidants such as BHA (2- and 3-tert-butyl-4-hydroxyanisole), TBHQ (tertbutylhydroquinone) and BHT (3,5-di-tert-butyl-4-hydroxytoluene).

CHELATING AGENTS

Free radicals may be formed by the reaction of transition metal ions with the hydroperoxides initially produced by the auto-oxidation reaction, for example:



Chelating reagents form very stable complex ions with transition metals and hence reduce the occurrence of these reactions. Many plants such as rosemary, tea and mustard, contain natural chelating agents. Salts of EDTA (ethylenediaminetetraacetic acid) are sometimes added as artificial chelating agents.

REDUCING AGENTS

Reducing agents (electron donors) can react with both oxygen in the food and with the hydroperoxides initially produced by auto-oxidation. Examples of naturally occurring reducing agents include ascorbic acid (vitamin C) and carotenoids. Artificial preservatives that are reducing agents, such as sulfur dioxide, sulfites and nitrites, may act in a similar manner.

F4 COLOUR

F.4.1 Distinguish between a dye and a pigment.

F.4.2 Explain the occurrence of colour in naturally occurring pigments.

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Many foods have distinctive colours and we often use the appearance of the food to judge its quality and freshness. The colouring materials naturally present in foods are referred to as **pigments**, but **dyes** (i.e. coloured compounds, either synthetic or from a different natural source) are often added to enhance the appearance of processed products. These dyes, which are usually water soluble, have to be thoroughly tested to prove that they are safe for human consumption. Both groups of compounds owe their colour to the fact that they absorb certain frequencies of visible light, whilst reflecting others which are able to stimulate the retina in the eye. For example green spinach looks green because it absorbs red light and blue light, but **does not** absorb (and hence reflects) green light.

Note that the structures of the pigments shown overleaf all involve extensive delocalised π -bonds (HL material).

F.4.3 Describe the range of colours and sources of the naturally occurring pigments anthocyanins, carotenoids, chlorophyll and heme.

F.4.4 Describe the factors that affect the colour stability of anthocyanins, carotenoids, chlorophyll and heme.

F.10.1 Compare the similarities and differences in the structures of the natural pigments: anthocyanins, carotenoids, chlorophyll and heme.

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There are various groups of compounds that are found as natural pigments in foods. Some of the most common of these are listed below along with the way that cooking, which, as well as subjecting them to heat, may involve changes of pH and an acceleration of oxidative reactions which can modify their colour:

ANTHOCYANINS

These are the most commonly found pigments. They are responsible for red, pink, purple and blue colours found in berries as well as the colour of beetroot and red cabbage. **Anthocyanins** also cause the colour of many flowers. Some typical anthocyanins are shown below; it will be noted that they all have very similar 3-ring $C_6C_3C_6$ structures with conjugated double bonds, but they vary in the number and position of the hydroxyl groups and alkoxy side chains. Anthocyanins are often found bonded to sugar side chains which also modify their precise colour. Refer to Figure 1707.

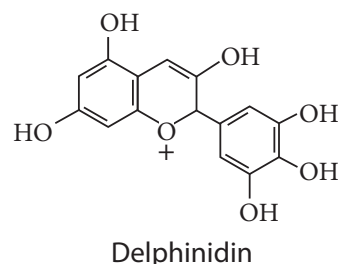
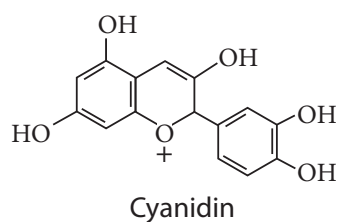
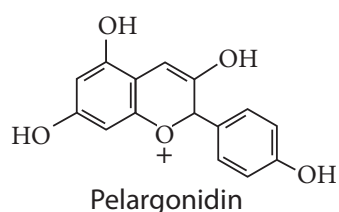


Figure 1707 The structure of some anthocyanins

The structure of anthocyanins is very dependent on pH, not only because of acid base effects, but also because of the effect of pH on the ease of hydration reactions. As a result the colour of foods coloured by anthocyanins can vary significantly during the cooking process, especially when mixed with acidic or alkaline ingredients. Anthocyanins form complex ions with metal ions such as Fe^{3+} and Al^{3+} , hence prolonged contact with these metals, from which saucepans are often made, may also contribute to changes in colour during the cooking process. At high temperatures, like many organic compounds, anthocyanins decompose and this may lead to browning in some cooking processes.

There are four closely related structural forms of anthocyanins which are often in equilibrium, the exact position depending on factors such as pH and temperature, which allows these compounds to be used as acid-base indicators. The most brightly coloured forms (A and B below) however are stable at low temperature and, for A, at low pH. The structures of these forms and the equilibria linking them are illustrated below, with the changes in structure highlighted:

The absorption spectra of the anthocyanins therefore vary with pH, causing the colour changes discussed above. At low pH the flavylium cation (AH^+) predominates and the mixture is red, at neutral pH values there is a sufficient concentration of hydroxide ions for this to hydrolyse and the solution becomes almost colourless as it is converted to the carbinol pseudobase (B) and chalcone (C). At even greater pHs the flavylium cation (AH^+) in equilibrium with this is converted to the quinoidal base (A) so all the equilibria are shifted to yield this product and the solution turns blue. This is illustrated in the Figures 1708 and 1709.

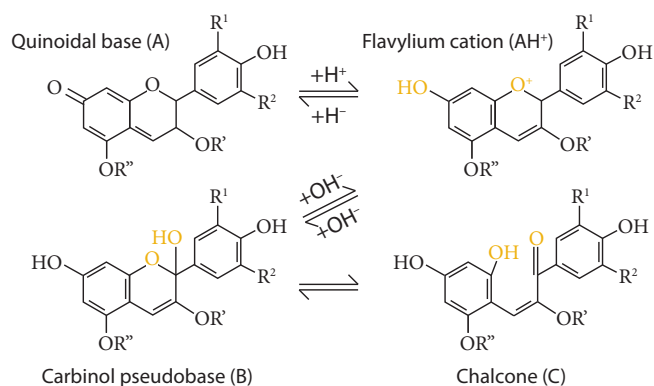


Figure 1708 Colour changes in anthocyanins

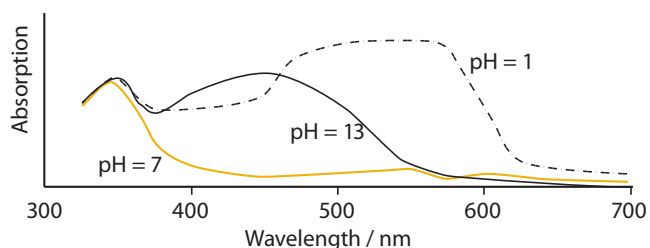


Figure 1709 Absorption of anthocyanins at various pH levels

Flavanones, of which quercetin (shown below) found as the colouring material in red grapes and many berries is a typical example, are closely related to anthocyanins. See Figure 1710.

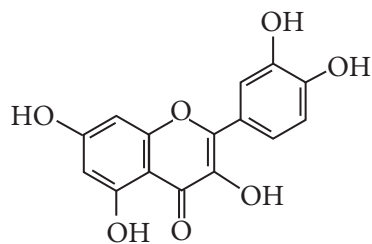


Figure 1710 Quercetin

Carotenoids – These are widely found in all living things, especially in algae. They are responsible for yellow, orange and red colours and, as well as being responsible for the colour of carrots, they cause the colour in bananas, tomatoes and saffron. Because their low levels in grass are concentrated in milk fats they also give butter its colour. Carotenoids also have nutritional value because they can be converted into vitamin A, as well as being effective antioxidants. The structures of some typical carotenoids are illustrated below. The essential feature of carotenoids is the long hydrocarbon chain, which may also have methyl groups attached. In some cases there may be ring structures at the ends of the chain, in other cases not. Similarly some carotenoids have hydroxyl groups near the end of the chain or on the ring, whereas others, sometimes called **carotenes** (see Figures 1711, 1712), have a hydrocarbon structure. Vitamin A, as can be seen from Figure 1713, is very closely related to the carotenes which act as precursors for it.

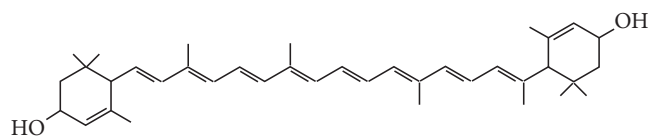


Figure 1711 Xanthophyll – a typical carotenoid

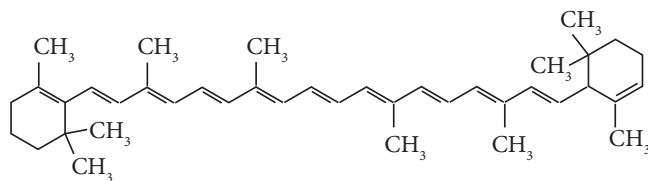


Figure 1712 Beta-carotene

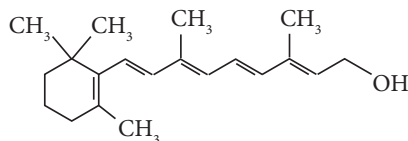


Figure 1713 Vitamin A

Carotenoids are stable under most conditions used for processing foods so little loss of colour occurs, though heating can cause some discolouration and the *trans*-

coordination around double bonds to change to *cis*-coordination. The presence of the polyunsaturated hydrocarbon chain means that, like poly unsaturated oils carotenoids are subject to oxidative degradation. As could be expected, this is accelerated by light, which can produce hydroperoxide free radicals and which is catalysed by the presence of transition metal ions. This oxidation as well as causing discoloration also means that the carotenoids can no longer be converted to vitamin A.

Astaxanthin is a red pigment closely related to carotenoids (compare the structures). When it is found naturally it is usually bonded to proteins, which modify the frequencies of light it absorbs so that it gives the blue and green colours found in live lobsters and crabs. High temperatures disrupt the bonding to the protein, hence the startling change in colour when these animals are cooked. Like carotenoids it acts as an antioxidant, hence the health benefits ascribed to eating the shells of shrimps and prawns. This pigment is also responsible for the pink colour of salmon meat.

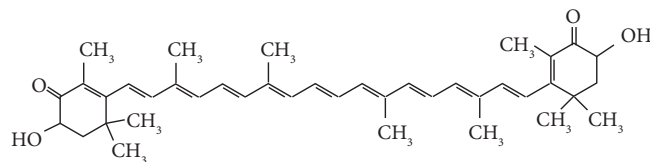


Figure 1714 Astaxanthin

CHLOROPHYLL

This is the green coloured pigment responsible for catalysing the photosynthetic process in green plants and hence is widely found in green vegetables. In the structure (See Figure 1415), which is actually that of chlorophyll a, note the presence of magnesium at the centre of the ring. There are actually two very closely related forms of chlorophyll, chlorophyll a and chlorophyll b, which differ only in whether a side chain is a methyl group (a) or an aldehyde group (b).

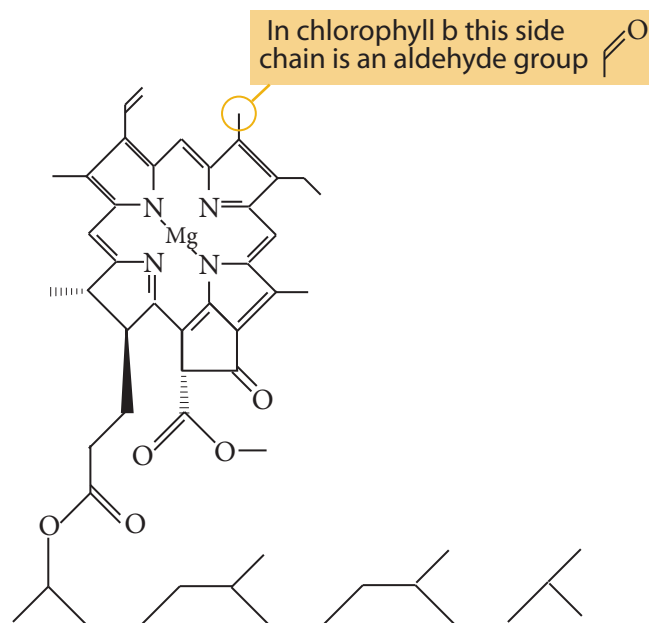


Figure 1715 Chlorophyll a and b

During cooking plant cells break down and this releases acids, decreasing the pH of the solution. Whilst stable in neutral and alkaline solution, in acidic solution hydrogen ions displace the magnesium ion from the ring into solution, resulting in a colour change to olive-brown. These changes also make the pigment less stable to light and **photodegradation** can occur.

HEME

This is the red pigment found in the red blood cells of higher animals. Its structure is shown in Figure 1716. Note the similarity of structure to that of chlorophyll, but in this case iron(II), rather than magnesium is found at the centre of the ring. The essential features of both chlorophyll and heme are the planar ring systems in which the metal ion is bonded to four nitrogen atoms, which act as **ligands**. This is referred to as a **porphyrin ring**.

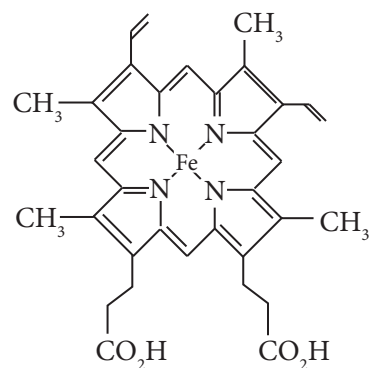
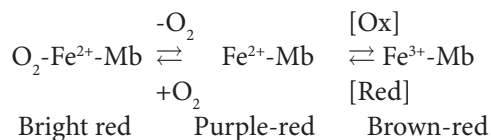


Figure 1716 The Heme group

In muscles, heme is found associated with **myoglobin**, a protein molecule, and this has a purplish-red colour. It binds easily to oxygen molecules, hence its role in oxygen transportation, and this results in a colour change to bright red. A much slower reaction with oxygen, called **auto-oxidation**, results in the oxidation of the iron from iron(II) to iron(III), forming **metmyoglobin** and the colour changes to a brownish red colour, which is considered less desirable. These changes are summarised in the diagram below:



The colour of the meat can be preserved by storing it in an oxygen free environment, by vacuum packing it, or packing it in an inert gas (such as CO_2), using polymers with low gas permeability.

F.10.2 Explain why anthocyanins, carotenoids, chlorophyll and heme form coloured compounds while many other organic molecules are colourless.

F.10.3 Deduce whether anthocyanins and carotenoids are water- or fat-soluble from their structures.

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It is interesting to enquire why all of these compounds absorb light in the visible region of the spectrum and hence appear coloured. The answer to this is that they all have extensive systems of delocalised π -bonding. The greater the extent of delocalisation, the closer together in energy the bonding and antibonding π -orbitals become. Hence the region in which photons can excite an electron from one to the other shifts from the ultraviolet region

(as in benzene) into the visible region. In the structures drawn the extensive system of delocalisation is indicated by alternate single and double bonds ('conjugated' double bonds). In anthocyanins this can be seen to extend over all three rings and closely related molecules in which this does not occur (such as **carbinol**, see below, in which it is disrupted by the sp^3 hybridised carbon indicated). See Figure 1717.

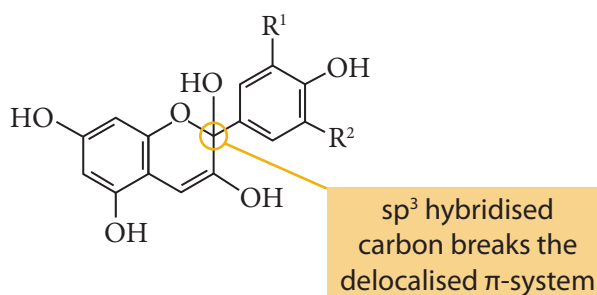


Figure 1717 Carbinol

In carotenoids, even though the rings themselves are not fully delocalised, the delocalised system spreads from the sections of the rings closest to the chain and along the entire hydrocarbon chain. In chlorophyll and heme the delocalised system is essentially the ring that surrounds the central metal ion, though it does extend slightly into some of the side chains. The colour of the food depends on the reflected rather than the absorbed light, hence chlorophyll, which absorbs red and blue light, appears green because light of this wavelength is reflected rather than absorbed.

It can be seen that anthocyanins have many hydroxyl groups attached to their ring structure. These can hydrogen bond to water molecules and as a result anthocyanins tend to be water soluble. In contrast carotenoids have a long hydrophobic hydrocarbon chain and the hydroxyl groups on the rings are not sufficient to confer water solubility, so carotenoids are soluble in oils and fats.

F.4.5 Discuss the safety issues associated with the use of synthetic colourants in food.

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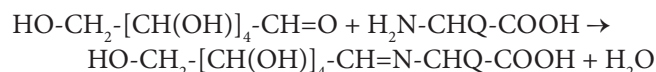
Many synthetic dyes are quite biochemically active and hence pose health threats. It is obviously important that such materials are not used to colour foodstuffs, hence in most countries the dyes that can be used in foods are regulated and there are authorities responsible for testing and licensing food additives. Unfortunately there are no international standards on this and colouring materials permitted in one country may be banned in another, posing

difficulties for international trade. Synthetic dyes, such as malachite green and sudan red, are sometimes found in imported foodstuffs even though they are not permitted in many countries. Another problem is that whilst short term, acute toxicity is easy to test for, chronic effects are less easy to prove, especially with substances that may be suspected of having long term carcinogenic effects.

F.4.6 Compare the two processes of non-enzymatic browning (Maillard reaction) and caramelization that cause the browning of food.

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Cooking foods often causes them to turn brown and this colour change is often used as an indication of whether they have been sufficiently cooked. There are two distinct processes that lead to this colour change. The first process is known as the **Maillard reactions** (after the French chemist Louis-Camille Maillard). These are responsible for the smell and colour change of many common cooking processes, such as grilling meat, toasting bread, malting barley and making fudge (Maillard reactions are also used in some self-tanning treatments.). In these condensation reactions the aldehyde group in reducing sugars (such as glucose and lactose) reacts with the free amino group of an amino acid, or amino groups on the side chains of peptides and proteins. Because there is such a variety of possible reactants, many Maillard reactions are known and over a thousand different products have been identified. The polymeric ones are often brown and hence responsible for the colour change, whilst the lower molar mass products are thought to be responsible for many of the aromas of cooking and resulting changes in flavour. The equation for the first stage of these reactions can be written as:

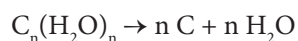


Reducing sugar + Amino acid → Initial condensation product

The initial products then polymerise to form brown pigments (known as melanoidins). Maillard reactions usually only occur at temperatures over about 140°C, though their rate varies significantly, especially with the nature of the amino acid involved. Cysteine is one of the least reactive, whereas lysine is much more reactive, so foods that contain a lot of this (such as milk) brown readily (as for example in the formation of fudge).

The second process is referred to as **caramelisation**. This occurs when foods with a high carbohydrate concentration,

especially sugars, are heated and start to dehydrate. Initially this process leads to polymerisation and produces a wide variety of products responsible for the appearance of the brown colouration. If continued this eventually leads to the production of carbon and the burning of the food:



The rate of caramelisation varies with the sugar involved, with fructose, found in fruits, being the most easily caramelised. Extremes of pH, both high and low, also promote caramelisation. Because the Maillard reaction requires proteins or amino acids, the browning of foods that do not contain these, such as making toffee from sugar, or the crisp sugar topping of *crème brûlée*, results from caramelisation. In practice however the browning of food on cooking usually involves both processes.

F5 GENETICALLY MODIFIED FOODS

F.5.1 Define a genetically modified (GM) food.

F.5.2 Discuss the benefits and concerns of using GM foods.

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Modern biological techniques mean that it is possible to artificially modify the DNA sequence of micro-organisms, plants and animals. Using organisms modified in this way, it is possible to produce foods that are different from those that occur naturally. Foods produced from these organisms are collectively known as genetically modified (or GM) foods. There are a number of possible advantages to GM foods, some of which are listed below.

Pest and disease resistance

The yields from many plants and animals are reduced by pests and diseases. **Genetic modification** can increase their resistance to these, reducing the need to treat with herbicides, pesticides, vaccines etc., all of which add to production costs and may leave potentially toxic residues in the food. Examples are the production of potatoes that are resistant to fungal diseases and bananas that are resistant to attack by nematodes.

Improved quality and range

Many crops are geographically limited because of the conditions required for their growth. Genetic modification can enable the production of varieties that can grow in a wider range of climatic conditions as well as produce greater yields and mature in a shorter time. Examples are the development of higher yielding rice varieties and maize that can grow in areas of lower rainfall.

Production of medicinal and other novel products

Genetic modification can be used to enable plants and animals to produce products that they would not normally produce, such as biologically active molecules that can be used as medicines. Examples are GM hens that lay eggs containing human interferon and cows that produce milk rich in nutritionally desirable omega-3 fatty acids.

There are however many people and organisations that are very concerned about the proliferation of genetically modified organisms and food produced from them. The main reasons for this concern are:

Are GM foods safe?

Some people who have no problems with natural foods will develop allergic reactions to GM varieties. The composition of GM foods may be different from the equivalent natural foods and hence subtly alter the balance of our diets.

Will the production of GM foods damage natural ecosystems?

Even though genetically modified plants are currently limited to certain farms, there is the risk that pollen from them will escape into the wild population with unforeseen consequences.

Do we understand enough about genetic modification?

Genetic modification is a relatively recent technique. Do scientists understand enough about the process, or could we be tampering with things that could have a catastrophic effect we currently cannot predict?

F6 TEXTURE

- F.6.1 Describe a dispersed system in food.
- F.6.2 Distinguish between the following types of dispersed systems: suspensions, emulsions and foams in food.
- F.6.3 Describe the action of emulsifiers.

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TOK What conflict of concepts and values are raised by GM foods?

If you have studied Option D you may remember the TOK Box on scientific responsibility and if you studied Option E I said a little about ‘reasonable doubt’ and the impartiality of scientific opinion. These two concepts sort of come together in the idea of ‘acceptable risk’ which is what probably governs the GM food debate. I don’t think any scientist maintains that it is totally risk free, nor does any environmentalist deny that there are huge potential advantages. The debate would seem to be over whether one justifies the other. Facts, even when agreed on by both sides of the debate (in itself a rarity), can sometimes be manipulated by statistics to back both causes, but it is rare to see a debate on this issue that centres around the differing interpretations of agreed facts, or even the reasons why one side finds unacceptable a particular body of evidence quoted by the other side.

Our scientific name is *Homo sapiens*, but maybe *Homo emotionalis* might be more appropriate? Do we use logic for the important decisions in life – which university to go to, who to get married to, what kind of pizza to order? The answer is a resounding “No”. We might use logic to narrow things down a little bit (e.g. with the weather, food and friends) but when it comes down to it our final call is a gut reaction, an emotional one. Knowing that, both sides have tried to move the discussion to an emotional level, though this has been achieved with spectacularly more success by the environmentalist lobby. *Do a search with Google to see what I mean.*

The texture of food depends on its physical properties, such as its hardness and its elasticity. These are almost always affected by cooking, such as meat and vegetables becoming softer as their cell structure breaks on heating or biscuits becoming crisp as water is lost. Contrasts in texture, such as a crisp crust on soft bread, are very attractive to the palate. A creamy texture is something that is often sought in foods and often this comes from a **disperse system**, i.e. a stabilised, macroscopically homogenous mixture of two immiscible phases. There are many types of disperse systems and their naming depends on the physical states of the components, those most important in food chemistry all contain a liquid as one component:

LIQUID-SOLID

In fact there are two types of disperse liquid-solid systems that do not separate; a **suspension** or **sol** comprises solid particles suspended in a liquid, whereas a **gel** has liquid particles suspended in a solid medium. An example of a sol would be blood in which the solid red and white cells remain suspended in the plasma, or the fine precipitate of sulfur that forms when very dilute acid is added to aqueous sodium thiosulfate. A fruit jelly, in which water is trapped in a protein matrix would be an example of a gel.

LIQUID-LIQUID

A stable blend of two immiscible liquids is known as an **emulsion**. Mayonnaise, which is a suspension of oil droplets in an aqueous system would be a good example.

LIQUID-GAS

Again there are two types of stable disperse liquid-gas systems. **Foams** are comprised of gas bubbles trapped in a liquid medium. Whipped cream or egg whites, would provide a good example. **Aerosols**, which comprise liquid droplets suspended in a gas, may well be responsible for many of the smells of food and cooking.

A question that arises with disperse systems is why they do not separate. In fact often they do, but only very slowly. Gravity, coupled with the differing densities of the components will often cause a disperse system to slowly settle out. Some disperse systems, referred to as **colloids**, do not however separate. Often this is because the suspended particles are electrically charged and hence repel each other. In food preparation substances, known as **emulsifiers**, are frequently used to promote mixing of the two phases, and stabilisers are often added to slow down

their separation. Emulsifiers are molecules that can bond to both phases so they are found at the surface between the phases and hence are known as **surfactants**. This is very similar to the action of soap as shown in Figure 1718.

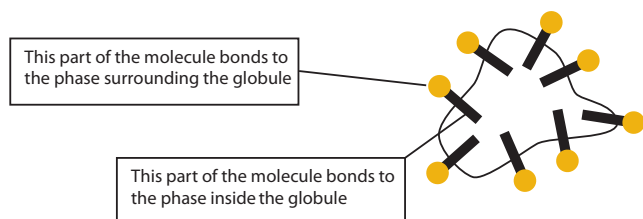


Figure 1718 The action of soap

In food preparation one of the most commonly used emulsifiers is lecithin, a phospholipid which occurs naturally in egg yolks. As can be seen from its structure below, lecithin has many charge centres and oxygen atoms at one end of the molecule which bond strongly to water (hydrophilic). It also has two hydrocarbon chains which will tend to break the hydrogen bonds in water, but be unable to form any bonds of their own to replace these. As a result these parts of the molecule will avoid water (hydrophobic) and bond to the non-aqueous phase. See Figure 1719.

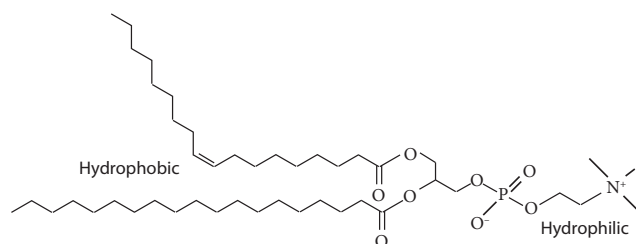


Figure 1719 Lecithin is an emulsifier

In mayonnaise, made by beating oil and vinegar with egg yolks, the hydrophilic end of lecithin will bond to the vinegar and the hydrophobic hydrocarbon tails will bond to the oil. Each oil droplet will therefore be surrounded by a layer of lecithin molecules. Note that it is important to physically beat the mixture so that small droplets of the suspended phase are formed, maximising the surface area on which the surfactant can be adsorbed. Stabilisers are often also added to stabilise disperse states. Inorganic phosphates, such as trisodium phosphate, are effective at stabilising emulsions. Chefs often prefer metal bowls for beating egg whites and recent research has shown that minute traces of the metal are in fact incorporated into the foam and stabilise it.

F9 STEREO-CHEMISTRY IN FOOD

F.9.1 Explain the three different conventions used for naming the different enantiomeric forms.

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You may recall that if a molecule contains a chiral carbon atom (one that is bonded to four different groups) then two distinct spatial arrangements of the molecule, called enantiomers, are possible. These enantiomers are mirror images of each other and have identical physical and chemical properties, except that one of them will rotate the plane of polarisation of plane polarised light in a clockwise direction, whilst the other will rotate the plane of polarisation of plane polarised light in an anticlockwise direction. The clockwise rotating enantiomer is said to be **dextrorotatory**, {+ or (*d*)}, and has a positive specific rotation value, whilst the other enantiomer is said to be **laevorotatory**, {- or (*l*)}, and it has a negative specific rotation value. Whether it is dextrorotatory or laevorotatory does not however give any indication as to the spatial arrangement of the components, their absolute configuration. Unfortunately there are two separate systems used to indicate this.

The first system, known as the D,L system (it is most unfortunate that upper case D and L are used for this and lower case *d* and *l* for the totally unrelated dextrorotatory and laevorotatory) is an older convention and used for sugars and amino acids. In this the absolute configuration of the molecule is related to that of glyceraldehyde, the absolute configuration of which was defined originally by guesswork. Fortunately a correct guess now confirmed by X-ray crystallography. See Figure 1720.

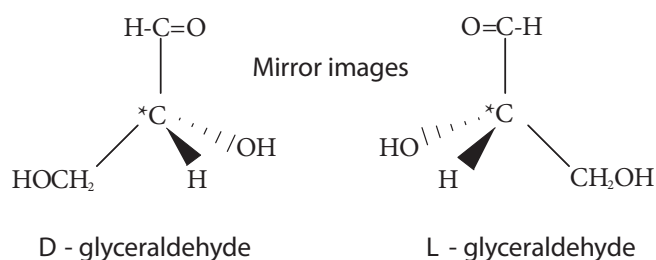


Figure 1720 D and L forms of glyceraldehyde

The absolute configuration of other sugars about each chiral centre is then named by analogy, that is, if the molecule is

viewed along the chain with the C=O pointed away, the D-isomer has the -OH group on the right. The system is also applied to amino-acids, where a useful rule of thumb is the 'CORN' rule. The molecule is viewed with the C-H bond pointing away from the observer (fortunately the same as in the R,S system below). If the groups COOH, R, NH₂ (where R- is the side chain) are arranged clockwise around the carbon atom then it is the D-form. If anticlockwise, it is the L-form.

Consider applying this to the alanine (2-aminopropanoic acid) enantiomer illustrated in Figure 1721.

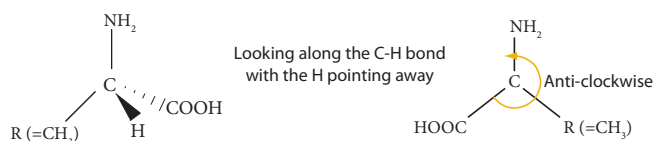


Figure 1721 The 'CORN' rule

It can therefore be seen, applying the 'CORN' rule, that this is L-alanine (COOH → R → NH₂ anticlockwise). In fact almost all naturally occurring amino acids are the L-form. These are usually tasteless, whereas the synthetic D-amino acids taste sweet. Conversely most naturally occurring sugars are the D-form, which taste sweet. Often the enantiomer that does not occur naturally cannot be metabolised by our bodies.

The second system, the R,S system (or CIP system, after Cahn, Ingold and Prelog, who first proposed it) is used for most other groups of compounds. In this system there are three steps:

1. The atoms bonded to the chiral carbon are ranked in order of increasing atomic number (H < C < N < O < F < Cl < Br for the most common atoms).
2. Where two or more atoms have the same atomic number (e.g. there are two C-atoms, one a -CH₃ and the other a -COOH), the second atoms are used to rank the substituents (so in this case the order would be -CH₃ < -COOH as 3 × atomic number of H is less than that of O). If the second atoms are also the same, the sums on the third are used, and so on (in this case a double bond counts as double, so that the -COOH would be equal to 3 × O).
3. Imagine you are viewing the molecule with the lowest ranking substituent pointing away from you, the other three substituents must either decrease in order in a clockwise direction, in which case it is the R-enantiomer, or they must

decrease in an anticlockwise direction, in which case it is the S-enantiomer.

Consider applying these to 2-bromobutane as shown in Figure 1722.

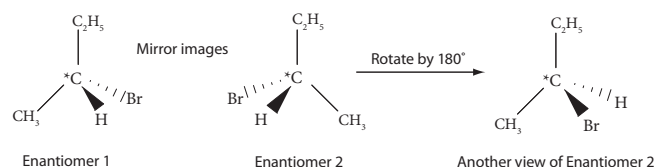


Figure 1722 The CIP system

1. Applying the first rule, the order of the substituents attached to the central carbon is H < (C,C) < Br.
2. Applying the second rule, the order of the two carbons is CH₃ < CH₂-CH₃ (as 3 × H < C), so the complete order is H < CH₃ < C₂H₅ < Br.
3. Consider looking at the two enantiomers with the C-H bond pointing away from you (so the H-atom is below the page). The order of the substituents will be:

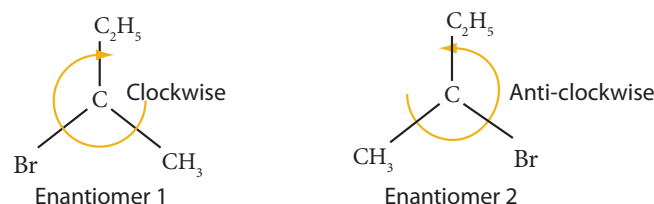


Figure 1723

It can be seen that in Enantiomer 1 the order decreases clockwise and in Enantiomer 2 the order decreases anticlockwise. Enantiomer 1 is therefore R-2-bromobutane and Enantiomer 2 is S-2-bromobutane.

F.9.2 Distinguish between the properties of the different enantiomeric forms of stereoisomers found in food.

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Even though they are so similar, different enantiomeric forms of molecules found in food often have different smells, tastes and toxicity. One well known example of this is the molecule **carvone**, a terpenoid. Refer to Figure 1724

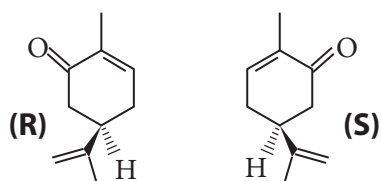


Figure 1724 R and S forms of the molecule carvone

The R-form (which is laevorotatory, has a smell and flavour of spearmint, whilst the S-form has a smell and flavour of caraway seeds. Similarly the closely related molecule limonene has a $+(d)$ -enantiomer which smells of oranges and a $-(l)$ -enantiomer that smells of lemons.

Sometimes a natural flavour is a pure enantiomer, because biosynthesis tends to be stereospecific, whereas the synthetic equivalent is often a racemic mixture (a mixture of equal amounts of the enantiomers) because this is much easier to synthesise. An example of this is alpha-ionone, one of the flavours present in raspberries where the natural material is the pure R- alpha-ionone. The toxicity of molecules can also vary tremendously between the different enantiomers, as became tragically apparent in the thalidomide disaster.

QUESTIONS FOR OPTION F

Note that questions intended for HL students only are marked with an asterisk [*].

F1 Food Groups

1. Distinguish between a food and a nutrient. Is it possible to have a food that is not a nutrient? What about a nutrient that is not a food?
2. Describe the common chemical structure of oils and fats? Given this common structure, in what way do oils and fats differ and how may this be explained.
3. Proteins are comprised of many 2-amino acid units. Draw the structural formula of a typical 2-amino acid and show how amino acids join together to form proteins. What name is given to the bond linking the amino acid units?
4. Glucose has the chemical formula $C_6H_{12}O_6$. To what group of chemical compounds does it belong? Name a food component that comprises many glucose units joined together. Give an example of a food that is rich in this component.
5. For the following foods, identify firstly the major food group that they belong to and also give the major use that is made of this by the body.

Olive oil	Flour	Honey
Eggs	Rice	Chocolate

6. The major food groups are carbohydrates, lipids and proteins. Explain why it is that other substances, such as minerals, vitamins and water can be considered as nutrients.

F2 Fats and oils

7. Olive oil is mainly mono-unsaturated, whereas sunflower oil is mainly poly-unsaturated. Explain what is meant by these terms. How would you expect the melting points of these two oils to compare? Explain why this is so.
8. Most naturally occurring unsaturated oils are the *cis*-isomer, but hydrogenation of poly-unsaturated oils can give the *trans*-isomer of unsaturated oils. Explain how *cis*- and *trans*- isomers differ and state what differences you would expect between these isomers firstly with regard to melting point and secondly with regard to nutritional value.
9. You are planning to make a 'strawberry candy' with a texture similar to chocolate by blending together a lipid base, sucrose, food colouring and artificial strawberry essence. What kind of lipid would you choose for this? Justify your choice.
10. Going from lard, through olive oil to canola oil to corn oil the degree of unsaturation increases. How would you expect the chemical stability of these lipids to vary? Explain this.
11. Vegetable oils are frequently hydrogenated. Give the reagents and conditions used for these reactions. Give two advantages for the food industry of doing this and two health concerns that the general public might have about the products.

F3 Shelf life

12. Give three specific examples of changes you might notice in specific foods that would indicate that they had been in storage beyond their shelf life.
13. Many cultures have traditional ways of preserving foods. Some that are common across a number of cultures are fermentation, pickling, salting and drying. For each of these give an example of a food that is preserved in this way and explain the reason why this method of preservation works.
14. What is meant by the term 'rancidity'? State which food group becomes rancid and give two changes you could make to the way in which the food is stored which would decrease this effect.
15. Adding antioxidants can increase the shelf life of foods. What is meant by the term antioxidant and what type of food degradation does it combat? Name one synthetic and one naturally occurring antioxidant used in foods.
16. Rancidity can occur by two distinct processes. Describe a way in which substances become rancid that
 - i) affects all types of lipids.
 - ii) affects unsaturated lipids much more than saturated ones.

In the case of the latter what other conditions are likely to accelerate the reaction?
17. If you were wanting to increase your consumption of antioxidants, name two foods that you would be advised to eat more of and for each food name the active antioxidant present in it.
18. In food storage often:
 - i) the moisture level is kept very low.
 - ii) the packaging excludes air.
 - iii) the wrapping is opaque.
 - iv) the product is stored at a low temperature.

Explain how each of these will help to increase the shelf life of the product.

19. Additives are often introduced into foods to delay the onset of microbial growth. Name two specific additives used for this along with one example for each of a foodstuff they are generally added to.
20. Auto-oxidation occurs by a free radical chain reaction. Explain what this means. Write equations for the two reactions that are responsible for generating the major product.
21. Antioxidants added to food can reduce oxidative degradation in three specific ways. Outline these mechanisms and give a specific example of an antioxidant that operates in this manner.
- 22*. The initiation stage of the auto-oxidation reaction of lipids has a very high activation energy and so occurs relatively infrequently. Explain therefore why auto-oxidation can rapidly lead to the deterioration of foods containing a high proportion of oils.
- 23*. Explain why it is that trace quantities of transition metals can rapidly accelerate the rate at which lipids become rancid.

F4 Colour

24. Name three groups of compounds that are responsible for the colours of foodstuffs and, for each, give two examples of specific foodstuffs in which they produce the colour.
25. One group of naturally occurring pigments has a structure closely related to that of vitamin A. Which group of pigments is this and what are the principal structural features of this group of compounds?
26. The colour of red cabbage often changes when it is cooked or preserved. What is the principal colouring agent in red cabbage? Give three factors that might affect the colour of this group of compounds when being prepared as foodstuffs.
27. Heme and chlorophyll are both frequently responsible for the colour of foods. Which groups of foods are they found in? They have closely related structures; state one similarity and one difference in their structures. What is the principal change that occurs when heme is converted into myoglobin, the major pigment in muscle tissue?
28. Discuss some health concerns that people have with regard to the use of synthetic dyes in processed foods. What regulatory changes, other than banning their use, would you propose that could reduce public concerns in this regard.
29. When heated on their own, carbohydrates undergo changes that result in the formation of a brown colour. What name is given to this process and how does it occur?

When carbohydrates are heated with proteins a second group of browning processes can also occur. What name is given to this second group? Describe how these food groups interact to produce brown products.

30. What is the normal oxidation state of iron in heme. Under some conditions this may alter and lead to undesirable changes in the appearance of meat – describe this change and the conditions required. Give suggestions of two ways in which the storage of meat could be altered to delay this undesirable change.

- 31*. Anthocyanins, carotenoids and chlorophyll all have very different structures. Why is it that all are coloured?
- 32*. When beetroot is boiled the water becomes a bright purple colour, but when carrots are boiled little colouration of the water is noticed, but if carrots are fried, the oil becomes orange coloured. Use your knowledge of the compounds responsible for the colour of these vegetables to explain these observations.
- 33*. If a molecule of β -carotene was subject to catalytic hydrogenation, would you expect the product to be coloured? Explain.

F5 Genetically modified foods

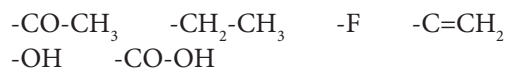
34. Briefly describe the process by which a plant or animal can be modified to produce a genetically modified (GM) food.
35. Give three separate ways in which genetic modification might improve the yield from a food crop.
36. As well as improving the viability of plants and animals, genetic modification can also result in novel substances being produced by organisms. Give a specific example of such a modification.
37. Many people are opposed to the introduction of genetically modified plants and animals. Explain what their major concerns are.

F6 Texture

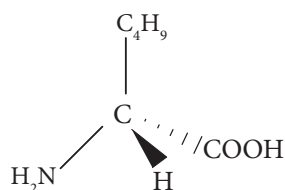
38. What physical properties of a food contribute to its texture? Disperse systems often display highly desirable textures. What is meant by a disperse system?
39. Three common disperse systems are suspensions, emulsions and foams. Distinguish between these in terms of the states of the components.
40. The production of stabilised disperse systems often depends on additives such as emulsifiers and stabilisers. Explain the role of these two groups of substances and name a synthetic example of each.
41. What characteristics do all emulsifiers have? Explain how these characteristics allow an emulsifier to produce a stable disperse system from two immiscible components.
42. As well as requiring an emulsifying agent, the production of an emulsion always involves vigorous beating of the components. Explain why this mechanical agitation is necessary.

F7 Stereochemistry in food

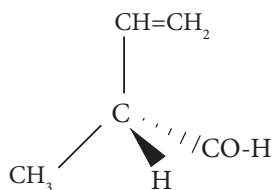
- 43*. What is meant by an absolute configuration? Place the following substituents in increasing order for the R-S system of indicating absolute configurations:



- 44*. Is the compound shown the D or L enantiomer of the amino acid leucine?



- 45*. Draw the R-isomer of 2-chloropropanoic acid.
- 46*. Is the compound illustrated below the R-isomer or the S-isomer of 2-methylbut-3-enal?



- 47*. Draw the D-isomer of the 4-carbon sugar erythrose ($\text{HO}-\text{CH}_2-\text{CO}-\text{CH}(\text{OH})-\text{CH}_2\text{OH}$).
- 48*. The specific rotation of naturally occurring sucrose is $+66.5^\circ$. Is it dextrorotatory or laevorotatory? What would be the specific rotation of its enantiomer?
- 49*. Explain how it may be possible to tell whether a food colouring containing a chiral centre comes from a natural or a synthetic source.
- 50*. Give a specific example of a compound for which the two enantiomers have different smells or tastes.