7 Particulates are a type of primary air pollutant produced in several industries and by the burning of fuels. 
(a) The emission of particulates by some industries is reduced by an electrostatic method. Explain how this is done. (3) 
(b) State one type of fuel that is very likely to produce particulates when burned. (1) 
(c) Deduce the equation for a combustion reaction of methane in which particulates are formed. (1)

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8 (a) Use equations to show how ozone undergoes natural depletion in the atmosphere. (2) 
(b) Identify one pollutant that contributes to the lowering of the ozone concentration in the upper atmosphere. State a source of the pollutant identified. (2) 
(c) Fluorocarbons and hydrofluorocarbons are now considered as alternatives to some ozone-depleting pollutants. Outline one advantage and one disadvantage of the use of these alternatives. (2)

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9 Discuss the advantages and disadvantages of incineration as a method of disposal compared with landfill sites. (4)

10 Describe the role of humus in retaining positive ions in the soil. (2)

11 Radioactive waste from nuclear power stations is often divided into high level and low level wastes. Describe the materials present in these wastes and the methods used for storage and disposal. (6)

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12 Identify four materials which are recycled and discuss the advantages and challenges of recycling. (6)

13 Discuss salinization and nutrient depletion as causes of soil degradation. (4)

14 Water that allows marine life to flourish needs a high concentration of dissolved oxygen. Several factors can alter the oxygen concentration. 
(a) State how an increase in temperature affects the oxygen concentration. (1) 
(b) Eutrophication is a process that decreases the oxygen concentration of water. Explain how the accidental release of nitrates into a river can cause eutrophication. (2)

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15 (a) Acid rain can affect plants and buildings. 
(i) Outline how acidic soil can damage the growth of trees. (1) 
(ii) Give an equation for the reaction of acid rain on marble statues or limestone buildings. (1) 
(b) Explain how the addition of calcium oxide to lakes could neutralize the effects of acid rain. (1)

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16 Describe how pure water can be obtained from sea water by ion exchange. 
(You may assume that sea water is sodium chloride solution.) (5)

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Practice questions 9, 10, 12, 13 © International Baccalaureate Organization
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.

F.4 Colour
F.4.1 Distinguish between a dye and a pigment.
F.4.2 Explain the occurrence of colour in naturally occurring pigments.
F.4.3 Describe the range of colours and sources of the naturally occurring pigments anthocyanins, carotenoids, chlorophyll and haem.
F.4.4 Describe the factors that affect the colour stability of anthocyanins, carotenoids, chlorophyll and haem.
F.4.5 Discuss the safety issues associated with the use of synthetic colorants in food.
F.4.6 Compare the two processes of non-enzymatic browning (Maillard reaction) and caramelization that cause the browning of food.

F.5 Genetically modified foods
F.5.1 Define a genetically modified (GM) food.
F.5.2 Discuss the benefits and concerns of using GM foods.

F.6 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.

F.1 Food groups

Foods and nutrients

Substances which are accepted as food by one community may be unacceptable in other parts of the world. What we are prepared to eat can depend on our social and religious background and psychological and other factors. The Codex Alimentarius Commission, which was set up by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations, defined food as: 'any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drinks, chewing gum and any substance which has been used in the manufacture, preparation or treatment of “food” but does not include cosmetics or tobacco or substances used only as drugs'.

Food provides the nutrients that are essential for human beings to survive. A nutrient is any substance obtained from food and used by the body to provide energy, to regulate growth, and to maintain and repair the body's tissues. Proteins, fats and oils, carbohydrates, vitamins, minerals and water are considered to be nutrients. Malnutrition can occur when either too little or too much of the essential nutrients are eaten. The amount of the different components needed in a diet depends on age, mass, gender and occupation but a balanced diet should have the relative composition shown on the next page.
Compounds with three acids attached to the glycerol are known as **triglycerides**. They are formed by a condensation reaction:

\[
\begin{align*}
\text{CH}_2\text{OH} & \quad \text{O} \\
\text{CHOH} + \text{HO-} & \quad \text{C-} \quad \text{R}_1 \\
\text{CH}_2\text{OH} & \quad \text{O} \\
\text{O} & \quad \text{O} \\
\text{HO-} & \quad \text{C-} \quad \text{R}_2 \\
\text{CH}_2\text{O-C-} & \quad \text{CH} \\
\text{O} & \quad \text{O} \\
\text{HO-} & \quad \text{C-} \quad \text{R}_3 \\
\text{CH}_2\text{O-C-} & \quad \text{R}_1 \\
\end{align*}
\]

If the three fatty acids in a triglyceride are the same it is called a **simple** glyceride; if they are different it is called a **mixed** glyceride. Most naturally occurring fats and oils are mixed glycerides. The chemical and physical properties of the fat depend on the nature of the fatty acid group R.

The R groups generally contain an even number of between 10 and 20 carbon atoms and are almost all straight-chain carboxylic acids as they are made from a series of ethanoic acid CH₃COOH molecules. Fats which are animal in origin are solid at room temperature and have **saturated** R chains with no carbon–carbon double bonds. Oils, which derive from plants and fish, have **unsaturated** R chains and are liquid at room temperature.

**Carbohydrates**

We generally obtain carbohydrates from plant foods such as cereals, fruit and vegetables. Carbohydrates have the empirical formula \( C_m(H_2O)_n \). The main function of carbohydrates in our bodies is as an energy source. Plants are the main source of dietary carbohydrates, which are produced from carbon dioxide and water by **photosynthesis**:

\[
6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

Light supplies the energy needed for photosynthesis. Plants are able to synthesize a large number of different carbohydrates. **Sugars** are low molar mass carbohydrates, which are crystalline solids and dissolve in water to give sweet solutions.
The closing of the ring can result in two different isomers or **anomers** with the hydroxyl group on either side of the ring. The form shown is called α-D-glucose (see page 269 for more details).

**Disaccharides**

Disaccharides are formed in condensation reactions by the elimination of one water molecule from two monosaccharides. There are many disaccharides known, but those important to the food industry are maltose, lactose and sucrose.

<table>
<thead>
<tr>
<th>Monosaccharides</th>
<th>Disaccharides</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-D-glucose + α-D-glucose</td>
<td>maltose</td>
</tr>
<tr>
<td>β-D-glucose + β-D-galactose</td>
<td>lactose</td>
</tr>
<tr>
<td>α-D-glucose + β-D-fructose</td>
<td>sucrose (table sugar)</td>
</tr>
</tbody>
</table>

Maltose, for example, is formed from the condensation reaction between two molecules of glucose. Two molecules of α-D-glucose are joined by a 1,4-glycosidic bond; the C1 forms the linkage with the hydroxyl group on the C4 of the second α-D-glucose molecule.

Maltose is used in brewing, soft drinks and foods.

**Exercise**

2. Lactose is found in milk. Its structure is shown here. Deduce the structural formulas of the two monosaccharides that react to form lactose.
molecules it cannot be digested and so has no nutritional value. It is, however, valuable in the diet as fibre as it gives bulk to food which aids its passage through the alimentary canal. Cellulose is a major component of plant cell walls.

**Exercises**

3 (a) Describe how and where carbohydrates are produced.
(b) Outline the difference between monosaccharides and polysaccharides.
(c) Discuss the difference between starch and cellulose with regard to their:
   (i) simplest units and structures
   (ii) nutritional value of each for humans.

4 Cellulose is a carbohydrate made from approximately 10 000 glucose units. Explain why it is not classed as a nutrient, but is acknowledged as of value in the human diet.

Selection of foods rich in carbohydrates and dietary fibre. These include rice, bread, pasta, flour and oats. Carbohydrates are the main source of energy for the body. Dietary fibre is any carbohydrate that is not affected by digestion and thus makes up the bulk of faeces. Digestible carbohydrates are broken down in the gut to glucose, which is then distributed by the blood to cells which need energy.

**Proteins**

Proteins are vital components of all life. They are natural polymers made from combinations of 20 different 2-amino acids. As amino acids have both a carboxylic acid group and an amino group, they are able to undergo condensation reactions:

\[
\begin{align*}
H_2N-C-C-OH + H\text{N}-C-C-OH & \rightarrow H_2N-C-C-N-C-C-OH + H_2O \\
R_1 & H & R_2 & & R_1 & H & R_2
\end{align*}
\]

The product, a dipeptide, is an amide made up of two amino acids joined by a peptide bond or peptide linkage. One molecule of alanine and glycine, for example, can form two dipeptides:

\[
\begin{align*}
H_2N-C-C-OH + H\text{N}-C-C-OH & \rightarrow H_2N-C-C-N-C-C-OH + H_2O \\
CH_3 & H & H & & CH_3 & H & H
\end{align*}
\]

\[
\begin{align*}
H_2N-C-C-OH + H\text{N}-C-C-OH & \rightarrow H_2N-C-C-N-C-C-OH + H_2O \\
H & H & CH_3 & & H & H & CH_3
\end{align*}
\]

Each amino acid can be identified by a three letter code (see Table 19 of the IB Data booklet). The two dipeptides can be represented as Ala–Gly and Gly–Ala.
F.2 Fats and oils

Most naturally occurring fats contain a mixture of saturated, mono-unsaturated and poly-unsaturated fatty acids with different chain lengths. They are classified according to the predominant type of unsaturation present.

Saturated and unsaturated fatty acids

The saturated fatty acids, which are often animal in origin, are all carboxylic acids with the general formula \( \text{C}_n\text{H}_{2n+1}\text{COOH} \). The carbon chain is made from only single carbon–carbon bonds. The carbon atoms are bonded in a tetrahedral arrangement which allows the chains to pack closely together. The van der Waals' forces are sufficiently strong between the chains to make the compounds solid at room temperature.

Unsaturated fats contain the carbon–carbon double bond. This produces a 'kink' in the chain, which prevents the molecules from packing closely together and reduces the intermolecular forces. Unsaturated oils, which are often vegetable in origin, are liquids. The greater the number of \( \text{C}=\text{C} \) double bonds, the greater the separation between the chains and the lower the melting point.

Worked example

Consider the three fatty acids:
- stearic: \( \text{C}_{17}\text{H}_{35}\text{COOH} \)
- oleic: \( \text{C}_{17}\text{H}_{33}\text{COOH} \)
- linoleic: \( \text{C}_{18}\text{H}_{32}\text{COOH} \)

Deduce the number of carbon–carbon double bonds in each of the acids.

Solution

The general formula of a saturated fatty acid is \( \text{C}_n\text{H}_{2n+1}\text{COOH} \). This gives \( \text{C}_{17}\text{H}_{35}\text{COOH} \).

Stearic acid is a saturated acid.

To form a double bond, two H atoms need to be removed.

Oleic acid, \( \text{C}_{17}\text{H}_{33}\text{COOH} \), has one carbon double bond.

Linoleic acid, \( \text{C}_{18}\text{H}_{32}\text{COOH} \), has two carbon–carbon double bonds.

Exercise

The following table shows the melting point for a number of common fatty acids found in dietary fats and oils.

<table>
<thead>
<tr>
<th>Name of acid</th>
<th>Formula</th>
<th>Structural formula</th>
<th>Melting point/°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>lauric</td>
<td>( \text{C}<em>{12}\text{H}</em>{25}\text{COOH} )</td>
<td>( \text{CH}_3\text{CH}_2\text{COOH} )</td>
<td>44</td>
</tr>
<tr>
<td>myristic</td>
<td>( \text{C}<em>{14}\text{H}</em>{29}\text{COOH} )</td>
<td>( \text{CH}_3\text{CH}_2\text{COOH} )</td>
<td>58</td>
</tr>
<tr>
<td>palmitic</td>
<td>( \text{C}<em>{16}\text{H}</em>{33}\text{COOH} )</td>
<td>( \text{CH}_3\text{CH}_2\text{COOH} )</td>
<td>63</td>
</tr>
<tr>
<td>stearic</td>
<td>( \text{C}<em>{18}\text{H}</em>{37}\text{COOH} )</td>
<td>( \text{CH}_3\text{CH}_2\text{COOH} )</td>
<td>70</td>
</tr>
<tr>
<td>oleic</td>
<td>( \text{C}<em>{18}\text{H}</em>{36}\text{COOH} )</td>
<td>( \text{CH}_3\text{CH}_2\text{COOH} )</td>
<td>16</td>
</tr>
<tr>
<td>linoleic</td>
<td>( \text{C}<em>{18}\text{H}</em>{36}\text{COOH} )</td>
<td>( \text{CH}_3\text{CH}_2\text{COOH} )</td>
<td>5</td>
</tr>
</tbody>
</table>

(a) Which of the fatty acids are solids at a room temperature of 25° C?
(b) Describe and explain the trend in the melting points in the first four fatty acids listed.
(c) Describe and explain the pattern in the melting points of the last three acids mentioned.

Linoleic acid is an essential fatty acid in our diet as our body is unable to synthesise it. The absence of the essential fatty acids in the diet may result in disorders such as eczema.
Cholesterol is a steroid and has the structural formula shown.

It is an essential component of cell membranes and is the starting material from which the human body synthesizes important compounds such as hormones and vitamin D. As cholesterol is insoluble in water, it cannot be transported in the bloodstream. It is made soluble by forming an association with lipoproteins, which are combinations of lipid and protein. Low density lipoprotein (LDL) transports cholesterol from the liver to the various synthesis sites in the body. Excessive LDL ('bad') cholesterol results in fatty material being deposited in the blood vessels. These deposits harden and constrict blood flow, resulting in increased risk of heart attacks and strokes. High density lipoproteins (HDL) 'good' cholesterol is thought to transport excess cholesterol back to the liver, where it is converted to bile acids and excreted. There is some evidence that eating large amounts of saturated or trans-unsaturated fats increases the tendency for cholesterol to be deposited in blood vessels, leading to a greater risk of heart disease. cis isomers do not cause such deposits to form and reduce the chance of developing coronary heart disease.

Stability of fats

Hydrolysis of fats

Oils and fats develop an unpleasant or rancid smell if they are kept too long. Rancid or 'off' food has a disagreeable smell, taste, texture or appearance. One cause of rancidity is the release of fatty acids produced during the hydrolysis of the fat by the water present in food. Free fatty acids are generally absent in the fats of living animal tissue, but can form by enzyme action after the animal has died.

Fats are hydrolysed in the presence of heat and water to their fatty acids and propane-1,2,3-triol in the reverse of the esterification reaction.

- Assorted cholesterol-rich foods including red meat and dairy products. Cholesterol is a fatty substance which is essential in moderation, but excess can be harmful. Foods such as brains (far left) have very high cholesterol levels. Too much cholesterol in the diet can lead to its deposition on the inside of the arteries, which can cause a stroke or a heart attack.
- Test your cholesterol IQ with this quiz. Now go to www.heinemann.co.uk/hotlinks, insert the express code 4259P and click on this activity.
- Hydrolysis is the splitting of a compound by reaction with water.
the catalyst. One of the disadvantages of the process, however, is that some unsaturated fats are produced in the less healthy trans form. The advantages and disadvantages of the hydrogenation process are compared below.

<table>
<thead>
<tr>
<th>Advantages of hydrogenation</th>
<th>Disadvantages of hydrogenation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• changes a liquid oil to a semi-solid or solid, to make the melting point of an unsaturated fat more like that of a saturated fat</td>
<td>• mono- and poly-unsaturated fats are healthier for the heart than saturated fats</td>
</tr>
<tr>
<td>• decreases the rate of oxidation (stability increases with increasing saturation)</td>
<td>• in partial hydrogenation, trans fatty acids can form</td>
</tr>
<tr>
<td>• increases hardness</td>
<td>• trans fatty acids are hard to metabolize, accumulate in fatty tissue, are difficult to excrete from the body, increase levels of LDL (bad) cholesterol and are a low-quality energy source</td>
</tr>
<tr>
<td>• controls the feel and plasticity (stiffness)</td>
<td></td>
</tr>
</tbody>
</table>

### F.3 Shelf life

The quality of food changes owing to chemical reactions with the environment and the action of microorganisms. Some of these effects are beneficial; certain cheeses, for example, are deliberately produced by the actions of microorganisms. Controlled and selective hydrolysis is also used in the manufacture of yogurt and bread, but most changes brought about by microorganisms make food less acceptable.

A food reaches the end of its shelf life when it no longer maintains the expected quality desired by the consumer because of changes in flavour, smell, texture and appearance (colour, mass) or because of microbial spoilage. The shelf life is quantified in different ways in different parts of the world. A food that has reached the end of its shelf life may still be safe to consume but optimal quality is no longer guaranteed.

The demand for food is generally constant throughout the year, but most food production is seasonal. All food was once part of a living organism. Meat and fish are from organisms which had to be killed before the food becomes available. Fruits and vegetables are still living when they are harvested. Food contains enzymes and is therefore susceptible to change and spoilage. There are two types of food spoilage: autolysis and microbial spoilage. Autolysis is the breakdown of food by the enzymes present in the food and causes the release of nutrients from the cells. These nutrients then become available to microorganisms, which feed and multiply, eventually making the food unacceptable.
Changes in the water content

Water is typically the most abundant constituent in food. It is bonded to the proteins and carbohydrates in the food by hydrogen bonding and plays a critical role in determining food quality, as it makes food juicy and tender. A reduction in water content can affect the texture, lead to the loss of nutrients and increase the rate of enzymatic browning and hydrolytic rancidity. Its presence in dried food can also produce undesirable chemical changes as it increases the rate of the degradation of the food by microorganisms. Water can be removed from food by either drying or smoking. Salting or adding sugars also reduce the water content by osmosis.

Oxygen and water from the air can be prevented from reacting with food if it is wrapped in an air-tight cover, or stored in a vacuum or unreactive gas such as nitrogen.

pH

The pH has a marked effect on the activity of most enzymes and the action of microorganisms. Bacteria require suitable nutrients and minerals and most prefer a neutral or slightly alkaline medium. Acid tolerance varies considerably among organisms, but most will grow at pH values ranging from 4.5 to 10. Reducing the pH inhibits microbial and enzymatic activity and has been widely practised for many years. Ethanolic acid is used to preserve food such as onions by pickling, and acids such as ascorbic, citric and malonic acids, which are naturally found in fruit and vegetables, are added to food to control enzymatic browning. A number of weak acids, such as sorbic and benzoic acids, are used as preservatives as they have little effect on flavour. Although a given concentration of a strong acid is more effective in lowering the pH than a weak acid, weakly dissociated acids are better preservatives. The concentration of the undissociated acid, rather than the hydrogen ion concentration, is the inhibitor.

Light

Light initiates the oxidation of fats and oils, which leads to rancidity, and of other nutrients such as vitamins. Exposure to light can also cause the natural colour of a food to fade.

Storing food in the dark or using packaging or coloured or opaque containers which prevent light from passing through to the food will stop photo-oxidation of fats and other photochemical free radical reactions.

Temperature

An increase in temperature can increase the rate of the chemical reactions which result in food spoilage. An increase in temperature can also affect the water content and thus the texture of the food. If the temperature is raised above 60 °C, the enzymes are denatured as the secondary and tertiary structure of the protein is disrupted. This can reduce the rate of the degradation reactions. Dairy products are often refrigerated as low temperatures slow down the rate of the lipase hydrolysis which produces rancidity.

Food preservation and processing

The aims of food preservation and processing are to prevent undesirable changes and bring about desirable ones. Food preservation techniques are designed to increase the food’s shelf life beyond that of the raw material by reducing the
• Vitamin C (ascorbic acid) is found in citrus fruits, green peppers, broccoli, green leafy vegetables, strawberries, red currants and potatoes.
• β-carotene is found in carrots, squash, broccoli, sweet potatoes, tomatoes, kale, cantaloupe, melon, peaches and apricots.
• The element selenium is found in fish, shellfish, red meat, eggs, grains, chicken and garlic.

The action of antioxidants has been found to be improved by the use of synergists. Synergists (citric acid and ascorbic acid) function by forming complexes with metals such as copper, which otherwise catalyse oxidation.

**Synthetic antioxidants**

Unfortunately, for economic reasons, it is not always possible to use natural antioxidants. Many of the synthetic antioxidants can be distinguished from natural antioxidants by their molecular structures. They are often phenols, which have a hydroxyl group attached to the benzene ring.

Another common structural unit found in many synthetic antioxidants is the **tertiary butyl group**, which has three methyl groups bonded to one carbon atom. These groups are free radical scavengers and react with the free radicals which would otherwise oxidize the food.

![Figure 17.2 Some antioxidants.](image)

**Exercise**

11 Identify the antioxidants in Figure 17.2 which have both a phenol group and a tertiary butyl group.
Advantages and disadvantages of using natural antioxidants in food

Synthetic antioxidants are generally more effective at slowing down the rate of rancidity and less expensive than natural antioxidants. Natural antioxidants can also add unwanted colour and an aftertaste to food. The use of synthetic antioxidants is, however, an area of some concern as:

- Consumers perceive natural antioxidants to be safer than synthetic ones because they occur naturally in food.
- Naturally occurring vitamins C, E and carotenoids reduce the risk of cancer and heart disease by inhibiting the formation of free radicals.
- Vitamin C is vital for the production of hormones and collagen.
- β-carotene can be used as an additive in margarine to give colour (yellow) and act as a precursor for vitamin A.
- Natural oxidants can enhance the health benefits of existing foods and boost overall health and resilience.
- Consumers perceive synthetic antioxidants to be less safe because they are not naturally occurring in food.
- Policies regarding the labelling and safe use of food additives can be difficult to implement and monitor, especially in developing countries and internationally.

Exercises

12 State the names of two additives which are used to delay the growth of microorganisms and give examples of the food they are added to.
13 Explain how the traditional methods of pickling and fermentation preserve food.

F.4 Colour

Food, in addition to providing nutrients, must be attractive. Colour is an important property of foods that adds to our enjoyment of eating, and it is one of the first factors we evaluate when purchasing food. The yellow colour of the carotenoids or the red colour of anthocyanins, for example, gives us an indication of the ripeness of fruit. As we cannot taste food before we buy it, we rely on what our eyes tell us. Foods have colour because of their ability to reflect or emit different quantities of energy at wavelengths able to stimulate the retina in the eye. They absorb light in the visible region of the electromagnetic spectrum and transmit the remaining light in the visible spectrum which has not been absorbed. Red meat appears red as it absorbs green light and so reflects red which is the complementary colour.

Dyes and pigments

Food can be coloured naturally or artificially. A pigment is a naturally occurring colour found in the cells of plants and animals. The main pigments responsible for the colours of fruit, vegetables and meat are porphyrins, carotenoids and anthocyanins.
In addition to providing colour in fresh food, carotenoid pigments are also important in processed foods. However, processing and cooking, in particular, can affect the pigments.

**Anthocyanins**

The anthocyanins are a sub-class of flavonoids responsible for a range of colours including yellow, red and blue. They are very water soluble and are the most widely distributed pigment in plants. They are present, for example, in strawberries and plums. Many anthocyanins are red in acidic conditions and turn blue at higher pH.

Over 500 different anthocyanins have been isolated from plants. They all have a similar three-ring C6C3C6 structure with conjugated carbon–carbon double bonds, which vary in the number of hydroxyl functional groups. The structure of the flavylum cation is shown.

As sugars such as glucose can be coupled at different places and many different sugars are present in plants, a very large range of anthocyanins can be formed.
**Worked example**

The absorbance of an artificial dye is shown. Identify $\lambda_{\text{max}}$ and use the colour wheel plus the chart on page 430 to deduce the colour of the dye.

![Absorbance graph](image)

**Solution**

The wavelength which corresponds to the maximum absorbance is 600 nm. Orange is absorbed.

The dye is blue (the complementary colour of orange).

---

**Exercises**

17 Identify the colour of the dye from its absorption spectrum.

![Absorbance graph](image)

18 Lobsters change colour when they are cooked. The visible spectra of the carotenoid astaxanthin responsible for the colour is shown for live and cooked lobster.

![Absorbance graph](image)

Deduce the colour change that occurs when lobsters are cooked.

Red astaxanthin when complexed with protein gives the blue or green hue found in live lobsters. When the lobster is cooked and the protein is denatured the lobster appears red.
Stability of anthocyanins

The structure of anthocyanins and their colour changes with pH. The flavylium cation discussed earlier found in acidic solution is bright red. In basic solution, a H⁺ ion can be removed from the OH group on the left ring to form a quinoidal base which is blue.

\[
\begin{array}{c|c}
\text{(AH⁺) flavylium} & \text{(A) quinonoid} \\
\text{red} & \text{blue} \\
\end{array}
\]

As the colour of anthocyanins is pH dependent, they can be used as acid–base indicators.

In aqueous solution anthocyanins can exists in four possible structural forms depending on the pH and temperature.

\[
(A) \rightleftharpoons (AH⁺) \rightleftharpoons (B) \rightleftharpoons (C)
\]

<table>
<thead>
<tr>
<th>quinonoid</th>
<th>flavylium</th>
<th>carbinol base</th>
<th>chalcone</th>
</tr>
</thead>
<tbody>
<tr>
<td>(blue)</td>
<td>(red)</td>
<td>(colourless)</td>
<td>(colourless)</td>
</tr>
</tbody>
</table>

The species present at different pH values depends on the nature of the pigment. The colourless carbinol base is formed when hydroxide ions attack the carbon atom next to the oxygen atom in the middle hexagon. The species no longer has a carbon–oxygen double bond next to the benzene ring on the left and so loses its colour.

\[
\begin{array}{c|c}
\text{(AH⁺) flavylium} & \text{(B) carbinol pseudobase} \\
\text{red} & \text{colourless} \\
\end{array}
\]

The colourless chalcone, which has a structure with only two hexagons, can also be produced in basic solution. As the stability of anthocyanin is also affected by the temperature, the colour of the anthocyanins can vary significantly during the cooking process. The anthocyanins are most stable and most highly coloured at low pH and low temperature. The equilibrium shown above moves to the right at higher temperatures. The less stable compounds thermally decompose at higher temperatures, which can result in a loss of colour and browning.
Non-enzymatic browning of food

Most enzymatic browning, which occurs when food is stored or when, for example, apples or potatoes are peeled and sliced, is undesirable. Enzymatic browning is a chemical process which occurs in fruits and vegetables containing the enzyme polyphenoloxidase. It produces brown pigments and is detrimental to quality. Enzymatic browning may be responsible for up to 50% of all losses during fruit and vegetable production. Under some conditions, however, sugars in the food can produce brown colours, which enhance the appearance and flavour of the food. There are two distinct processes which lead to this change: caramelization and Maillard browning.

Caramelization

Foods with high carbohydrate content and low nitrogen content can be caramelized. The process of caramelization starts with the melting of the sugar at temperatures above 120 °C. The compounds are dehydrated and double bonds are introduced into the structures. The small sugar molecules react together by condensation reactions to produce polymers with conjugated double bonds which absorb light and give brown colours. Smaller volatile molecules are also formed by a fragmentation reaction and these give the food unique flavours and fragrances. Caramelization produces desirable colour and flavour in bakery goods, coffee, soft drinks, beer and peanuts. Undesirable effects occur when the process is not controlled and all the water is removed and carbon is produced:

$$C_nH_{2n}O_m \rightarrow nC + mH_2O$$

Caramelization starts at relatively high temperatures compared to the other browning reactions and depends on the type of sugar. The table below shows the initial caramelization temperatures of some common pure carbohydrates.

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Initial caramelization temperature/°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>fructose</td>
<td>110</td>
</tr>
<tr>
<td>glucose</td>
<td>160</td>
</tr>
<tr>
<td>galactose</td>
<td>160</td>
</tr>
<tr>
<td>maltose</td>
<td>180</td>
</tr>
<tr>
<td>sucrose</td>
<td>160</td>
</tr>
</tbody>
</table>

The highest rate of colour development is caused by fructose as caramelization starts at a lower temperature.

Exercises

21 Explain why baked goods made from honey or fructose syrup are generally darker than those made with sugar.

22 Caramelization plays an important role in the roasting of coffee and the browning on the top of baked egg dishes. Explain why caramelization occurs during the baking and roasting of foods, but not when they are boiled in water.

The rate and products of caramelization can be controlled by the use of catalysis. Acid catalysis operates at pH values below 3 and base catalysis at pH values greater than 9.
Genetically modified foods

Genetic engineering is of major importance as it enables food scientists to alter the properties and processing conditions for foods. The DNA is the genetic material which determines the characteristics of an organism. Genetic engineering involves the alteration of the DNA of one or more of these genes to achieve improvements in the quality and the shelf life of foods. In the past this was done by cross breeding, but conventional plant breeding methods can be very time consuming and are often not very accurate. Genetic engineering can create plants with the exact desired trait very rapidly and with great accuracy.

It is also used to transfer DNA across species barriers that cannot be crossed by conventional techniques to produce foods which are not found in nature. One example of these transgenic organisms is corn into which bacterial DNA has been inserted. This allows the plant to produce a compound that is poisonous to certain caterpillars, which reduces the agricultural dependence on pesticides and herbicides. There are a number of possible benefits of genetically modified (GM) foods, but it is also an issue of public concern.

An example of a GM food is the Flavr Savr Tomato, which is genetically engineered chemically to 'turn off' the gene that produces a decay-promoting enzyme. The tomatoes can be left on the vine until ripe, picked and transported without rotting. This improves the flavour, appearance, nutritional value and shelf life of the food.

Benefits of GM foods

Genetic modification can add a gene to a cell to change cell behaviour, inactivate a gene in a cell to remove undesired behaviour, or modify a gene so that higher yields of products are obtained. This leads to a number of benefits:
Exercises

23 Describe on a molecular level how a plant can be genetically modified to give a GM food.
24 State three benefits and three concerns of using genetically modified foods.

F.6 Texture

Food, in addition to providing nutrients and colour, must have a pleasing texture. Whereas the taste, colour and smell of a food are chemical properties, the texture is a physical property. Many food ingredients are completely immiscible and so will form separate phases within the food. However, in some cases the size of these phases can be very small, so as to appear homogenous to the naked eye. A colloidal particle is many times larger than an individual molecule but many times smaller than anything that can be seen with the naked eye. A colloid is a mixture of a dispersed phase and a continuous phase.

Milk is an example of such a dispersed system. It appears white because light is scattered by protein and fat droplets dispersed in water. Most foods are dispersed systems.

| rays of light passing through a solution; the rays of light pass through the solution without being deflected | rays of light passing through a colloid; the rays of light are deflected as they are scattered from the colloidal particles |

Dispersed systems

A dispersed system is a kinetically stable mixture of one phase in another largely immiscible phase: it will separate into its components with different densities owing to action of gravity but this only happens very slowly.

Examiner’s hint: Avoid sloppy language. The fact that anti-cancer substances can be incorporated into GM foods is an acceptable benefit, but ‘cures cancer’ is not.

GM foods raise issues of conflict of concepts and values. Examine the facts, language, statistics and images used in the debate over their use. How certain is the scientific community about the outcomes of genetic modifications? What is an acceptable risk and who should decide whether particular directions in research are pursued?

Figure 17.8 A dispersed system with a continuous and dispersed phase.

A colloid is a mixture of a dispersed phase and a continuous phase (disperse medium). A colloid is not a solution, as although the colloid particles are not usually seen under a microscope, they are much larger than molecules and also bigger than the molecules of the continuous phase.

Milk appears white because light is scattered by the fat particles dispersed in the continuous water phase.
Exercise

25 Identify the type of dispersed system in each of the following foods.

<table>
<thead>
<tr>
<th>Food type</th>
<th>Continuous phase</th>
<th>Dispersed phase</th>
<th>Type of dispersed system</th>
</tr>
</thead>
<tbody>
<tr>
<td>ice cream</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bread</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>jam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>salad cream</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>beer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>whipped cream</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>butter</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emulsifiers

There are two important types of food emulsion, oil-in-water found in milk and salad dressing and water-in-oil emulsions such as butter. The non-polar oil molecules do not generally mix with the polar water molecules and so an emulsifier is often needed. These are substances which aid the mixing of the two phases and stabilize the dispersed state and prevent the mixture from separating into its two components. An emulsifier generally has a polar head which is hydrophilic and so attracted to the water and a non-polar tail which is hydrophobic and so dissolves in oil at the interface between the two phases.

Lecithin is widely used as an emulsifier. It is present in egg yolk which is added to oil and water mixtures to make mayonnaise and other salad dressings. Mechanical energy is needed physically to make an emulsion, which is why beating, mixing and whisking are important culinary skills.

Whereas emulsifiers help the different phases to mix, stabilizers such as trisodium phosphate Na$_3$PO$_4$ are added to prevent the emulsions from separating out into the separate phases.

Exercises

26 Describe and explain the characteristics of an emulsifier molecule.

27 Distinguish between the dispersed systems of suspensions, emulsions and foams.
(c) A triglyceride is also formed in the reaction between glycerol and three molecules of oleic acid, C_{17}H_{33}COOH. State and explain which of the two triglycerides (the one formed from stearic acid or the one formed from oleic acid) has the higher melting point. 

(Total 5 marks)

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7 Most naturally occurring unsaturated fats are cis isomers, but hydrogenation of polyunsaturated fats can lead to the formation of trans isomers. Distinguish between the types of isomers and state and explain which type of isomer generally has the higher melting point. 

(4 marks)

8 (a) Explain the meaning of the term shelf life. 

(b) State and explain two ways in which the packaging can increase the shelf life of food. 

(c) Explain how antioxidants extend the shelf life of food. 

(d) State the names of two antioxidants. 

(e) The structure of the synthetic antioxidant BHA is given in Table 22 of the IB Data booklet. Explain its antioxidant properties with reference to its molecular structure. 

(Total 9 marks)

9 (a) Distinguish between a food pigment and a food dye. 

(b) One group of chemicals responsible for the colour of some food has a structure closely related to vitamin A. Identify the class of compound and describe the structural feature responsible for their colours. 

(c) Explain how changing the pH changes the colour of the anthocyanins. 

(Total 5 marks)

10 Compare the two processes of non-enzymatic browning (Maillard reaction) and caramelization in terms of the chemical composition of the food affected and the products formed. 

(Total 5 marks)

11 The structures of the amino acids are given in Table 19 of the IB Data booklet. 

(a) Identify an amino acid which can take part in a Maillard reaction when it is part of a protein chain and explain your answer. 

(b) Suggest why it is unlikely that a polymer molecule could be responsible for a food’s fragrance. 

(Total 6 marks)

12 (a) Distinguish between an emulsion and a foam and give one example of each. 

(b) Lecithin is an example of a natural emulsifier found in egg yolk. Explain, with reference to its molecular structure, how it can act as an emulsifier for oil and water mixtures. 

(Total 6 marks)

13 (a) State how genetically modified food differs from unmodified food. 

(b) List two benefits and two concerns of using genetically modified crops. 

(Total 5 marks)

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