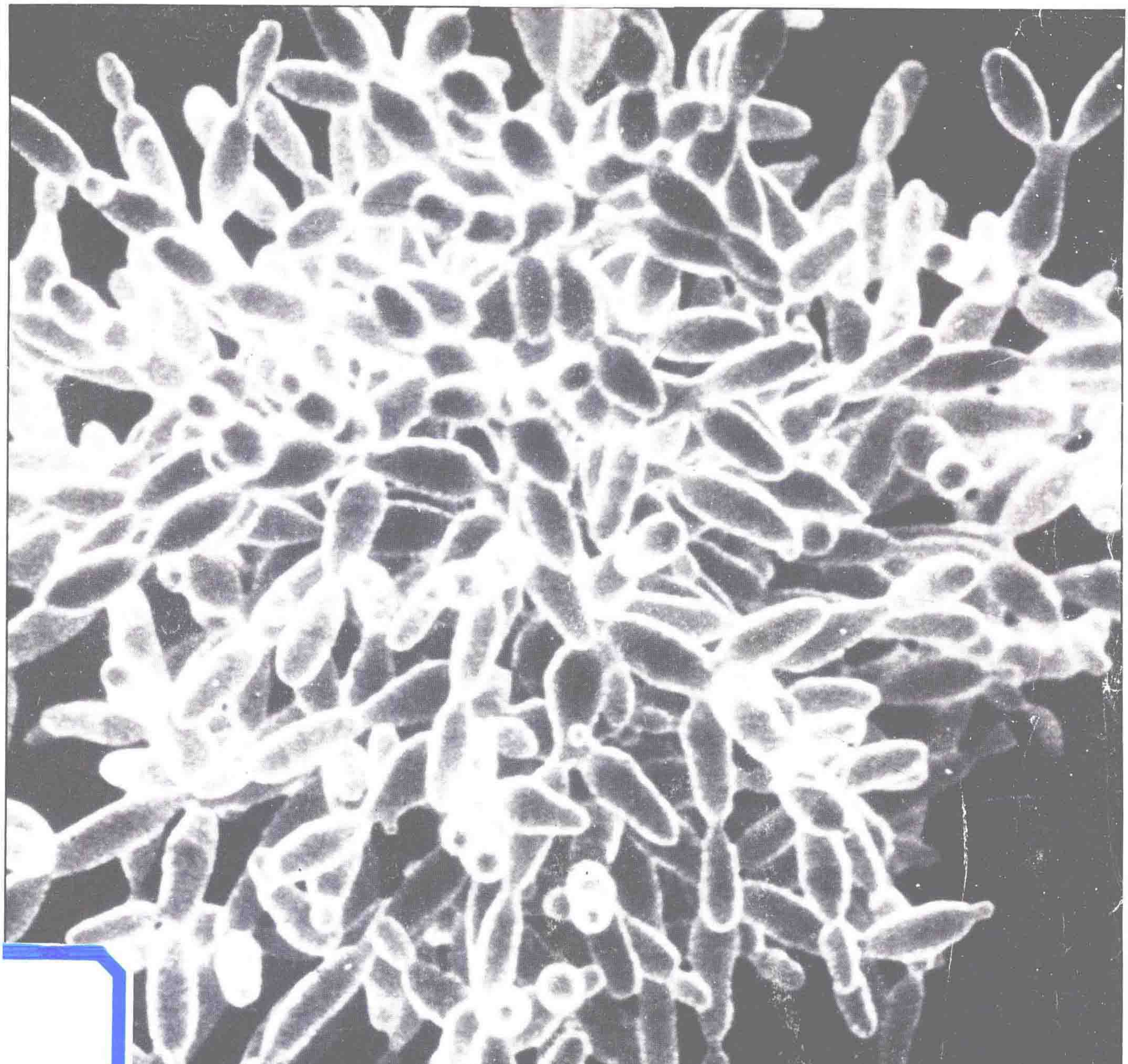
REVISE

NUFFIELD ADVANCED SCIENCE

CHEMISTR

FOOD SCIENCE
A Special Study



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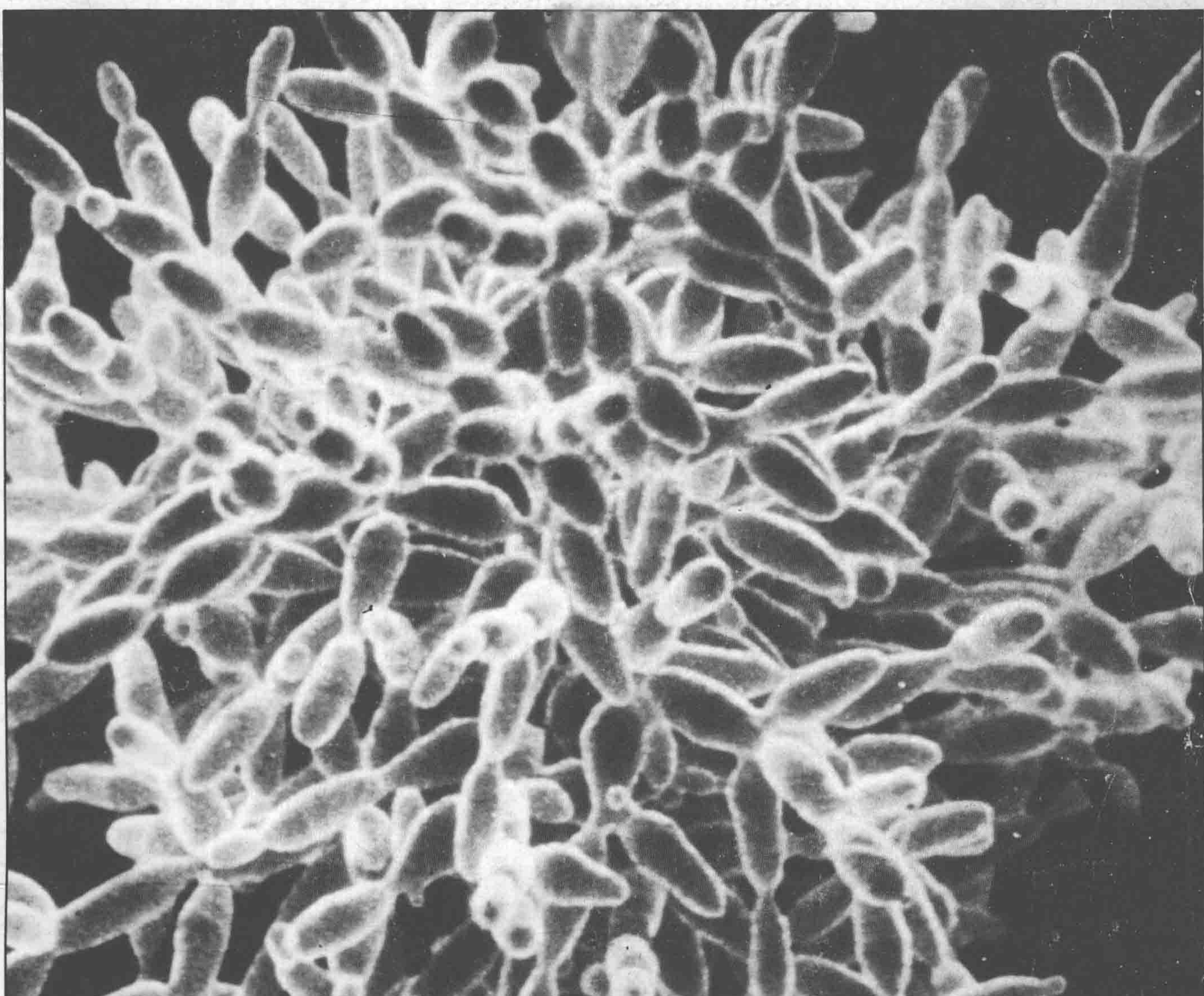

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FOOD SCIENCE

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SAFETY NOTE:

When food is being used in experiments, there is a great temptation to sample it, or to finish off unused portions. The dangers of eating
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CHAPTER ONE INTRODUCING FOOD SCIENCE

1.1 SCIENCE AND FOOD

Food production is one of the World's most vital industries. On[illegible] a community progresses beyond a nomadic culture, food production becomes essential. In so-called underdeveloped communities, most people spend their working lives attempting to produce enough food to feed their families. Any surplus, if they are lucky enough to produce a surplus, is sold to those not working on the land. In the richer industrialized countries, the majority of the population is fed more than adequately by a minority who are involved in food production. In 1900, 30 % of the labour force in the U.K. was involved in agriculture. By the 1970s, less than 10 % of the population produced 60 % of the food consumed. During the last 100 years, annual World food production has increased continuously, and in some areas dramatically. The rapid increase in food production has not been worldwide, but has largely been confined to the rich, technologically developed countries of the northern hemisphere. The abundance of food in the developed countries is due to the application of science and technology to all stages of the food industry, from the sowing of the seed to the attractively packaged and displayed item on the supermarket shelf.

As the consumer becomes more and more detached from the producer and the producing areas, the importance of processing, preservation, and packaging increases. If these activities were not carried out, large urban populations would be unable to enjoy the range of good quality foods that is now available at reasonable prices.

Food science is concerned with: the nature, composition, nutritive value, and behaviour of food materials; the biochemical and microbiological causes of spoilage; and the scientific principles of the methods of processing and preservation.

As this definition suggests, food science embraces various aspects of chemistry, biochemistry, biology, bacteriology, physics, and chemical engineering. The chemical aspects and chemical approach, however, are of considerable importance. This is because, although food is a very complex mixture of substances, it is composed of chemical compounds. Furthermore, processing and preservation techniques may involve the use of additives which are also chemical compounds. The changes which take place in food during processing, storing, cooking, and deterioration are mainly chemical changes.

1.2 THE NATURE OF FOOD

Figure 1.1 lists the six types of nutrients which must be present in a healthy diet. A lack of the minimum amount of any one of the six nutrients will result in malnutrition. A general deficiency of all six nutrients will lead to undernutrition and eventually starvation.

After digestion and absorption, the three basic functions of nutrients are *i* to provide chemicals for growth and repair of tissues, *ii* to maintain the basic structure of the body, and

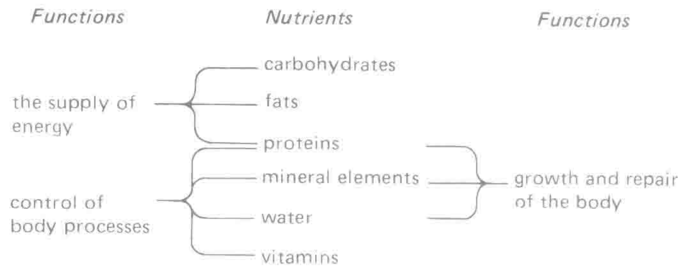


Figure 1.1

iii to provide energy for external activity and for regulation of internal processes.

For a substance to be classified as a food, it must contain one or more of the six nutrients. Not everything that is eaten is a food. Take, for example, salt and pepper, which are both widely used in our food. Salt is a food because it is essential in controlling some of the processes in the body. Pepper contains 12 % water, 11 % protein, 8 % fat, and 40 % carbohydrate, but it is consumed in such small amounts that it makes an insignificant contribution to the daily nutritional intake. Tea and coffee are both very popular beverages. Their nutritional value is due to the water and added milk and sugar. However, they are not drunk for their nutritional value, but for their flavour and for their caffeine content, which acts as a mild stimulant. If coffee and tea were eaten in sufficient quantities to be nutritionally significant, the physiological effects of their stimulant and flavour constituents would be dangerous.

A substance can only be defined as a food if, in addition to providing the various nutrients, it is accepted as being a food by the community concerned. Throughout history, and in various parts of the World, social, religious, and psychological factors have prevented the consumption of some nutritional and edible materials. These factors cannot be dismissed, although in some cases the *reason* behind the taboos and beliefs is not always understood. We would not normally contemplate eating grubs and insects, but they are eaten as food in some parts of the World. In severe conditions such things might be eaten in the Western World. We expect our food to be appetizing as well as nutritious. Factors such as flavour, texture, colour, aroma, presentation and, in some cases, the environment in which we eat, all contribute to the appeal of food.

In addition to the six nutrients mentioned, we need a continuous supply of oxygen. Ingested food (carbohydrates, fats, and proteins) undergoes oxidation and provides energy for all living cells. The energy made available by oxidation is not all liberated as heat, although some heat is necessary to maintain the body temperature. Some of the available energy is needed to perform mechanical work in muscles; some is needed for the synthesis of cell constituents. Oxidation of ingested food is needed to provide enough energy to enable the body to perform both internal and external activities. Even during sleep, when the body is in its least active state, energy is consumed. The minimum energy required to

Age and sex	*Energy* /MJ	*Proteins* /g	*Iron* /mg	*Calcium* /mg	*Thiamin (a B vitamin)* /mg	*Nicotinic acid (a B vitamin)* /mg equivalents	*Ascorbic acid (vitamin C)* /mg
0–1 year							
infants	6	35	7	600	0.6	7	20
15–17 years							
boys	12	72	12	600	1.2	19	30
girls	9	53	12	600	0.9	19	30
Men, 18–35 yrs							
moderately active	12	72	10	500	1.2	18	30
very active	14	84	10	500	1.3	18	30
Women, 18–55 yrs							
most occupations	9	54	12	500	0.9	15	30
pregnancy	10	60	13	1200	1.0	18	60
lactation	11.5	69	15	1200	1.1	21	60

Figure 1.2 Recommended daily intake of energy and some nutrients for the United Kingdom (*not* a complete list).

maintain the essential bodily functions – expansion and contraction of lungs, pumping action of the heart, and temperature regulation – is called the *energy of basal metabolism*. The minimum energy required for these vital functions varies according to sex, age, and size, but is about 6700 kJ per day for the average human. Expenditure of energy varies with activity and between individuals doing the same activity. Nevertheless, approximate figures have been calculated for the average person.

Activity	*Example*	*Energy expenditure* /kJ minute^{-1}
Sedentary	school work	8
Light	house work	15
Medium	football, netball	25
Heavy	manual work, *e.g.*, digging	33

Figure 1.3 Activity and energy expenditure.

The average amounts of energy needed daily by different groups of people to meet these various needs are given in Background reading 3 at the end of Topic 6.

The British Medical Association recommends that about 30 % of the energy intake should be in the form of fats, and 70 % in the form of carbohydrates.

In addition to the energy requirement, a balanced diet contains a minimum quantity of protein, minerals, and vitamins. The minimum requirements vary with age and sex.

A national food survey which was carried out in the U.K. in 1980 assessed the contributions of various foods to the nutritional content of the average diet. The survey showed that dairy products provide 60 % of the calcium intake and 25 % of the protein as well as being a source of various vitamins. Meat provides 26 % protein, 30 % fat, with significant quantities of vitamins and minerals – it is the main source of iron. Cereals provide 30 % of our protein requirement and 30 % of our energy requirement, in the form of carbohydrates. With the exception of vitamins A, C, and D, which they lack, bread and flour provide considerable quantities of most nutrients. Fruits and vegetables contribute mainly vitamin C. Potatoes provide most of our vitamin C intake in the U.K. In addition to providing valuable nutrients, they also provide our main source of roughage, which is essential in a healthy diet. Roughage is a carbohydrate which is not absorbed by the body and adds bulk to the faeces. Because of its water-binding capacity, it assists the passage of waste products through the intestine. The importance of adequate amounts of dietary fibre has attracted considerable interest.

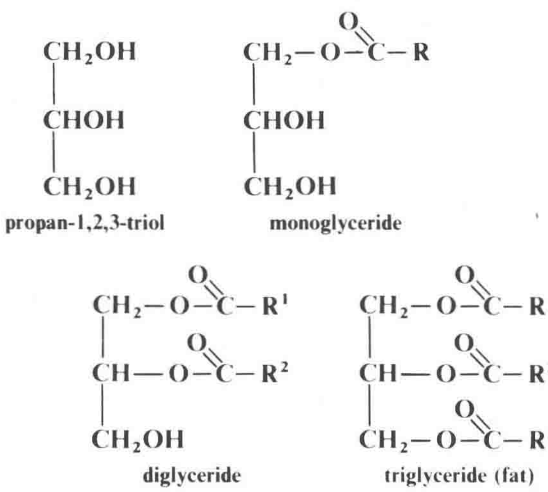
Figure 1.4 This girl's legs are bent because she has rickets, caused by a deficiency of vitamin D.

CHAPTER TWO THE NUTRIENTS IN FOOD

2.1 FATS

Fats belong to a group of compounds called lipids, which are soluble in non-polar solvents. (There is an introduction to lipids in the Background reading on naturally occurring carboxylic acids in Topic 13). Fats are esters of propane-1,2,3-triol (glycerol) and long chain carboxylic acids, which, for obvious reasons, are called fatty acids. Since propane-1,2,3-triol has three hydroxyl groups, it can form mono-, di-, or triesters known as mono-, di-, or triglycerides respectively.

Figure 2.1



The chemical and physical properties of the triglycerides depend on the nature of the R-group. The R-group (fatty acid chain) may have different degrees of saturation. Highly unsaturated fats tend to be liquids, and occur naturally in vegetable oils. Highly saturated fats are more viscous, and are likely to be solids at room temperature.

A correct proportion of fats is essential in a balanced diet. Fats provide the most concentrated source of energy. Certain fats provide essential fatty acids such as linoleic, linolenic, and archidonic acid. The absence of any one of these essential fatty acids (E.F.A.) in the diet may result in disorders such as eczema.

Fats are also necessary because fat-soluble vitamins such as A, D, E, and K are essential for a healthy diet. Stored fat, apart from acting as a nutritional reserve, serves as insulation and protection. Some organs, such as the kidneys, are protected against physical injury and heat loss by a layer of fat.

The main sources of fat in our diet in the U.K. are butter, margarine, meat, and milk.

Figure 2.2

Fat/oil	*Main fatty acids*
Palm	oleic (45 %) palmitic (40 %)
Ground nut	oleic (57 %) linoleic (23 %) palmitic (12 %)
Olive	oleic (80 %) linoleic (10 %)
Lard	oleic (56 %) palmitic (28 %) stearic (8 %)
Butter fat	oleic (30 %) palmitic (30 %) stearic (11 %) myristic (10 %)

Figure 2.4 Average fat content of some raw foods (g/100 g)

Food	milk	cheese	eggs	beef	bacon	chicken
Fat content	4	34	17	17	40	7

Food	white fish	butter	potatoes	white bread
Fat content	1	81	0	2

In the U.K. we eat solid fat, in butter or margarine, spread on bread or other foods. Until the process of hardening fats by hydrogenation was perfected (in 1910), almost 95 % of fat consumption was animal fat. Since then the production and consumption of vegetable oils have increased dramatically. Unsaturated fats can be hardened by reducing the proportion of unsaturated fatty acids, principally oleic acid. Oils may be hardened by hydrogenating the oleic acid, and converting it to stearic acid.

$$CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2^-$$
oleic acid anion

$$\xrightarrow[\text{nickel}]{H_2\text{/catalyst}} CH_3(CH_2)_{16}CO_2^-$$
stearic acid anion

The nickel catalyst, which is usually in a finely divided state and freshly reduced, is added to the oil at about 180 °C. The oil is stirred and the hydrogen bubbled through. After hydrogenation the oil is separated from the catalyst by filtration. In addition to hardening the oil, hydrogenation increases its stability.

Essential fatty acids are unsaturated and the proportion of unsaturated to saturated fatty acids in the diet is also important nutritionally. The degree of unsaturation is measured by the oil's iodine value. When iodine is added to a triglyceride, formed from an unsaturated fatty acid, it reacts with the double bonds in the molecule, and the degree of unsaturation may be calculated from the amount of iodine absorbed:

Figure 2.3 Names and formulae of some fatty acids.

Common name of acid	*Chemical name of acid*	*Formula*	*Type*
Myristic	tetradecanoic	$CH_3(CH_2)_{12}CO_2H$	saturated
Palmitic	hexadecanoic	$CH_3(CH_2)_{14}CO_2H$	saturated
Stearic	octadecanoic	$CH_3(CH_2)_{16}CO_2H$	saturated
Oleic	octadec-9-enoic	$CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2H$	unsaturated
Linoleic	octadec-9,12-dienoic	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7CO_2H$	unsaturated

$—CH{=}CH— + I_2 \longrightarrow —CHI—CHI—$

One molecule of iodine is used to saturate each double bond. The result is expressed as the iodine value, which is the number of grams of iodine required to saturate 100 g of oil or fat. In practice, the measurement is carried out using Wij's solution, which consists of iodine monochloride dissolved in tetrachloromethane. Iodine monochloride reacts more readily than iodine.

Experiment 2.1
The iodine value of an oil

Safety note: Wij's solution must be handled with care. It is harmful to the skin and you should avoid breathing the vapour. Wear protective gloves when shaking the stoppered bottle.

Weigh out a suitable quantity of oil. (Your teacher will tell you how much.) Put this into a dry glass-stoppered bottle of about 250 cm^3 capacity. In a fume-cupboard add 10 cm^3 of 1,1,1-trichloroethane to the oil to dissolve the oil. Use a pipette with safety filler to add 10 cm^3 of Wij's solution, replace the stopper, and allow the mixture to stand in the dark for about 30 minutes. Then add 15 cm^3 of 10 % potassium iodide solution and 100 cm^3 of water. Shake the bottle to make sure that the contents mix, and titrate the liberated iodine with 0.1M thiosulphate solution, using starch as an indicator. Carry out a blank titration using 10 cm^3 of 1,1,1-trichloroethane, 10 cm^3 of Wij's solution, 15 cm^3 of 10 % potassium iodide solution, and 100 cm^3 of water.

Calculations

Titration using a sample of oil = V_1 cm^3

Blank titration = V_2 cm^3

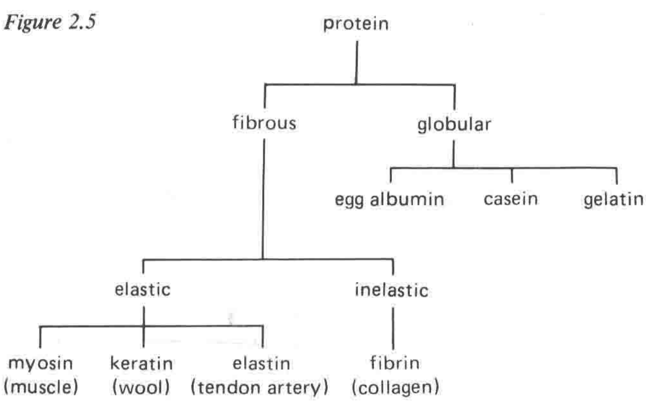
$$\text{Iodine value} = \frac{(V_2 - V_1) \times 1.269}{\text{mass of sample (in g)}}$$

2.2
PROTEINS

The natures of amino acids and proteins are described in Topic 13. You should study section 13.4 carefully and make sure that you understand how amino acids are linked together by peptide bonds. You are also expected to be familiar with the structure of proteins as described in the Background reading in section 13.4. The amino acid sequence is the primary structure of a protein. The protein chain is often coiled into a spring-like shape known as the α-helix. This is an example of the secondary structure of a protein which is held in this form by extensive hydrogen bonding (Topic 10). The folding or coiling of the α-helix gives rise to the tertiary structure, as illustrated by myoglobin in Topic 13. The tertiary structure is also maintained principally by hydrogen bonding, and, to some extent by ionic bonding between $—NH_3^+$ and $—CO_2^-$ groups.

Structurally, proteins may be classified into two groups – fibrous and globular. Fibrous proteins may be further subdivided into elastic and inelastic.

Figure 2.5



In inelastic proteins, the polypeptide chains are held together by cross-links. They are in the form of extended helical strands, and are not readily further extended. In elastic proteins, the polypeptide is in the form of an unextended coil, the loops being held in place by hydrogen bonds.

Globular proteins are more complicated than fibrous

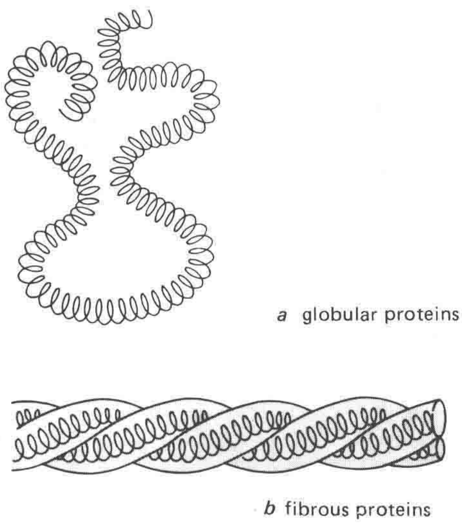


Figure 2.6 Two different types of tertiary structure in proteins.

proteins. In globular proteins the α-helix chain is folded and twisted to form a ball-like structure.

The properties of fibrous proteins are very different from those of globular proteins. Fibrous proteins are insoluble in water, resistant to dilute acids and dilute alkalis, and unaffected by moderate temperatures. Globular proteins, on the other hand, are relatively soluble. Also, they are affected by extremes of pH and by high temperatures, which disrupt the hydrogen bonding which maintains their tertiary structure.

Proteins fulfil many important functions. Proteins form part of the structure of the body. An example is the collagen in bone and cartilage. The albumen in egg acts as a food store. Haemoglobin in blood acts as an oxygen carrier. Another important function of proteins is that they act as enzymes, the catalysts in cell reactions. The main characteristics of enzymes are described in Topic 13, section 13.5.

Proteins can be very effective buffers because they can combine with both acids and alkalis and prevent the pH from changing. The buffering action is important, particularly when a protein is acting as an enzyme, when the pH must be maintained within a narrow range.

The complex activities needed to sustain life in the human body take place within the cells. Biochemical processes involve many steps, each controlled by a specific enzyme. The specific action of enzymes is due to their tertiary structure, which is maintained by hydrogen bonds. Consequently enzymes are very sensitive to changes in temperature and pH. All enzyme action is destroyed on boiling.

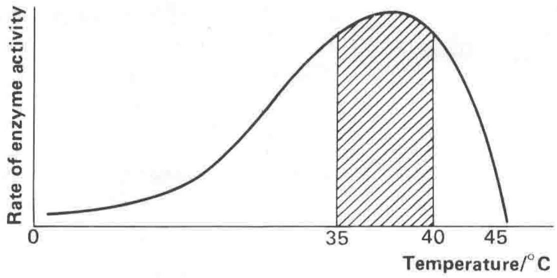


Figure 2.7 The shaded region shows the optimum temperature range for animal enzyme activity.

In general, plant enzymes work best at 5 °C. Enzymes in warm-blooded animals are most effective at about 37 °C. An increase in temperature usually increases the rate of a chemical reaction, but in the case of an enzyme-catalysed reaction, it will eventually lead to inactivation of the enzyme.

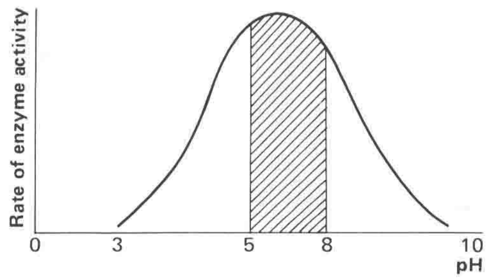


Figure 2.8 The shaded region shows the optimum pH range for enzyme activity.

Enzyme activity is also dependent on the pH of the medium in which it acts. Most enzymes operate in environments of pH 7. Some, like pepsin, can only function in acidic conditions.

Proteins, when digested, are hydrolysed and break down into the various amino acids. A maximum of 21 amino acids is released on hydrolysis. Of all the amino acids obtained from proteins, only eight are essential to adults. The other thirteen amino acids can be synthesized by the body fast enough to meet its needs and are not required in the diet. A diet containing the eight essential amino acids will provide enough suitable material to manufacture all the amino acids required. Animal protein is generally more valuable nutritionally than vegetable protein, because animal protein contains the full complement of essential amino acids. Vegetable protein, in general, tends to lack one or more of the essential amino acids. Cereal protein, for example, lacks lysine, which is an essential amino acid. Bean protein, although lacking in other essential amino acids, contains a high proportion of lysine and can be used to supplement cereal proteins.

Figure 2.9 Average protein content of various foods.

Food	beef	white fish	cheese	milk	bread
Protein/%	15	16	25	3	8.5

Food	apples	nuts	potatoes	yeast
Protein/%	0.3	28	2	43

2.3 CARBOHYDRATES

Plants are the main sources of dietary carbohydrates. Plants make carbohydrates from carbon dioxide and water by photosynthesis. The overall equation for this process can be written:

$$6CO_2(g) + 12H_2O(l) \rightarrow C_6H_{12}O_6(s) + 6O_2(g) + 6H_2O(l)$$

Light energy is needed for photosynthesis, and in this way solar energy is stored as chemical energy. These energy considerations are discussed in the Background reading at the end of section 15.7. Plants are able to synthesize a large number of different carbohydrates, including glucose, sucrose, starch, and cellulose. Sugars are low relative molecular mass carbohydrates which are crystalline solids and dissolve in water to give sweet solutions. The simplest sugars are monosaccharides. An example of a monosaccharide is glucose, which is found in many fruits and vegetables. The structure and properties of glucose are described in section 11.4 of Topic 11.

Disaccharides are formed by the condensation of two monosaccharides to form a dimer.

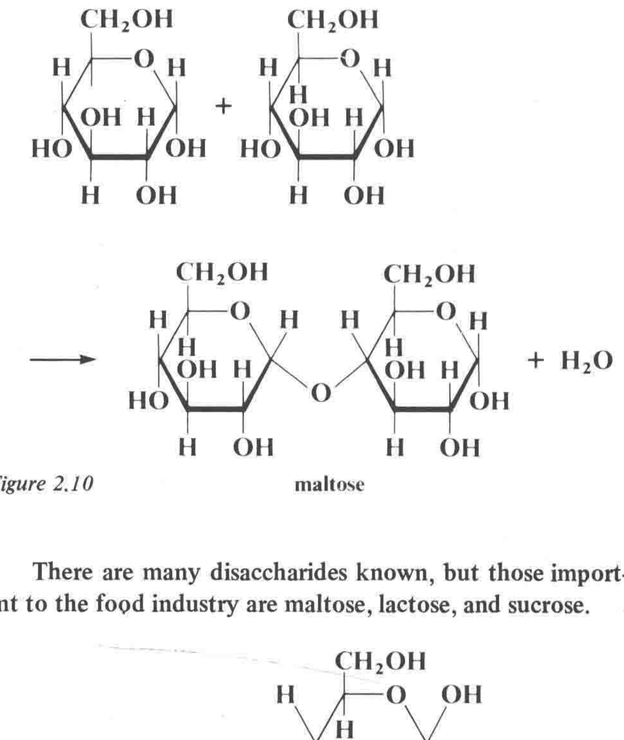


Figure 2.10 maltose

There are many disaccharides known, but those important to the food industry are maltose, lactose, and sucrose.

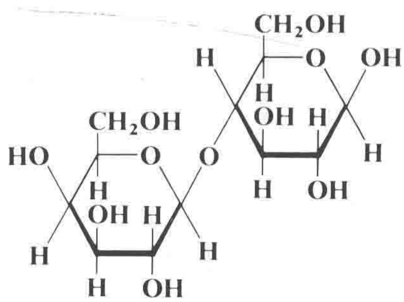


Figure 2.11 lactose

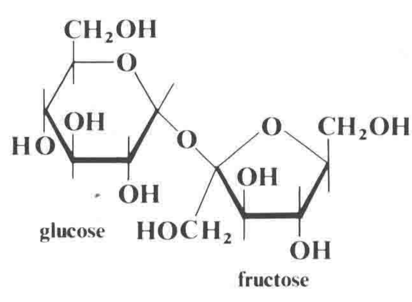


Figure 2.12 sucrose

Polysaccharides are polymers formed by linking very large numbers of monosaccharide molecules. Glucose is the most important monomer of the naturally occurring polysaccharides.

Starch

Starch is the main food reserve of plants. Under the microscope, we can see that it consists of irregularly shaped granules. The shape and size of the granules depend on the source and can be used to identify the origin of the starch.

Starch consists of two types of glucose polymer, amylose, which is linear, and amylopectin, which is branched. Most starches are about 20–25 % amylose, but there are exceptions. Pea starches are about 60 % amylose and some varieties of cereals have very little.

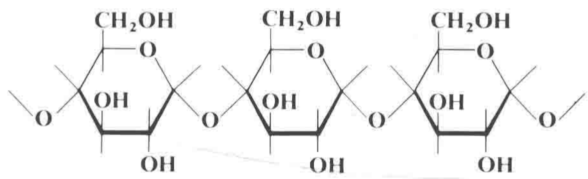


Figure 2.13 amylose

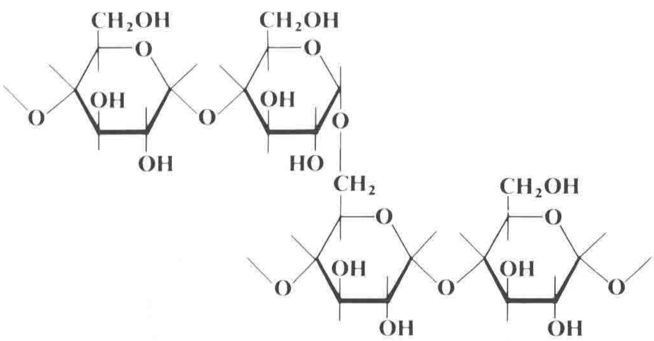


Figure 2.14 amylopectin

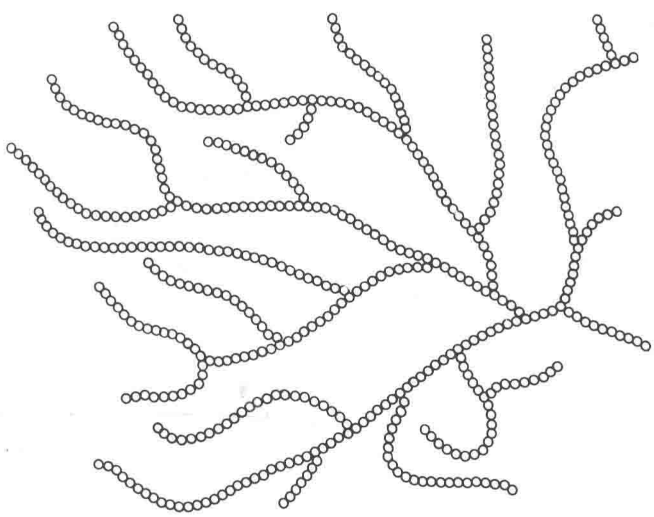


Figure 2.15 The general structure of amylopectin. Each circle represents a glucose residue.

Cellulose

Cellulose is a structural carbohydrate and is widely distributed. It consists of about 10 000 glucose units. It cannot be digested by humans and has no nutritional value. This is because humans do not have the enzymes necessary to break the links between the glucose units. Nevertheless it is of value in the diet as roughage.

We obtain carbohydrates from plant foods such as cereals and root plants. In the developed countries of the North, the consumption of carbohydrates from traditional sources has declined, while the consumption of sugar has increased at an alarming rate. In the U.K., sugar consumption has gone up from 2 kg to more than 50 kg per person per annum, over the last 80 years. The high level of sugar in our diet is considered to be undesirable by the medical profession. It is claimed that it contributes to obesity and dental decay, and there appears to be some correlation between a high sugar diet and heart disease.

Food	milk	meat	jam	potatoes	baked beans
Sugar/%	4.8	0	69	0.4	5.2
Starch/%	0	0	0	17.6	5.1

Food	bread	biscuits	orange	ice cream
Sugar/%	0.3	28	8.5	20
Starch/%	54	37	0	0

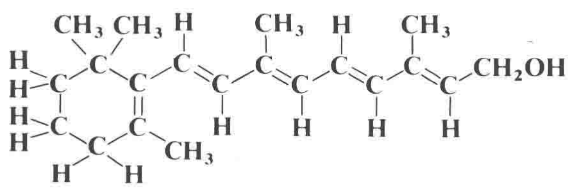
Figure 2.16 Average carbohydrate content of some foods.

2.4 VITAMINS

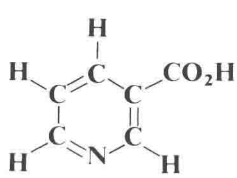
Until about 80 years ago, it was thought that a diet containing proteins, carbohydrates, fats, minerals, and water was sufficient to maintain a healthy body. For example, Scott's expedition contrived diets which were carefully balanced for fat, carbohydrate, and protein. Unfortunately they were virtually vitamin-free. It was not the expedition's fault. Vitamins were not discovered until they were on their way back from the South Pole. They died of malnutrition, not from cold.

It was only after much research that scientists found that small quantities of certain vitamins were also necessary in a healthy diet. It was also found that, with a few exceptions, the body is unable to produce the vitamins it needs. Although most vitamins are quite complex molecules (figure 2.17), most of them can be prepared synthetically. Before the chemical formulae and structures of vitamins were known, they were referred to, and identified, by using letters of the alphabet (figure 2.18 on the next page).

A lack or a shortage of any one of the necessary vitamins in the diet causes a deficiency disease.



retinol (vitamin A)



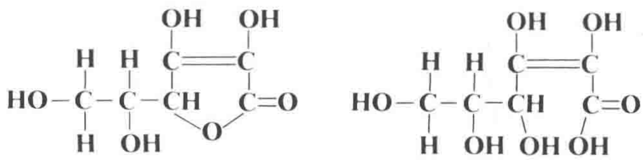
nicotinic acid (vitamin B)

Figure 2.17

Vitamin	Source	Function in the body	Average adult daily requirement/mg
A Retinol (β-carotene)	fish liver oils, butter, margarine, carrots	keeps eyes and skin moist and healthy – lack of vitamin A can cause blindness	0.75
B_1 Thiamin	cereal germ, yeast	growth, appetite, functioning of muscles, liberation of energy, healthy nervous system; deficiency produces beri-beri	1.2
B_2 complex Includes riboflavin	yeast, milk	similar to B_1; deficiency produces diseased eyes and cracks and sores at the corners of the mouth	1.7
and nicotinic acid	yeast, liver	deficiency causes pellagra, a disease of the skin, and diarrhoea	18
B_{12}	yeast, animal protein	formation of red blood cells	0.001
C Ascorbic acid	fruits, vegetables	necessary for blood and bone-forming tissue, resistance to infection; deficiency produces bleeding gums, scurvy	30
D Cholecalciferol Calciferol	fish liver oils, egg yolk, butter, margarine	necessary for healthy bones; deficiency produces rickets	0.0025
E Tocopherol	cereal germ, green leaves	healthy reproduction, muscle health	–
K	green leaves	thought to resist blood clotting	–

Figure 2.18

Ascorbic acid, although referred to as an acid, does not contain a free carboxylic acid group. The —CO_2H group reacts with an —OH group in the molecule to eliminate a molecule of water and form a ring compound. (See figure 2.19.) Ascorbic acid is readily oxidized and is therefore a good reducing agent. Ascorbic acid is more likely to be deficient in people's diet than some of the other vitamins. This is due to various properties of vitamin C. Vitamin C is present in significant amounts in a limited range of foods. It is relatively soluble in water and may be washed out of foods on cooking. It is thermally unstable and may be destroyed on cooking. It decomposes slowly when foods containing vitamin C are stored for any length of time. The amount of vitamin C in vegetables is at its greatest during the summer period of active growth.



ascorbic acid

free acid corresponding to ascorbic acid

Figure 2.19

Experiment 2.4
Investigating the effect of cooking on the vitamin C content of cabbage

Standardization of indicator solution

The 2,6-dichlorophenolindophenol indicator has been made up by dissolving 0.4 g of the dye in 200 cm^3 of warm water, filtering the solution, and making up the filtrate to 1 dm^3 with distilled water, to give approximately 0.04 % solution (400 mg dm^{-3}). Before the indicator is used to determine the vitamin C content of cabbage, it must be standardized – to find the number of mg of vitamin C equivalent to 1 cm^3 of dye solution.

Use a pipette, with safety filler, to transfer 25.0 cm^3 of standard (200 mg dm^{-3}) vitamin C solution to a conical flask and titrate rapidly with the dye solution from a burette. As the dye is run in, the deep blue colour of the dye is discharged to give a colourless solution. The end point is taken to be when the pink coloration, due to the dye, persists for 10 seconds. A blank titration using 25.0 cm^3 of 5 % orthophosphoric acid solution must be carried out to the same end point.

Calculation

By deducting the blank titre from the standardization titre and using the concentration of vitamin C, the number of mg of vitamin C equivalent to 1 cm^3 of dye (dye factor) may be calculated. (See the bottom of this page.)

Estimation of vitamin C in uncooked cabbage

Weigh out 50 g of cabbage and put it in a liquidizer with 250 cm^3 of 5.0 % orthophosphoric acid. Liquidize at high speed. Filter off the liquid into a 500-cm^3 measuring cylinder, using muslin. Make up the volume of extract plus washings to 300 cm^3. Titrate 25.0 cm^3 of the extract with indicator solution as before. All titrations should be carried out in duplicate.

Calculation

Mass of sample = 50 g
Volume of extract solution = 300 cm^3
Volume of dye titre = V cm^3
Dye factor = F mg cm^{-3}
300 cm^3 of 5 % orthophosphoric acid extract contain 50 g of sample
25 cm^3 of 5 % orthophosphoric acid extract contain $V \times F$ mg of vitamin C
300 cm^3 of 5 % orthophosphoric acid extract contain $V \times F \times 300/25$ mg of vitamin C
100 g of sample contain
$V \times F \times 300 \times 2/25$ mg of vitamin C

Estimation of vitamin C in cooked cabbage

Simmer 50 g of cabbage in 100 cm^3 of water for 10 minutes, allowing some of the water to evaporate. Repeat the above experiment on the cooked cabbage. Determine the loss in vitamin C on cooking cabbage for 10 minutes. If time allows, repeat the titration on the residual water and determine the amount of vitamin C present in solution.

$$\text{dye factor } (F) = \frac{\text{volume of standardized vitamin C} \times \text{concentration of vitamin C/mg dm}^{-3}}{(\text{standardization titre} - \text{blank titre}) \times 1000}$$

dye factor (F) = mg of vitamin C equivalent to 1 cm^3 of dye solution

2.5 MINERALS

The residue or ash left after food is heated at a high temperature for about an hour is called the *mineral matter* – sometimes called mineral salts or inorganic nutrients. Although a large number of inorganic elements are found in the body, only about a dozen are known to be essential and must be included in the diet. Inorganic nutrients have three main functions in the body:

i As part of the body structure. Calcium, magnesium, and phosphorus are mainly used to form the bones and teeth.

ii As part of the fluids in the tissues, and as assisting in the control of pH and osmotic functions. The pH is controlled within narrow limits by the buffering actions of the ions present. For example, the blood is buffered at pH 7.4 by the hydrogencarbonates and carbonates present.

iii As an essential component of a large number of enzymes which are necessary for the release and utilization of energy. Iron in haemoglobin is one example.

As the essential minerals occur only in some foods, it is important that the diet should include a wide variety of foodstuffs.

Element	*Source*	*Function*	*Average daily requirement of adult/g*
Sodium and chlorine as sodium chloride	bacon, bread, added salt	fluid balance, body temperature	4 to 8
Potassium	fruit, vegetables	fluid balance	2
Calcium	dairy products	bones, teeth, blood, muscle	0.5
Phosphorus	dairy products	bones, teeth, blood, muscles, metabolism	2
Iron	liver, eggs	blood	0.01
Iodine	sea food, water	thyroid gland	0.001
Fluorine	tea, sea food, water	teeth, bones	0.018

Figure 2.20 Mineral/inorganic elements in the diet.

Food	milk	cheese	eggs	fish
Water content/%	87	37	75	82

Food	beef	potatoes	apples	bread
Water content/%	64	80	84	39

Figure 2.21 Average water content of some foods.

2.6 WATER

Water is essential to all living things. Approximately 60 % of the total mass of the human body consists of water. Water is continuously lost from the body as urine, as sweat, and as water vapour in respiration. If the body is to function, the lost water must be replaced. One of the functions of food is to replace and to supply the water that the body needs.

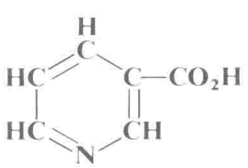
The main functions of water in the body are to transport nutrients and to take part in chemical changes in the tissues and during digestion (such as the hydrolysis of proteins to amino acids, and polysaccharides to monosaccharides). Water is also important as an essential part of the structure of plant and animal tissues in maintaining tissue rigidity.

Q1
What is the general structural formula of:
a a triglyceride
b an α-amino acid?
Give two main uses which the body makes of triglycerides.

Q2
What is meant by the primary, secondary, and tertiary structures of a protein? Give two main uses which the body makes of protein.

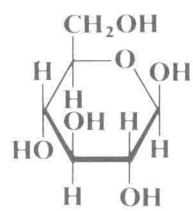
Q3
What is the effect on humans of a diet deficient in:
a calcium
b iron
c ascorbic acid
d β-carotene (vitamin A)?

Q4
Identify the type of nutrient represented by the formulae A, B, C, and D.

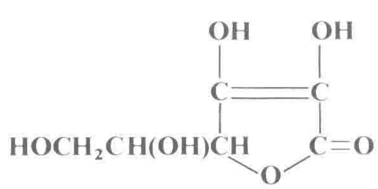


A

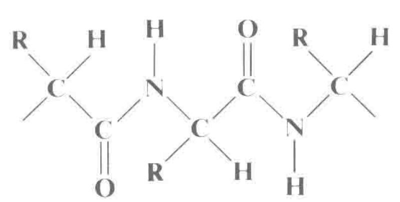
Q5
Plan a packed lunch for a winter's day, suitable for a student. Give reasons for including various types of food.



B



C



D

Q6
With the help of reference books, plan vegetarian menus for a day. Analyse the suggested menus to estimate the amounts of nutrients in the food. Is the diet you have suggested balanced and nutritious?

Q7
Consult a number of cookery books and describe some of the recommended methods for cooking green vegetables. Which methods are likely to retain the vitamin C content of the vegetables?

Q8
Why is it of interest to know the extent to which fats are saturated or unsaturated? What is the current medical view on the connection between heart disease and the amount and nature of fat in the diet?

Q9
What nutrients are present in a cheese and tomato sandwich made with wholemeal bread, and butter?
With the help of tables showing the nutritional values of foods, show that such a sandwich makes a good snack from the nutritional point of view.

Q10
Derive the formula used to calculate the iodine value of a fat or oil as used in Experiment 2.1.

CHAPTER THREE THE QUALITY OF FOOD

3.1 EATING QUALITIES

If you were provided with bottles containing a range of isolated nutrients such as fats, essential amino acids, glucose, vitamins, necessary minerals, and water, you could make up a mixture which would enable you to live. Such a mixture, however, would not be very palatable, and you would soon get bored and lose your appetite. Food in the rich, developed countries is not necessarily eaten for its nutritional value, but for its eating qualities. On average, we eat three meals a day, not always because we need the nutrients, but because we enjoy eating. Food, in addition to providing nutrients, must be acceptable – have a pleasing texture, flavour, and colour. Digestibility, although an important factor in defining a material as a food or non-food, does not detract from a material's acceptability. Wood, straw, and grass, which consist of lignin and cellulose, are carbohydrates. We would not consider eating them, not because they are indigestible, but because we do not approve of the taste or texture. There are a number of materials, however, which are just as indigestible and are chewed for hours on end, not for their nutritional value but for their taste and texture (for example, chewing gum). Food, or materials which people are prepared to eat and find attractive as food, must have desirable eating qualities. The eating qualities of food can be divided into two broad groups:

a Structural character	*b Chemical character*
water-holding capacity	taste
texture	odour
tenderness	colour
juiciness	

Plant and animal tissues are composed of discrete units, or cells, and each cell is bounded by a cell membrane. The membrane is a layered structure made up of *lipids* (the class of compounds of which fats are one group) and *proteins*; the material is therefore known as *lipoprotein*. Figure 3.1 shows the arrangement.

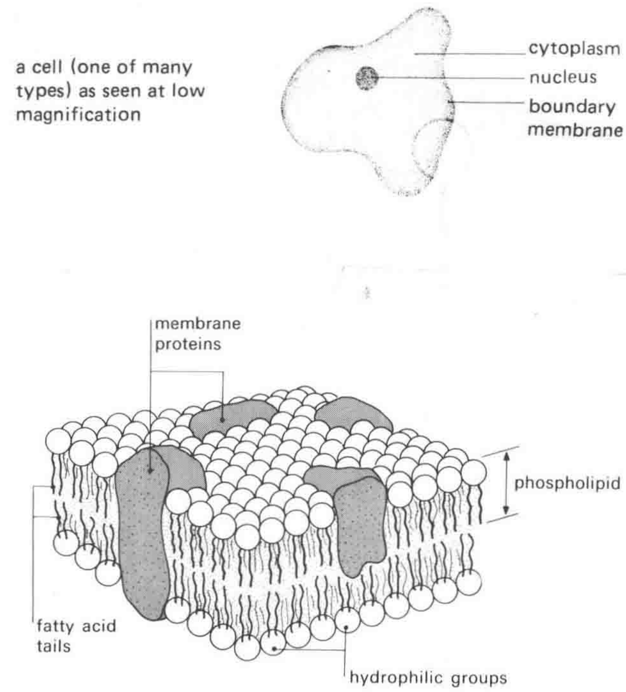


Figure 3.1 Diagrammatic representation of the chemical structure of a cell membrane.

This lipoprotein arrangement proves to be selectively permeable to ions and molecules, and it forms a semi-permeable membrane by which osmotic phenomena can operate in the cell.

3.2 WATER-HOLDING CAPACITY

Since water is the major component of living cells, it is also the principal constituent of foods, and a substantial part of the texture, tenderness, and juiciness of foods is determined by the various ways in which water is arranged in relation to insoluble materials. A small proportion of the total water is chemically bound to the polar groups of proteins and polysaccharides. This is achieved by hydrogen bonding between water molecules and the N—H and C=O groups in proteins, and the —OH groups in the polysaccharides. In addition, some molecules of water are held by the hydration of free ions or of ions such as Mg^{2+} and Ca^{2+} which occur in some protein structures. But a much larger proportion of water is non-combined, or 'free', with properties the same as those of liquid water outside the living organism. Since water does not pour out of plants or meats it is clear that this non-combined water must be held immobile in some way. It is believed that the long chains of the proteins link with one another by means of hydrogen bonds and ionic bonds to form a meshwork, and water is trapped in the interstices. Long chain polysaccharides also link up by means of hydrogen bonds to form an entrapping meshwork. Meshwork structures such as these which have trapped large quantities of water are known as *gels*.

Any factors which affect the bond forces holding the protein or polysaccharide chains together will affect the extent to which water can be held by the system. One factor is pH, which affects the electrostatic charges on the protein molecules. Another is heating, which ruptures hydrogen bonds. In these ways the meshwork may break down.

Acids, alkalis, and high temperatures, may affect not only the meshwork structure but also the tertiary and secondary (helical) structures of the individual protein molecules. Such denaturation will usually lead to the coagulation, solidification, and loss of water-holding capacity.

A fresh strawberry, although it has a high total water content, is firm enough to offer immediate resistance to the cutting edges of the teeth. This firm 'feel' and the sensation of the juice being released from the cells as the berry is bitten add greatly to the enjoyment of eating fresh strawberries. A frozen strawberry is quite a different article. The cell structure has been disrupted by freezing and thawing, and much more water is in the intercellular regions. This drips out of the thawed berry and the berry has a soggy texture. It offers no resistance to the teeth until it has completely collapsed; the sensation in the mouth is quite different from a fresh strawberry, and some people dislike it.

3.3
TEXTURE IN FOODS OF PLANT ORIGIN

In plants, carbohydrates perform a role of major importance both as structural materials and by reason of their water-holding capacity. The cell membrane is surrounded by a cell wall which imparts protection and firmness. The cell membrane is composed of lipoprotein (figure 3.1) and is semi-permeable. The cell wall is largely composed of carbohydrates, and it is usually freely permeable to solutes. It is the cell wall and its constituent polysaccharides which are primarily responsible for the texture of plant foods. Figure 3.3 shows diagrammatically and in simplified form the structure of two adjacent cell walls of a plant.

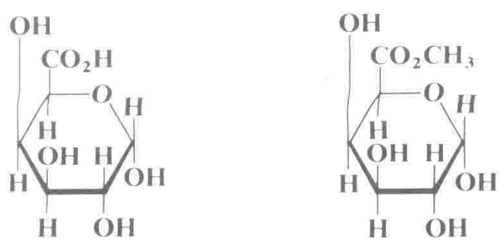
The *hemicelluloses* form a group which is difficult to define and to isolate. On hydrolysis they give a variety of different hexose sugars (for instance glucose and mannose), pentose sugars, and uronic acids. These components appear in widely differing relative amounts and in numerous combinations, reflecting a bewildering variety of mixed polymers.

Pectic substances are also difficult to isolate. An aqueous extract yields pectin, which is a mixed polymer whose monomers are α-D-galacturonic acid and the methyl ester of this acid. (See figure 3.2.)

The number of units in the chains varies with the type of plant material, with its age, and also with the method by which the pectin has been extracted from the plant. It ranges between 50 and 2000 (giving relative molecular masses of between 10 000 and 400 000). The middle lamella is largely composed of pectic material, some of it probably in the form of its calcium salts. The calcium content of cooking water can, by cross-linking pectin molecules together, affect the texture of cooked vegetables.

Pectins are important in the setting of jams. Firm jams and 'runny' jams may have little or no difference in water content. The important difference is in the amount and state of the pectin in the fruit after boiling the jam. This determines the firmness of the gel structure in the jam after cooling.

Attempts have been made to improve frozen strawberries by adding pectin preparations so that the juice sets to a jelly



α-D-galacturonic acid   methyl α-D-galacturonate

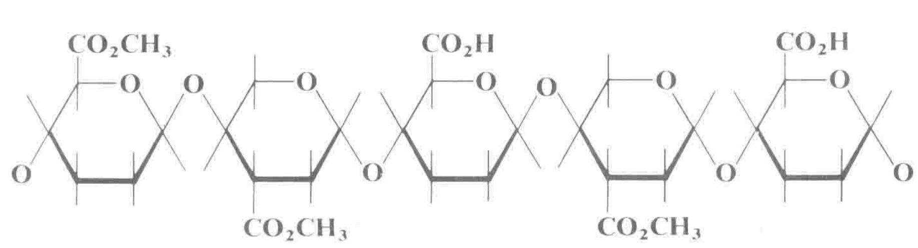


Figure 3.2   part of a pectin molecule (methyl pectate)

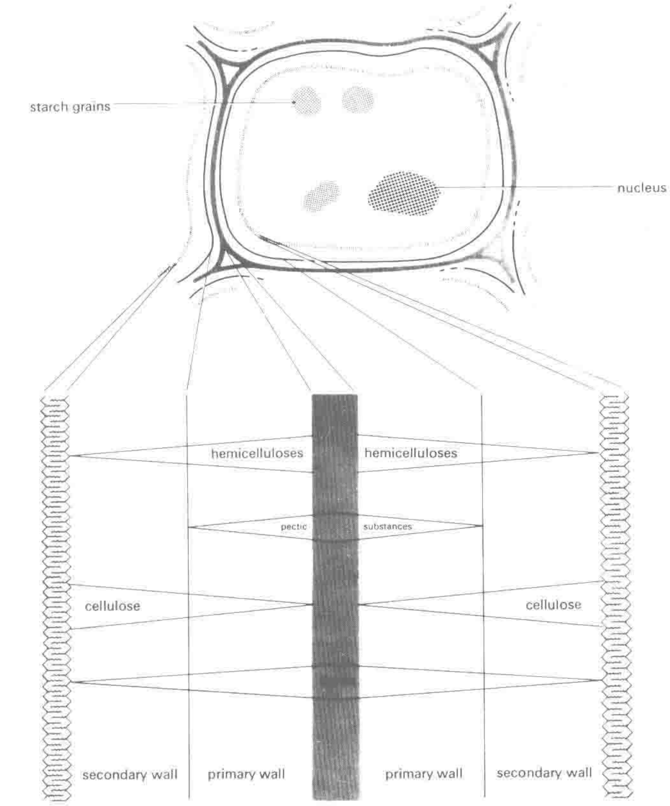


Figure 3.3 Simplified diagram of two adjacent plant cell walls and their main chemical components (not to scale). The wedges show the directions in which the substances become more, or less, prominent.

instead of running freely. However, although the juice does not run out of the berry, the sensation is no different from the one given by the untreated frozen berries when they are bitten into.

Changes in pectin

When vegetables are heated in water, the pectins become more soluble and some are extracted into the water. The effects on the intercellular pectins, which act as the cement in a vegetable structure, are the most important. The more soluble the pectins become, the softer and more floury the texture. This softening is desirable to some extent, but even slight over-cooking gives unpleasantly mushy vegetables.

When the pectins are hydrolysed by cooking to low-methoxy pectins, they can be precipitated by calcium and magnesium ions. These ions are present in hard water, and for this reason vegetables cooked in hard water are firmer or tougher than those cooked in soft water. Alkaline conditions tend to soften vegetables by increasing hydrolysis of pectins and by removing calcium. Thus, the sodium hydrogencarbonate added to preserve the colour of green vegetables also softens them, and if too much is added the effect can be disastrous, particularly in soft water.

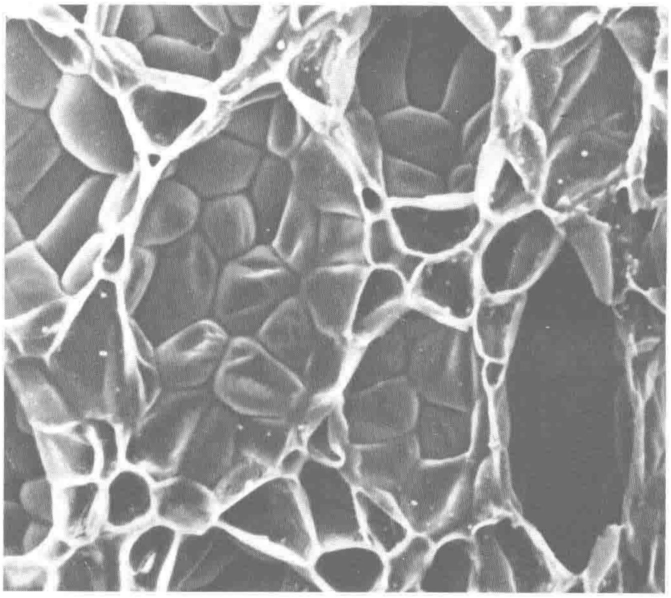


Figure 3.4a Raw apple (× 100). Note the firm cell walls and large air spaces.

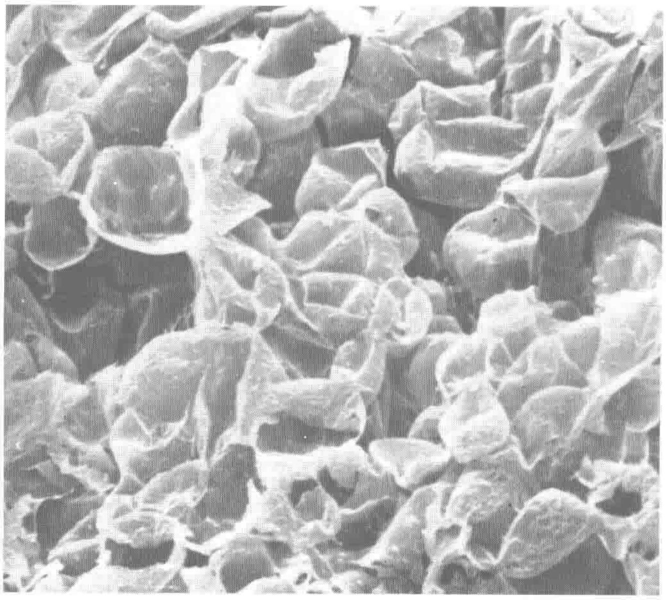


Figure 3.4b Cooked apple (× 100). Note the disrupted structure and the beginning of cell separation as the tissue disintegrates.

Experiment 3.3
The effect of calcium ions on the texture and flavour of peas

Safety note: remember the safety warning on page 3. Special glassware and chemicals are provided for this experiment because you will taste the peas.

Dried peas have been provided which have been soaked overnight in the following solutions:

1 distilled water
2 tap water
3 2 % calcium chloride solution
4 4 % calcium chloride solution

Rinse separate 30-g samples of soaked peas with distilled water and put them in 400-cm^3 beakers each containing 100 cm^3 of distilled water. Mark the height of the liquid and cover with a watch-glass. Bring each sample to the boil and simmer gently, keeping the level of the water constant with distilled water. After 10 minutes use a clean spoon to take a sample and note its texture and taste. Continue simmering and record the times taken to produce acceptably soft peas in each case.

3.4 TEXTURE IN FOODS OF ANIMAL ORIGIN

The main structural elements of animal cells consist of proteins. Connective tissue is made up of two basic types of fibres, *collagen* and *elastin*. These are cemented together by a jelly-like substance called the *matrix*. The connective tissue of meat, which surrounds the bundles of muscle, is mainly collagen, while the walls of the muscle fibre are mainly elastin.

Collagen consists of two or three different polypeptide chains which are in the form of a lefthand helix. These polypeptide chains are intertwined to form a righthand helix which is stabilized and made inelastic by cross-linking hydrogen bonds. Collagen has the form of an extended chain which cannot be stretched further. Elastin, on the other hand, has a similar extended form but also an unstretched form, in which the chain is compressed like a coiled spring and maintained in this position by hydrogen bonds or by disulphide cross-links. (See figure 2.6 on page 7.) Collagen and elastin are both insoluble and difficult to digest. However, when meat is cooked or treated with dilute acid, they are converted to gelatin, a derived protein, which is more soluble and readily digestible.

Cross-linking between individual polypeptide chains, and the quantity of collagen in the connective tissue, increase with the age of the animal and also when the animal is more active. These changes help to explain why meat from older animals is tougher and more difficult to chew.

Most of the edible tissue of animals is muscle. At a low magnification you can see that muscle is composed of a number of parallel fibres. At a higher magnification each fibre is found to be made up of many *myofibrils* with alternate light and dark bands. Closer examination shows that each light band is crossed by a line called the Z-line.

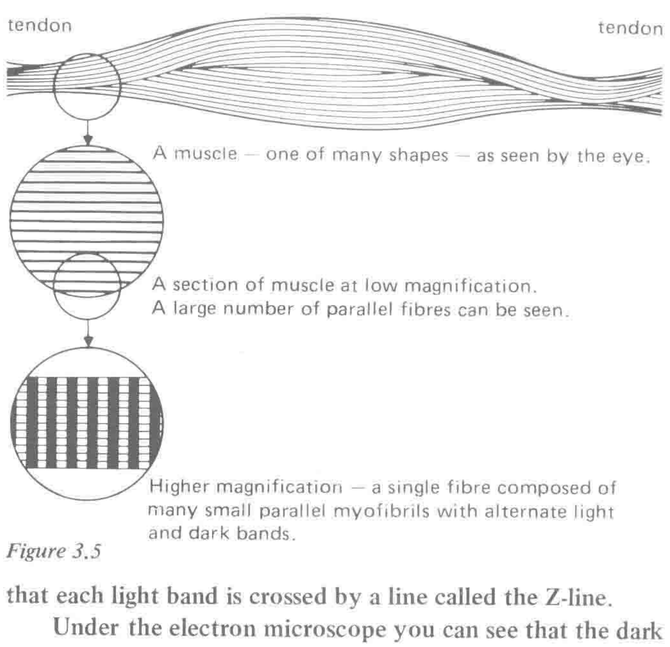


Figure 3.5

Under the electron microscope you can see that the dark bands consist of thick rods which are filaments of a protein called *myosin*. Between the thick rods there are thin rods of a second protein called *actin* (see figure 3.6 on the next page).

According to the generally accepted *sliding filament* theory, myofibrils contract as a result of chemical interaction between myosin and actin filaments. When this happens the filaments overlap more, and the Z-lines are pulled closer together.

So far as texture and eating quality are concerned, increased contraction makes the meat tougher. Contraction can occur before and after slaughter, the extent depending on how the animal is handled. If the animal is very excited just before slaughter, muscle contraction takes place and the meat becomes tougher. Contraction can also occur during cooking, resulting in shrinkage and toughening of the meat.

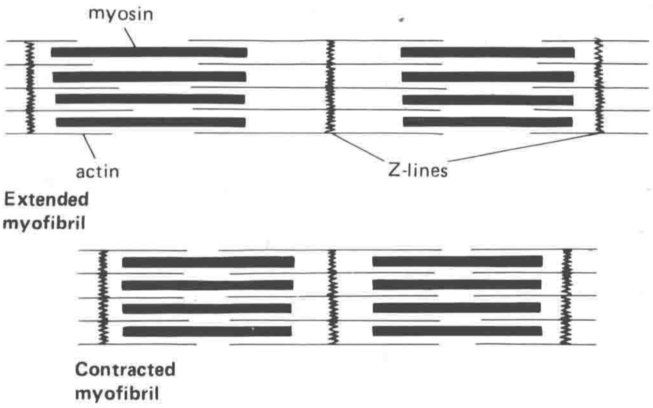


Figure 3.6

Apart from the possibility of contraction after slaughter, there is another factor peculiar to muscular tissue which affects texture and tenderness. This is the onset of rigor mortis. It shows as a stiffening of the tissue, because after death the actin and myosin filaments cross-link irreversibly. A day or two later the muscles become soft again as breaks occur when actin filaments separate from their connections to the Z-line because of enzyme activity. Part of the skill of the butcher is to ensure that conditions are right for this reaction to occur, so that the meat is tender.

3.5
FLAVOUR AND COLOUR

Flavour (taste), smell, and appearance are all important factors in determining our attitude to food and its palatability, and must be considered in relation to eating quality.

Flavour, as far as eating quality is concerned, is an important property of food. There are four primary tastes, and all are detected by the senses of taste and smell:

i bitter
ii salt
iii sour (acid)
iv sweet.

Primary tastes are detected by different areas of the tongue. Moreover, the ability to detect the various tastes tends to vary between individuals and from day to day. Training, however, can improve our ability to discriminate between tastes and increase our sensitivity to different tastes.

Particular tastes appear to be associated with a variety of unrelated compounds. Sugars such as glucose and sucrose are sweet, but so are compounds as diverse as lead nitrate and saccharine, which are completely unrelated to the sugars.

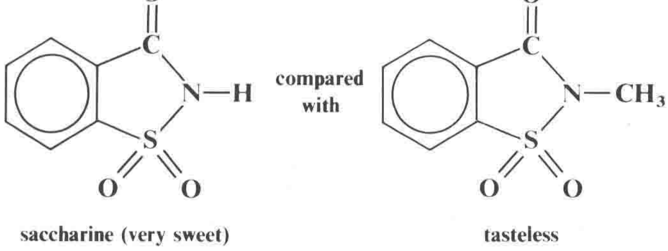


Figure 3.7

Bitterness, like sweetness, is a property of a variety of completely unrelated compounds such as quinine, caffeine, NH_4^+, Mg^{2+}, and Ca^{2+}. There does not appear to be any correlation between the sweetness or bitterness of a compound and the type or structure of the compound.

Acid (sour) and salty tastes, however, can be related fairly closely to chemical structure. Both these tastes are associated with the presence of ions – the hydrogen ion in the case of acidity.

Primary tastes will often affect one another. Salt will decrease the sweetness of sugar or decrease the sourness of acids in citrus fruits. Moreover, there are substances which, when added to food, enhance the flavour of the food. Monosodium glutamate, for example, although virtually flavourless, may be used to intensify the flavours in vegetables and meats and is extensively added to canned and dried food.

The quality of odour is detected by receptors in areas at the top of the two nasal cavities. Volatile substances, either in the gaseous phase or in solution in water or fats, are responsible for the odour of a particular food. The nose is an extraordinarily sensitive detector of odour. It can detect certain substances at concentrations as low as one part in 50 000 million.

The reason why different compounds have different odours is still unknown, but it appears to be related in some way to the size, shape, and charge distribution of the molecule.

However important the colours of food may be to the consumer, they are of no intrinsic value, and are irrelevant to its nutritive value. The compounds which give rise to these colours are more important to the plants and animals for chemical and physical reasons.

The main pigments responsible for the colours of fruits, vegetables, and meat are:

i porphyrins
ii carotenoids
iii flavonoids.

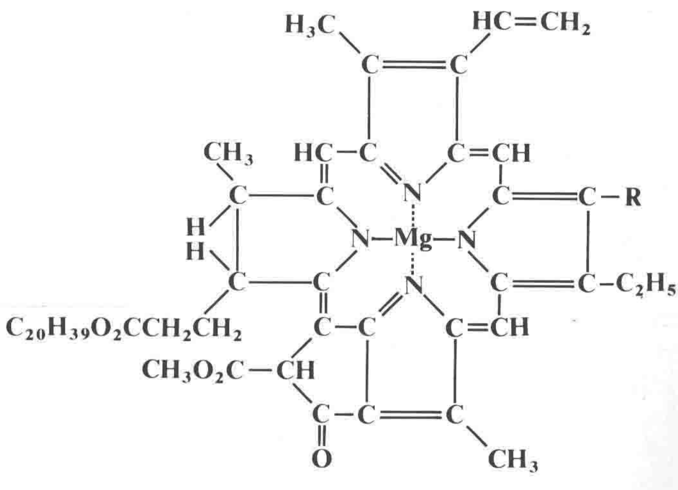


Figure 3.8 The structure of chlorophyll.

The porphyrins include the pigments chlorophyll (green) and haemoglobin (red). They are large ring-shaped molecules with a metal atom in the centre. In chlorophyll the metal atom is magnesium, whereas in haemoglobin it is iron. The carotenoids are a group of yellow/orange/orange–red, fat-soluble pigments. The flavonoids (yellow) are water-soluble pigments which are widely distributed in vegetables and fruits.

The compounds responsible for colours in plants and animals are water-soluble, thermally unstable, and affected by extremes of pH. As vegetables are cooked the brightness of the green colour fades, changing to olive green, then yellow green, and finally becoming brownish. The rate and extent of the colour change depend on the pH of the cooking water. When chlorophyll is heated in acid solution, the magnesium atom is removed from the porphyrin ring to give a brownish-green compound. On further heating, or in a more concentrated acid solution, the $C_{20}H_{39}OH$ (phytol) group is hydrolysed off to leave a brown compound. When chlorophyll is heated in alkaline solution, the phytol residue is removed without removing the magnesium atom, to give an olive green compound. To preserve the green colour of vegetables, therefore, sodium hydrogencarbonate is sometimes added to the cooking water, with a disastrous effect on the vitamin C content, as explained in section 3.3.

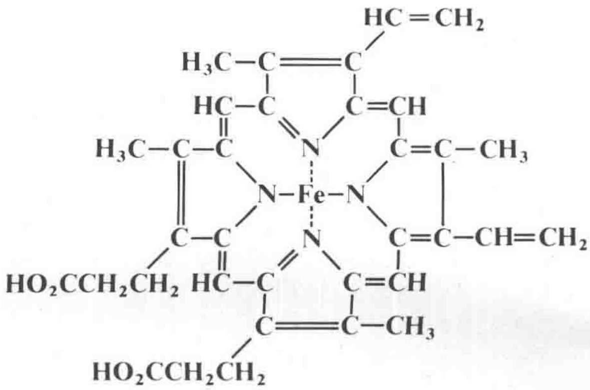


Figure 3.9 The structure of haem.

Experiment 3.5a
Taste

Safety note: Take full precautions during these tasting experiments. Remember the rules given on page 3.

Solutions of sodium chloride, citric acid, caffeine, and sugar have been put in four separate cups labelled A, B, C, and D, not necessarily in that order. Taste the four solutions and identify their tastes. If you cannot detect the flavours, ask your teacher for more concentrated solutions.

Experiment 3.5b
The tongue and the primary taste sensations

Use the same four solutions as in Experiment 3.5a. Draw up a small volume of sodium chloride solution into a drinking straw. Put a small quantity of the solution on to area A of your partner's tongue. Make a note if your partner finds the solution salty. Repeat this on each of the areas of the tongue and determine the areas sensitive to the sensation of saltiness. Rinse your mouth with fresh drinking water between samples.

Repeat the experiment using the other solutions – citric acid, caffeine, and sucrose.

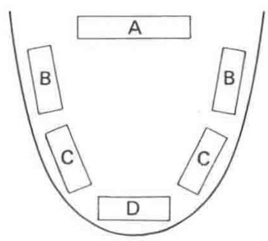


Figure 3.10
Areas of the tongue.

Q1
a Describe two ways in which water can be held in the structure of a food:
i of plant origin
ii of animal origin.
b How, and why, does heat affect the water-holding capacity of foods?

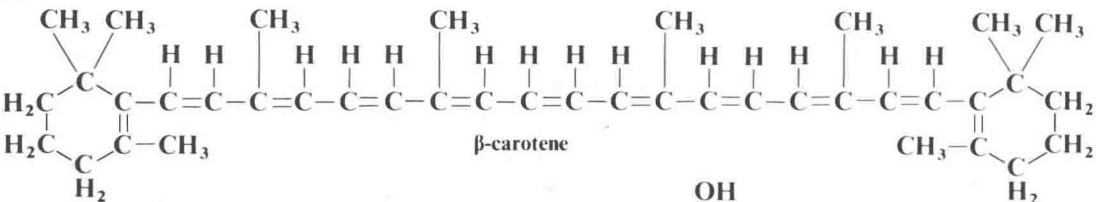
Q2
What factors affect the palatability of food?

Q3
Describe and explain the effect of heat and pH on the green colour of vegetables. Why can it be nutritionally bad to add sodium hydrogencarbonate to the water used to cook green vegetables?

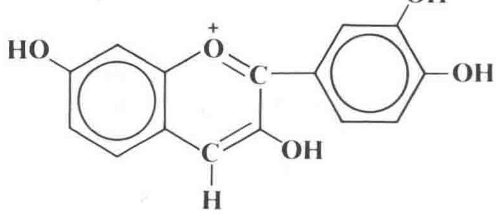
Q4
Draw diagrams to show *a* how calcium ions might give rise to cross links between $-CO_2H$ groups of neighbouring molecules of pectin and *b* why such cross links do not arise in the presence of sodium ions. How would you expect changes in pH to affect these interactions between pectin molecules?

Q5
The diagrams show the structures of a carotenoid and a flavonoid.
i Compare the structures of these two compounds with the structure of chlorophyll. What do the structures have in common?
ii Compare the structures with those of coloured indicators such as methyl orange and phenolphthalein.
iii To what extent are there opportunities for electron delocalization in these coloured, organic molecules?

Q6
Explain what you understand by the *flavour* of a food. How is the flavour of a food affected if you have a bad cold? Give examples of substances added to food to enhance flavour.



β-carotene



cyanidin
(a flavonoid)