Week 12 Pathways to Biomolecules

- Are molecules such as fats and oils, carbohydrates, proteins and nucleic acids that are found in all living things.

- Have an essential role in the
  - supply of energy to the body,
  - growth and repair of organs and tissue,
  - movement of muscles,
  - activity of nervous and hormonal systems,
  - the elimination of waste.

- Many are polymers *e.g.* cotton, wool and silk.

Fats

Describes a large number of organic compounds belonging to an even larger class of biological molecules called **lipids**.

Fats and **oils** are the best known types of lipids.
(The oils found in foods have quite different structures and properties from the hydrocarbon oils produced by petroleum refining).

Compounds such as waxes and **steroids** (which include **cholesterol**) are also members of the lipid family.

Lipids are based mainly on carbon and hydrogen with small amounts of oxygen and, occasionally, other elements.

Most lipids are essentially non-polar and so they are insoluble in water.

Substitution reactions

Fats and oils have very similar chemical structures. They are simply distinguished on the basis of their physical states at normal temperatures:
- Fats are solids
- Oils are liquids

Most fats and oils are formed by a condensation reaction between a single molecule of **glycerol** (alkanol) and three molecules of **fatty acids.**

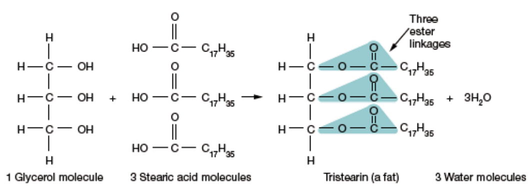


Figure 12.3
Glycerol reacts with three molecules of fatty acids to form a fat.

- Fatty acids contain a carboxy functional group which reacts with the hydroxy groups in the glycerol.
- The –COO– groups in fat are ester functional groups or ester linkages.
- Three molecules of water are also produced in this reaction.

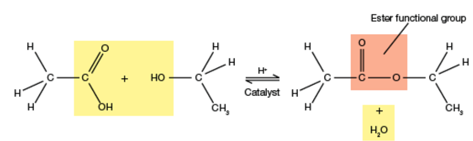


Figure 12.2
Ester links form when the carboxy group reacts with a hydroxy group. A water molecule is also produced.

Fats and oils formed from this process are called **triglycerides**.
Triglycerides are large, non-polar molecules and therefore insoluble in aqueous solutions.

Fats are distinguished on the basis of the fatty acids from which they are made.

Table 12.1 Examples of different types of fatty acids

Type	Semi-structural formula	Molecular formula	Name
Saturated	$CH_3(CH_2)_{14}COOH$	$C_{16}H_{32}O_2$	Palmitic acid
Mono-unsaturated	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	$C_{18}H_{34}O_2$	Oleic acid
Polyunsaturated	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$	$C_{18}H_{32}O_2$	Linoleic acid

Saturated fats are made from fatty acids that contain only *single* carbon–carbon bonds.
Saturated fats are generally unreactive and occur as waxy solids at room temperature.

Mono-unsaturated fats are made from fatty acids that contain *one* carbon–carbon *double* bond.

Polyunsaturated fats are made from fatty acids that contain *more than one* carbon–carbon *double* bond.
Polyunsaturated fats have lower melting points than saturated fats, and often occur as liquids (oils) at room temperature.
They are more reactive than saturated fats.

Both saturated and polyunsaturated fats are present in foods that contain fat.
In general, animal fats contain higher proportions of *saturated* fats, while vegetable oils are richer in *polyunsaturated* fats.

TABLE 12.2 Composition of fats and oils

Fat or oil	Saturated fat (%)	Polyunsaturated fat (%)	Mono-unsaturated fat (%)
Beef	52	4	44
Butter	66	4	30
Coconut	92	2	6
Palm	51	10	39
Peanut	18	34	48
Soybean	15	61	24
Olive	14	9	77
Corn	13	62	25
Sunflower	11	69	20
Safflower	9	78	13

What happens to fat in digestion?

The pancreas and the walls of the small intestine secretions enzymes that catalyse the **hydrolysis** of fat into fatty acids and glycerol, reversing the condensation reaction from which the fat was made.

Once the fatty acids and glycerol have been absorbed into the body, they are reassembled into triglycerides via condensation reactions.

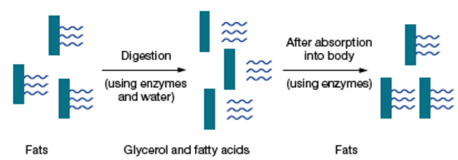


Figure 12.5
When fats are digested they are first hydrolysed and then re-formed by condensation reactions for transport to the adipose tissue.

Summary 12.1

- The functioning of large biomolecules is essential to life processes.
- Fats and oils belong to the class of biomolecules called lipids.
- Fats and oils are formed in a condensation reaction between glycerol and fatty acids.
- Three ester linkages are formed in the condensation reaction between glycerol and fatty acids to form triglycerides.
- Fatty acids can be saturated, mono-unsaturated and polyunsaturated.
- Fats and oils are broken down into glycerol and fatty acid molecules via a hydrolysis reaction in the digestive system.

Condensation polymerization

The monomers used to make a polymer by a condensation polymerisation reaction have ***a pair of functional groups*** that are able to react together, producing a new functional group that links the monomers and also producing a small molecule such as water.

Many biologically important molecules, including proteins, DNA, cellulose and starch, are formed in this way as are synthetic polymers such as nylon and polyester.

TABLE 12.4 Features of monomers used to produce different types of polymers

Type of polymer	Functional group in monomer(s)
Polyester	Carboxy, –COOH, and hydroxy, –OH
Polyamide (polypeptide)	Carboxy, –COOH, and amine, $-NH_2$
Polysaccharide	Hydroxy, –OH and hydroxy, –OH

Carbohydrates

The most abundant organic compound on earth is the polymer **cellulose**. Over half the world's organic carbon is bound up in plant material in the form of cellulose.

Cellulose belongs to a class of compounds called **carbohydrates**. As much as 75% of a plant's dry mass is cellulose or other carbohydrates.

Using sunlight, green plants, convert CO_2 and H_2O initially into the carbohydrate glucose.

- Carbohydrates are a source of energy in our diets.
- Carbohydrates are made from the elements C, H and O, and usually have the formula $C_x(H_2O)_y$ where *x* and *y* are whole numbers.
- Carbohydrates range in size from small molecules, with MW between 100 and 200, to very large polymers, with MW greater than one million.

Monosaccharides: The simple sugars

The smallest carbohydrates are the **monosaccharides**.
They are white crystalline solids that are highly soluble in water.
Most monosaccharides have a sweet taste.
Together with another group of carbohydrates called disaccharides, are often called **sugars**.

TABLE 12.5 Important carbohydrates

Carbohydrate	Composition	Where found
Monosaccharides		
Glucose	$C_6H_{12}O_6$	Fruit juices
Fructose	$C_6H_{12}O_6$	Fruit juices, honey
Galactose	$C_6H_{12}O_6$	Not found naturally in its free form
Disaccharides	*Formed from:*	
Maltose	Glucose + glucose	Germinating grain
Sucrose	Glucose + fructose	Sugarcane, sugar beet
Lactose	Glucose + galactose	Milk
Polysaccharides	*Polymer of:*	
Glycogen	Glucose	Energy store in animals—in the liver and muscles
Starch	Glucose	Energy store in plants—abundant in wheat, potatoes, corn etc.
Cellulose	Glucose	Plant fibre—in plant cell walls

The most abundant monosaccharide is glucose. It has the molecular formula $C_6H_{12}O_6$ and the atoms in the molecule are arranged in a ring.

Two other important monosaccharides are fructose and galactose.

All three molecules contain a number of polar OH groups, enabling them to form hydrogen bonds with water.
This explains the high solubility of monosaccharides in water.

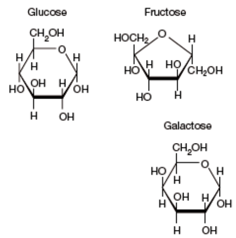


Figure 12.10
Structural formulas of glucose, fructose and galactose. The lines represent carbon–carbon bonds; carbon atoms in the rings have been omitted for clarity.

Glucose is found in all living things, especially in the juice of fruits, the sap of plants and in the blood and tissue of animals.

- functions as the key energy source in most forms of life,
- is also a major component of most of the larger carbohydrates,
- both glucose and starch are more rapidly digested food
  - ⇨the main sources of energy in most diets
  - ⇨ bodies use them for energy in preference to fats and proteins.

Fructose and galactose are not as abundant as glucose

- galactose is not found in nature as a free monosaccharide (occurs frequently as a component of larger carbohydrates),
- Fructose is found in many fruit juices and honey. It is the sweetest sugar known, being 1.7 times sweeter than table sugar!
- fructose: main role in the body is as an energy source (used in much the same way as glucose).

Disaccharides

When two monosaccharides undergo a condensation reaction, a **disaccharide** is formed.

Like monosaccharides, disaccharides also dissolve in water, taste sweet and are called sugars.

A disaccharide called

- **maltose** is formed when two glucose molecules react, with the elimination of a water molecule.
- **sucrose** is formed when glucose and fructose react with the elimination of a water molecule.

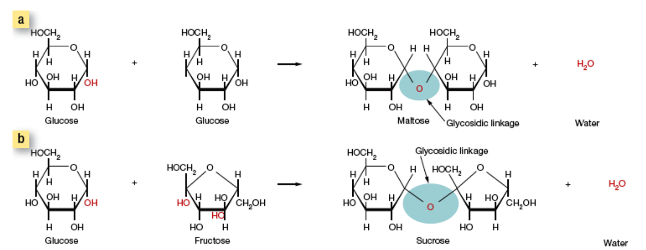


Figure 12.13
The condensation of a glucose molecules to form maltose, and b glucose and fructose molecules to form sucrose. Glycosidic linkages are highlighted.

Note how the hydroxy functional groups react to form the disaccharide and water. The two rings are joined via an oxygen atom. This linkage is called a **glycosidic** (or ether) **linkage**.

Two other important disaccharides are lactose and sucrose.

Lactose is a disaccharide made by the condensation of galactose and glucose.

- It is not as sweet as glucose.
- Lactose is synthesised in the mammary glands of mammals and is the main carbohydrate present in milk.

In contrast, sucrose is widely used as a sweetener because of its intense taste.

- is formed from the condensation of fructose and glucose.
- sucrose is found in the sap of some trees and the juices of many fruits. Table sugar is produced commercially by extracting sucrose from sugarcane or sugar beet.

Polysaccharides: The complex carbohydrates

Polysaccharides are polymer carbohydrates made by linking the monosaccharide glucose together in different ways by condensation reactions.

Polysaccharides are generally insoluble in water and have no taste.

The three most important polysaccharides biologically are:

- glycogen
- starch
- cellulose

Glycogen: a glucose storage molecule found in animals.

- As glucose can be oxidised to produce energy more rapidly than fat, all animals store some glucose for use when energy is required quickly.
- Excess glucose is polymerised to form glycogen, which is stored in the liver and in muscle tissue.
- When the stores are full, additional glucose is converted into fat.
- As energy is required, the glycogen is hydrolysed to yield glucose for respiration.

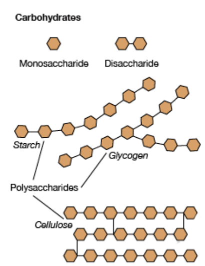


Figure 12.14
Starch and glycogen are polymers of glucose. The glucose molecules are joined together the same way, but glycogen is more highly branched than starch. Hydrogen bonds between parallel chains are formed in cellulose, producing strong, water-insoluble fibres.

Starch is the glucose storage molecule in plants (the equivalent of glycogen).
Starch is stored and used at night to meet the plant's ongoing energy requirements when glucose production from photosynthesis has ceased.

During digestion of starch and glycogen the polymers must be hydrolysed to release the glucose monomers. This hydrolysis is catalysed by enzymes

Starch/glycogen ⇨ Maltose ⇨ Glucose

These reactions can be regarded as the reverse of the condensation reactions from which maltose and starch or glycogen are formed from glucose.

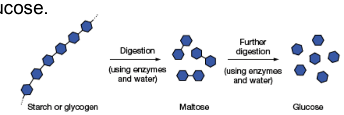


Figure 12.15
During digestion, enzymes catalyse the breakdown of starch into maltose and then into glucose.

Cellulose is the main structural material in plants.
It is a linear polymer of glucose (MW varying from 50 thousand to 2.5 million).
Chemical structure different from starch and glycogen due to slight differences in the linkages between the glucose monomers.

The CH_2OH groups on adjacent glucose monomers in starch are on the same side of the polymer chain, while in cellulose they are on alternating sides.

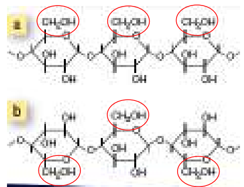


Figure 12.16
Sections of a starch and b cellulose polymers. Note the different orientations of the $-CH_2OH$ groups on adjacent glucose monomers.

summary 12.2–12.3

- Carbohydrates are a source of energy in our diets.
- Starch, glycogen and cellulose are condensation polymers of glucose.
- The condensation reactions that produce polysaccharides involve the formation of glycosidic linkages as hydroxy functional groups on adjacent monosaccharide molecules interact.
- During digestion, some complex carbohydrates are hydrolysed into monosaccharides.

key questions

6 Glucose is the most abundant monosaccharide. Draw a structural formula for glucose and use it to explain why it is highly soluble in water.

7 Glucose is described as a monosaccharide, maltose as a disaccharide and glycogen as a polysaccharide.
 a What is the difference between these three types of carbohydrate?
 b What type of reaction is involved in converting glucose to maltose and then to glycogen?
 c Which functional group in the molecules is involved in these reactions?

8 The structure of lactose is shown in Figure 12.21. Lactose undergoes hydrolysis in the digestion process.
 a What is meant by 'hydrolysis'?
 b Circle a hydroxy and a glycosidic functional group in the molecule.

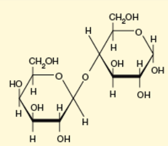


Figure 12.21
The structure of lactose.

key questions (cont.)

 i Draw the structures of the hydrolysis products.
 ii Lactose is a carbohydrate. Why does 10 g of lactose provide more energy for our bodies than 10 g of the main carbohydrate found in celery?

9 a i Write a chemical equation for the condensation reaction between two glucose molecules to form a maltose molecule.
 ii Draw structural formulas for all molecules involved in this reaction and circle the glycosidic linkage in maltose.
 b i Write a chemical equation for the condensation reaction between a glucose molecule and a fructose molecule to form a sucrose molecule.
 ii Draw structural formulas for all molecules involved in this reaction and circle the glycosidic linkage in sucrose.

11 Write a chemical equation for:
 a the hydrolysis of sucrose
 b the hydrolysis of [illegible] (see Figure 12.3)

Proteins

There are thousands of different types of proteins, each with its own specific purpose.

TABLE 12.6 Types of protein

Type	Function	Examples
Structural	Protection, support, movement	Skin, bone, cartilage, ligaments, tendons, muscle, hair, teeth, feathers, beaks, cocoons, insect exoskeletons
Enzymes	Biological catalysts	Digestive enzymes
Hormones	Regulation of body functions	Insulin
Transport	Movement of compounds between and within cells	Haemoglobin
Protective	Defence	Antibodies
Toxins	Attack	Snake and spider venoms
Most proteins	Energy source (only in extreme circumstances)	

Amino acids

Proteins are polymers built up from small monomer molecules called ***amino acids***.

Two of the simpler amino acids are glycine and alanine.

Every amino acid has an *amino group* (NH_2) and a *carboxy group* (COOH).

Twenty amino acids are commonly found in proteins in the human body.

They have the general formula $H_2N–CHZ–COOH$.

The major difference between amino acids is the **Z group**.
These amino acids are known as 2-amino acids or α-**amino acids** because the amino, carboxy and Z groups are all attached to the second carbon atom.

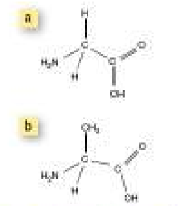


Figure 12.23 a Glycine. b Alanine.

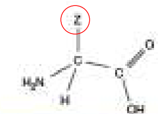
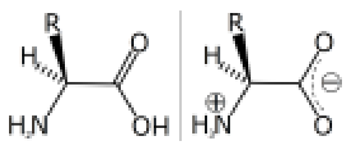


Figure 12.24 General structural formula of an α-amino acid. Different amino acids have different groups of atoms as the Z group.

As a consequence of the polar amino and carboxy functional groups, amino acids are soluble in water.

In solution, the amino group can act as a base and the carboxy group can act as an acid.

As a result, an amino acid molecule in a solution at a particular pH will usually be in the form $^+H3N–CHZ–COO^–$.
Such a molecule is called a **zwitterion** or **dipolar ion**.



A proton has been lost from the acidic carboxy group and the basic amino group has gained a proton.

The pH at which an amino acid exists as a zwitterion depends on the structure of the Z group.

In acidic solutions

$$^+H_3N–CHZ–COO^- (aq) + H_3O^+ (aq) \rightleftharpoons {}^+H_3N–CHZ–COOH (aq) + H_2O (l)$$

This form is predominant

In alkaline solutions

$$^+H_3N–CHZ–COO^- (aq) + OH^- (aq) \rightleftharpoons H_2N–CHZ–COO^- (aq) + H_2O (l)$$

This form is predominant

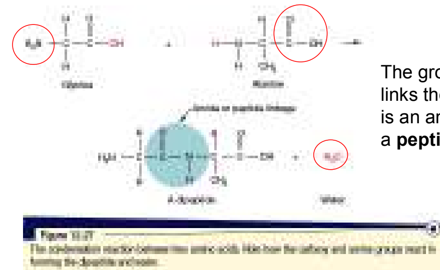
The ability of amino acids to react with both acids and bases means that they can act as *buffers*, minimising the effect that the addition of H^+ or $OH^–$ ions to a solution would have on acidity.
Their buffering action is of great importance in cells as biochemical processes can only operate correctly if the pH is maintained within a narrow range.

Protein structure

When a molecule that contains a carboxy group, COOH, combines with a molecule containing an amine group, NH_2, a condensation reaction occurs to form an amide functional group, –CONH–, that links the two molecules.
A water molecule, H_2O, is also formed.

Peptides / Proteins

Proteins are polymers formed by *condensation reactions* between amino acids
During these reactions the amino acids join and form long unbranched chains.
The amine group of one amino acid reacts with the carboxy group of an adjacent amino acid.
A covalent bond is formed and a molecule of water is eliminated.



The group of atoms –CONH– that links the constituent amino acids is an amide group, referred to as a **peptide linkage** in proteins.

Molecules made from amino acids are often called peptides *e.g.*
2 amino acid molecules = a dipeptide; 3 amino acid molecules = tripeptide
A polymer made from amino acids is known as a **polypeptide**,

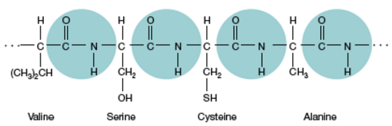


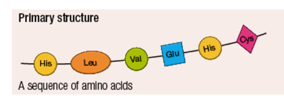
Figure 12.28
A section of a polypeptide chain, showing peptide linkages.

and polypeptides built up from more than 50 amino acids are usually called proteins. There can be more than 500 amino acid units in a large protein.

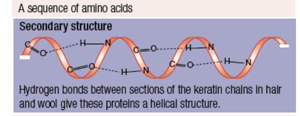
Proteins differ from one another in the number, type, and sequence of their constituent amino acids.
Each protein has a precise chemical composition, amino acid sequence, and three-dimensional shape.
Determining the structure of these complex materials has provided challenging problems for chemists.

Protein shape and function

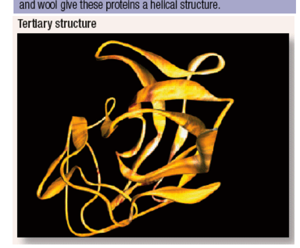
The role that any protein fulfils in an organism depends on its shape: primary, secondary and tertiary structures.



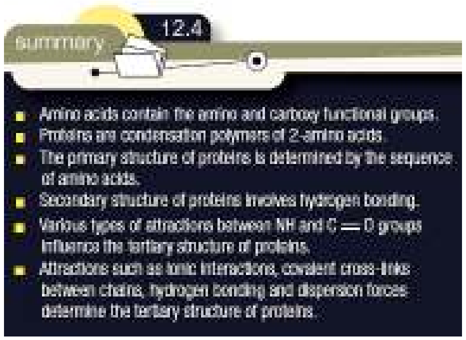
The order in which the amino acids making up the protein are joined together



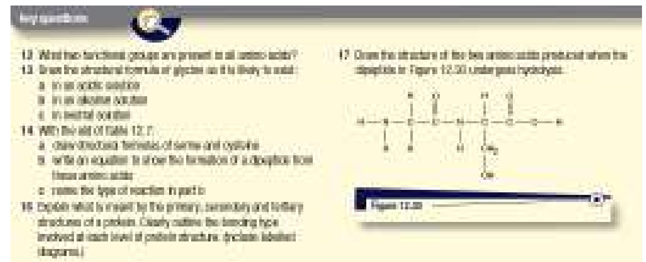
Folding and twisting of the chain, held in place by H bonds between the CO and NH groups in adjacent parts of the chain. Some proteins form a 3-dimensional helical shape



Overall 3-dimensional structure of the protein, which is formed by the presence of different functional groups in the Z-part of the amino acid, creating shapes that are held in place by disulfide (S-S) covalent bonds, ionic bonds between $NH3^+$ and COO^- groups, H bonds and dispersion forces.


summary 12.4

- Amino acids contain the amino and carboxy functional groups.
- Proteins are condensation polymers of 2-amino acids.
- The primary structure of proteins is determined by the sequence of amino acids.
- Secondary structure of proteins involves hydrogen bonding.
- Various types of attractions between NH and C $=$ O groups influence the tertiary structure of proteins.
- Attractions such as ionic interactions, covalent cross-links between chains, hydrogen bonding and dispersion forces determine the tertiary structure of proteins.



Enzymes: Biological catalysts

Biological catalysts are called **enzymes**.
Enzymes *control* the manufacture of complex substances as well as the breaking down of chemicals to provide energy.
Enzymes make life possible.

Compared to inorganic catalysts:

- *Enzymes produce much faster reaction rates.* They can increase the rate of a chemical reaction by as much as 1010 times.
- *Enzymes operate under much milder conditions.* Even with a catalyst, the conditions for the Haber process for ammonia are 500°C and 250 atm. Enzymes found in bacteria in the roots of leguminous plants perform a similar reaction at normal temperatures and pressures.
- *Enzymes are more sensitive.* The catalytic activity of many enzymes is destroyed when they are heated strongly because their delicate structure breaks down (described as being denatured).
- *Enzymes are very selective.* For example, platinum metal catalyses many reactions. On the other hand, the enzymes catalyse only particular reaction.

Enzymatic catalysis

The catalytic activity of an enzyme depends on its tertiary structure (its three-dimensional shape, a change in which can render an enzyme inoperative).

Some enzymes have small, non-protein parts called **cofactors**, such as vitamins or metal atoms, associated with the active site. These cofactors are necessary for the catalytic effect.

The **active site** of an enzyme is usually a flexible hollow or cavity within the molecule.

A reactant molecule, known as the **substrate**, is manoeuvred into this site and it is there at the *surface* of the enzyme that reaction takes place.

1. The reactant (substrate) enters the active site.
2. Bonds formed between the enzyme and substrate weaken bonds within the substrate, lowering the reaction's activation energy.
3. The substrate breaks or rearranges into new products and these products are released.

Figure 12.31
a-c Steps in the action of an enzyme.

The *selectivity* of enzymes is one of their most important features.

Although thousands of different reactions are possible in a cell, the presence of enzymes ensures that particular reactions occur rapidly and that others proceed at insignificant rates. In this way, order is maintained in living cells.

This selectivity is due to the shape and functional groups in the active site of the enzyme which allows it to bind only with certain substrates.

The enzyme and substrate are often described as fitting together 'like a lock and key'.

Denaturation of enzymes

Bonds responsible for holding the protein chains in particular shapes are often relatively weak
⇨slight changes in conditions can disrupt the attractions between parts of the chain,
⇨ the chain unfolds thus rendering the protein ineffective

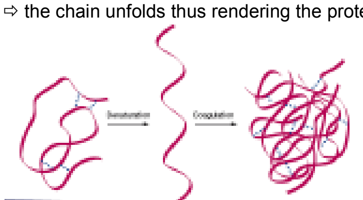


Figure 12.33

A change that destroys the biological activity of a protein is called **denaturation**.
Denaturation may result because of increased temperature, a change in pH, or the addition of various chemicals.

Enzyme activity is dependent on temperature

As temperature increases,

the rate of the reaction catalysed by the enzyme increases because of increased collisions between enzyme and substrate,

until an optimum temperature, about 40°C, is reached.

If the temperature increases further the enzyme is denatured and the reaction rate decreases rapidly.

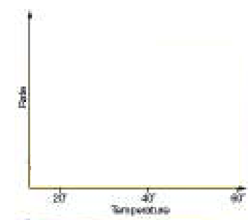


Figure 12.34
Effect of temperature on enzyme activity.

Enzymes operate effectively within a small pH range

Not all enzymes have the same optimum pH.

The ionisation of amino acids is dependent on pH.

The bonds that determine the tertiary structure of the enzyme are altered as changes in pH alter the ionisation of the amino acid residues in the protein.

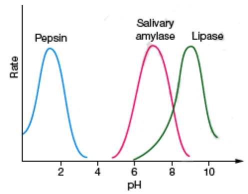
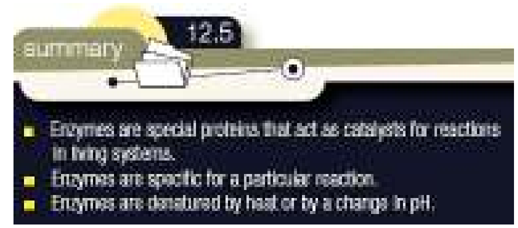
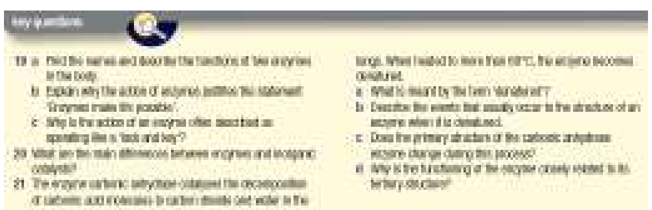


Figure 12.35
Effect of pH on enzyme activity.



- Enzymes are special proteins that act as catalysts for reactions in living systems.
- Enzymes are specific for a particular reaction.
- Enzymes are denatured by heat or by a change in pH.



key questions

19 a Find the names and describe the functions of two enzymes in the body.
b Explain why the action of enzymes justifies this statement: 'Enzymes make life possible'.
c Why is the action of an enzyme often described as operating like a 'lock and key'?

20 What are the main differences between enzymes and inorganic catalysts?

21 The enzyme carbonic anhydrase catalyses the decomposition of carbonic acid molecules to carbon dioxide and water in the lungs. When heated to more than 60°C, the enzyme becomes denatured.
a What is meant by the term 'denatured'?
b Describe the events that usually occur to the structure of an enzyme when it is denatured.
c Does the primary structure of the carbonic anhydrase enzyme change during this process?
d Why is the functioning of the enzyme closely related to its tertiary structure?

Proteins as markers for disease

Analytical techniques such as mass spectrometry (Chapter 8), infrared and NMR spectroscopy (Chapter 7) and advanced chromatographic techniques (Chapter 6) as well as two-dimensional electrophoresis are used to identify protein markers that indicate the presence of disease *e.g.* cancer; heart disease.

A raised level of these marker proteins in a patient's blood or tissue can be used to:

- identify a disease at early or advanced stages of development
- monitor the progress of the disease
- measure the effectiveness of treatment, and
- test for the recurrence of the disease.

A raised level of a particular protein marker may indicate the presence of disease before physical symptoms are evident.

There is a continuing search for new, specific, protein markers for a range of diseases.
The study of protein structure and function is called proteomics and it has an increasingly important role in the identification of disease.

Examples of the use of protein markers

Heart attack

The cells in the damaged part of the heart muscle release various cardiac enzymes into the blood stream:

- troponin (TnI, TnT)
- creatine phosphokinase (CPK)
- lactate dehydrogenase (LDH).

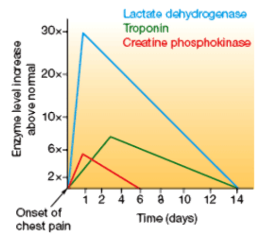
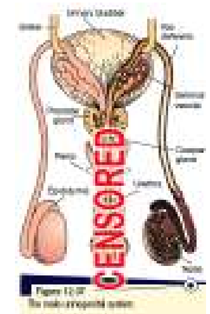
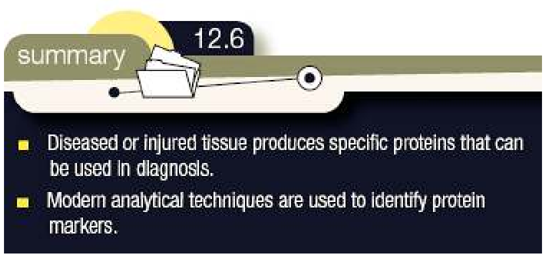


Figure 12.36 Changes in the levels of cardiac enzymes following a heart attack.

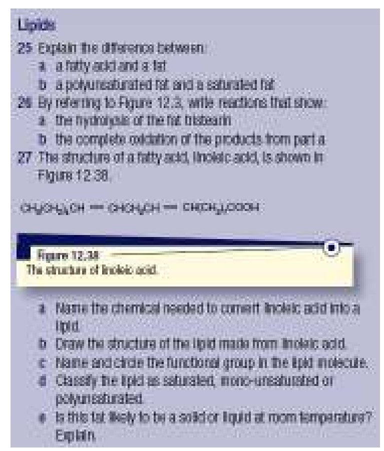
Prostate cancer

- Prostate gland cells produce PSA.
- Normally a small amount is present in the bloodstream.
- Abnormal cancerous or non-cancerous cell growths block the ducts in the prostate, forcing more PSA into the bloodstream.
- The concentration of PSA in the blood is used as a marker for possible prostate cancer.





Chapter review



Lipids

25 Explain the difference between:
  a a fatty acid and a fat
  b a polyunsaturated fat and a saturated fat
26 By referring to Figure 12.3, write reactions that show:
  a the hydrolysis of the fat tristearin
  b the complete oxidation of the products from part a
27 The structure of a fatty acid, linoleic acid, is shown in Figure 12.38.

$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOH$

Figure 12.38 The structure of linoleic acid.

  a Name the chemical needed to convert linoleic acid into a lipid.
  b Draw the structure of the lipid made from linoleic acid.
  c Name and circle the functional group in the lipid molecule.
  d Classify the lipid as saturated, mono-unsaturated or polyunsaturated.
  e Is this fat likely to be a solid or liquid at room temperature? Explain.

Carbohydrates

29 a By referring to Figure 12.13, draw structural formulas to show:

i the formation of a disaccharide from two fructose molecules

ii the hydrolysis of maltose

b Apart from water and maltose, what other substance is required for the hydrolysis of maltose?

29 Why is glycogen sometimes called 'animal starch'?

Proteins

31 Explain why body builders and weight-lifters eat a large amount of protein.

32 When alanine and glycine react, two different dipeptides can be formed.

a Write the formula for each dipeptide.

b How many tripeptides can be formed from three different amino acids?

c Proteins are formed using 20 different amino acids and can be hundreds of amino acid units in length. On the basis of your answers to parts a and b, what can you say about the number of different proteins possible?

34 a Circle the peptide linkages in the part of the protein chain shown in Figure 12.48.

Figure 12.48
A section of a protein molecule.

b Write the formulae of the amino acids that made up this part of the chain.

c Where in the body does hydrolysis of protein to form amino acids take place?

36 Proteins are often described in terms of their primary, secondary and tertiary structures. What is the difference between these levels of structure and how does each contribute to the role of the protein?

41 Jellied pineapple dessert cannot be made using gelatine and fresh pineapple because an enzyme in the pineapple causes molecules in the gelatine to break down instead of setting. Suggest how jellied pineapple might be prepared.