

1 Nutrition

1.1 The basic biochemistry of mammalian metabolites

The mammals are heterotrophic, that is to say they derive their essential nutrients, via food chains, from the primary producers, or autotrophs, which alone can fix carbon into organic molecules. The diet that a mammal ingests must include both energy-yielding substances and the nutrients needed for synthesis of its own proteins and other complex molecules. Mammals have restricted biosynthetic capabilities and many compounds, such as certain amino acids (the 'essential' amino acids) and some vitamins, must be taken in the diet in the form in which they will actually be used by the body.

In order to understand the nature of the digestive process, as well as the synthesis of proteins, and the physiological roles of other metabolites it is necessary to have some elementary knowledge of the properties and biochemistry of the substances involved. The classes of chemicals to be discussed are, in order, carbohydrates, lipids, proteins and vitamins.

1.2 Carbohydrates

1.2.1 General features

Among the carbohydrates are the primary products of plant photosynthesis. They are by far the most important energy-providing substrates for mammals. They may also, like the ribose sugars of the nucleic acids, be of structural importance. Most carbohydrates contain only the three elements carbon, hydrogen and oxygen, the ratio of hydrogen to oxygen in the molecule being typically 2:1. Compared with the lipids, there is a great deal more oxygen in the molecule for each atom of carbon. The general structural formula for carbohydrates is $C_x(H_2O)_y$.

Carbohydrates can be classified according to the number of basic sugar or saccharide units incorporated in the molecule. This saccharide unit is taken as a hexose or a pentose, that is a 6-carbon sugar or a 5-carbon sugar. However, trioses, or 3-carbon sugars, also exist and may be important intermediates in carbohydrate metabolism. A useful scheme of carbohydrate classification is shown in Fig. 1.1 (glycogen is not connected to a disaccharide as it goes directly to glucose on phosphorylation).

Foods with a high carbohydrate content, for example cereals, rice and potatoes, make up the bulk of human diet. As an adaptation to this diet

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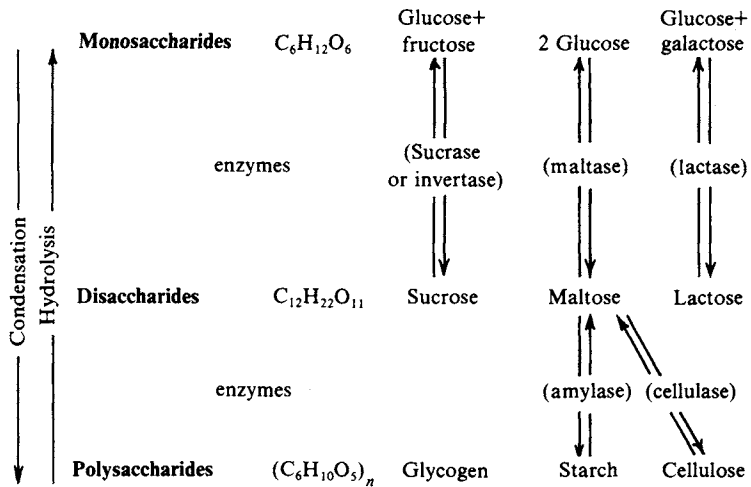


Fig. 1.1.
 A scheme of carbohydrate classification. (The *n* in the formula for polysaccharides may be some hundreds or thousands of units.)

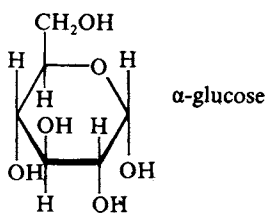
man has a collection of carbohydrases (or carbohydrate-splitting enzymes) capable of dealing with starch and the disaccharides maltose, sucrose and lactose. All these are hydrolysed in the alimentary canal to glucose or other monosaccharides which can be assimilated into the blood. Mammalian herbivores have symbiotic organisms in their gut for hydrolysing (the splitting of an organic molecule with the insertion of water) the polysaccharides such as cellulose with which they are unable to deal. (Cellulose in the walls of plant cells makes up the bulk of the herbivore's diet.)

Besides being able to hydrolyse carbohydrates, mammals are also able to synthesise them by condensation reactions involving energy-rich phosphates. (Condensation involves the removal of a water molecule and is the reverse of hydrolysis.) Many of the individual carbohydrates are interconvertible and fats may also be built up from monosaccharides.

On respiration carbohydrates yield 17.2 kilojoules per gram.

1.2.2 *Monosaccharides*

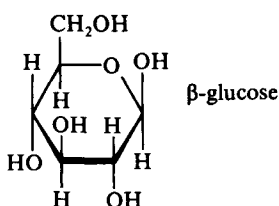
The most common monosaccharide is the hexose glucose. Its empirical formula is $C_6H_{12}O_6$ and the α form of the molecule may be represented as



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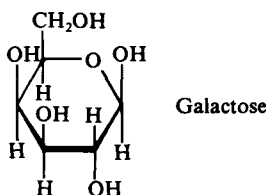
when two of the α forms of glucose condense together some form maltose and many of them form starch.

The β form of the molecule is represented by



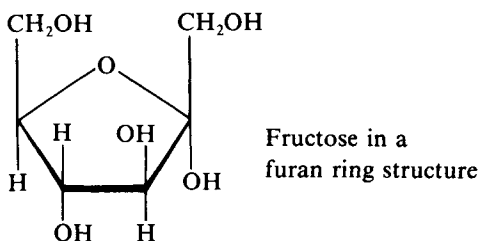
Two of these molecules condense to the transition product cellobiose, which on further condensation forms cellulose.

A hexose isomer which is produced by the hydrolysis of lactose is galactose.



As all the above contain the aldehyde ($-\text{CHO}$) group they are called aldoses. Included in this group is the important structural sugar ribose. Ribose has five carbon atoms in its molecule and, bound to nitrogen bases, it is a constituent of nucleic acids, adenosine triphosphate (ATP) and hydrogen carriers such as nicotinamide adenine dinucleotide (NAD).

Fructose is a hexose that exists in a five-sided furan ring structure (as well as the six-sided pyran ring of glucose).

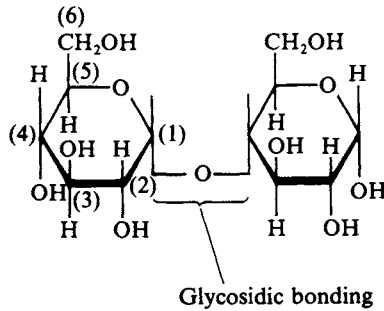


The empirical formula is $\text{C}_6\text{H}_{12}\text{O}_6$ and in the cyclic form the $>\text{C}=\text{O}$ group properties are not manifested.

All these monosaccharides can form condensation products by means of glycosidic bonds between particular atoms in adjacent sugars. The molecules thus produced are called glycosides. This bonding is similar to the formation of peptide links between amino acids and, as with these,

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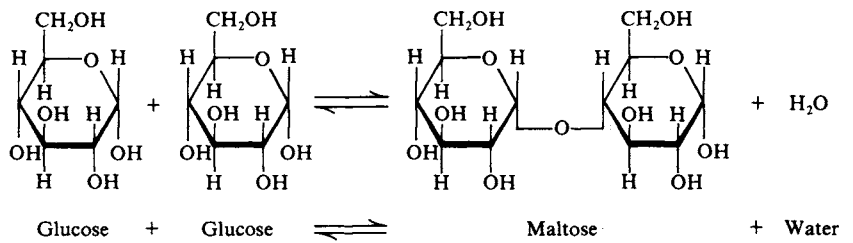
polymers are built up. Glycosidic bonds may also join monosaccharides to sterols and other chemicals.



Monosaccharides may also bond to other molecules via a nitrogen bridge. In this manner ribose bonds to nitrogen bases.

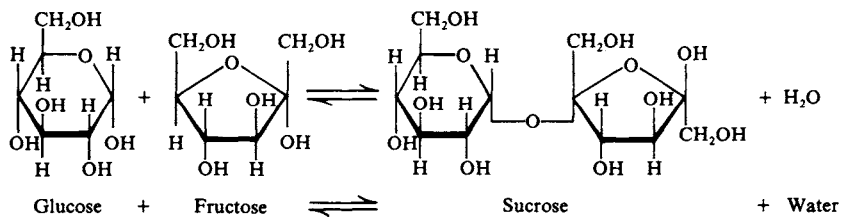
1.2.3 *Disaccharides*

The disaccharides are the most important subgroup of a larger group, the oligosaccharides, which also includes polymers with up to 10 sugar units in their molecules. The disaccharides most commonly met with in mammalian physiology are maltose, sucrose and lactose. Maltose is formed by condensation of two glucose units thus:



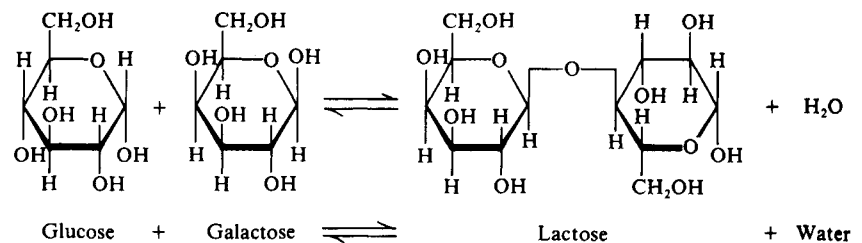
On hydrolysis by the enzyme maltase it yields the two monosaccharide units again.

Sucrose is formed by the condensation of glucose and fructose and is hydrolysed back to these units by the enzyme sucrase (sucrase is also called invertase because it inverts the optical rotation of the disaccharide).



1.2 Carbohydrates

Lactose, or milk sugar, is formed from glucose and galactose and in turn is hydrolysed by lactase. This enzyme is present in the young of mammals, including man. In some races of man it is not present later in life and ingestion of milk sugar can cause intestinal disturbance.



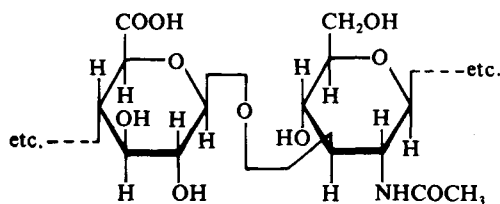
1.2.4 Polysaccharides

Where 10 or more sugar monomers are linked together the resulting molecule is termed a polysaccharide; when all the monomers are the same it is called a homoglycan polysaccharide and where they are different a heteroglycan polysaccharide. Cellulose is a structural polysaccharide which is synthesised from β -glucose units and is vitally important in plants. It is not found incorporated into animal tissues.

Mammals do not possess cellulase and cannot metabolise the polymer cellulose without the help of symbiotic micro-organisms which are able to hydrolyse the molecule via cellobiose to β -glucose. This latter can be utilised.

Chitin is another structural polymer. It is very important in the composition of the arthropod exoskeleton, though, like cellulose, it is not metabolised by mammals.

Hyaluronic acid is a heteroglycan with the following structure:



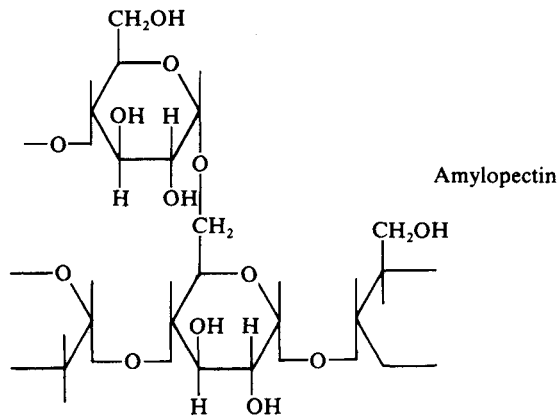
Repeating unit of hyaluronic acid

The chains are extremely long and the molecule has a molecular weight of many millions. It is an exceedingly important component of mammalian connective tissues, those tissues that hold all the other tissues together. It is also found in the vitreous humour of the eye and in the movable joints as part of the synovial fluid. Here it shows the remarkable property of changing its viscosity according to the strength of the shear forces that are acting on it at any given time. This makes it suitable for the lubrication of

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joints over a wide range of working conditions. Hyaluronic acid is also associated with collagen, a protein which may make up as much as a third of all the protein of the mammalian body.

The food-storage polysaccharides important to mammals are starch and glycogen. Starch is a heteroglycan made up of amylopectin and amylose. The former consists of branched chains of α -glycosides with the branches between adjacent carbon atoms as shown:



Amyloses, the other components of starch, are long unbranched chains of α -glucoses held together by glycosidic bonds. Both amylopectins and amyloses are hydrolysed in the mammalian digestive tract.

Glycogen is the typical storage polysaccharide of mammals. It has an interesting structure which, while keeping the glucose in a polymeric form that prevents it from having undesirable osmotic effects, at the same time allows rapid mobilisation. Glycogen has a long 'spine' chain out of which, every fourth or fifth monomer, comes a side chain of some 10 glucose units (Fig. 1.2). The enzyme phosphorylase is able to hydrolyse these side

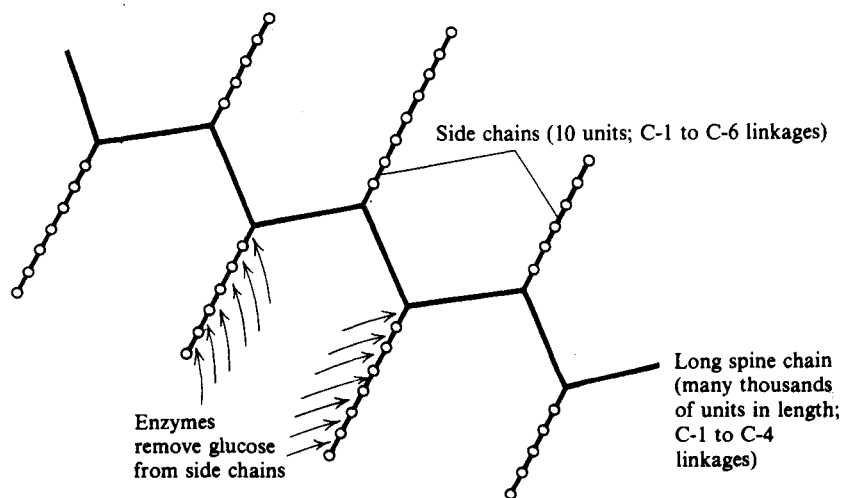


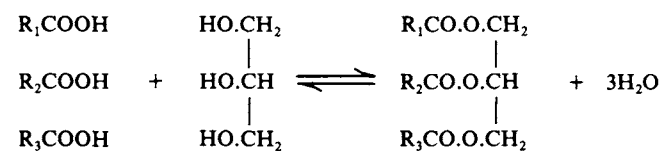
Fig. 1.2.
 The glycogen molecule.
 (After C. F. Phelps.)

1.3 Lipids

chains rapidly and thus to free large amounts of glucose as required. It does not split the long spine chain, however, although this can be done by another enzyme. The glycogen can be likened to a tree covered in fruit, the latter being readily removed (and, in the case of the glycogen, also readily returned) while the tree itself remains intact.

1.3 Lipids

The major lipids of the mammalian body are the fats and these are esters of fatty acids with polyhydric alcohols, especially glycerol, and their formation and hydrolysis can be represented as:



Fatty acids Glycerol A fat (a triglyceride)

Here R_1 , R_2 and R_3 may be the same fatty acid or different ones. If not all the positions are occupied then this gives monoglycerides or diglycerides.



Monoglyceride

Diglyceride

Or if the third position on the glycerol is taken by a phosphate/nitrogen base complex this gives the important class of molecules known as phospholipids (see below).

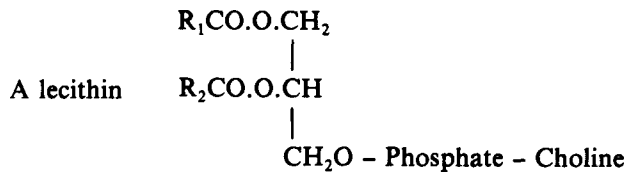
The fatty acids most commonly involved in fat formation are stearic ($\text{C}_{17}\text{H}_{35}\text{COOH}$), oleic ($\text{C}_{17}\text{H}_{33}\text{COOH}$) and palmitic ($\text{C}_{15}\text{H}_{31}\text{COOH}$) acid. Of these stearic and palmitic are saturated, that is they have no double bonds, while oleic acid is unsaturated. Fats which are solid at room temperatures tend to contain more of the saturated fatty acids, whereas oils, which are liquid at the same temperatures, contain more unsaturated acids.

Weight for weight there is more energy in fats than in other foods. They yield 39 kilojoules per gram on oxidation, which is more than twice the energy yield from carbohydrate or protein. Fats are therefore good forms of energy store and they are found in adipose tissues under the skin and around various internal organs in mammals. In the liver fats are oxidised via the tricarboxylic acid (or Krebs) cycle and for their effective metabolism a supply of carbohydrate is also necessary.

Besides their role in the provision of energy, fats have other essential functions in mammals. They also function as phospholipids which, as

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mentioned above, are formed when glycerides combine with phosphate and nitrogenous bases. Lecithins are phospholipids where choline is the nitrogen base:



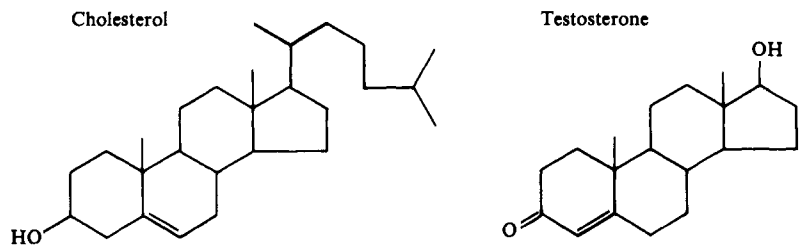
The phosphate/base end of the molecule is hydrophilic while the fatty acid end is hydrophobic. Such lipids are essential constituents of cell membranes. Besides lecithins, molecules incorporating glycerol, fatty acids and either serine, inositol or ethanolamine are also important. A further class of lipids combines fatty acids with the nitrogenous base sphingosine; these sphingolipids may also be incorporated in cell membranes.

Lipid composition of rat liver cell membranes (as percentage total lipid)

Cholesterol	17
Free fatty acids	} 10
Triglycerides	
Lecithins	} 60
Serine, inositol and ethanolamine lipids	
Sphingolipids	
Others	13

Lipids are also found in mammals as waxes. In these the alcohol component of the lipid is more elaborate than glycerol and may be aromatic in construction.

The final group of lipids is the sterols. These have a ring structure and are often combined with fatty acids. Two important mammalian sterols are cholesterol and testosterone.

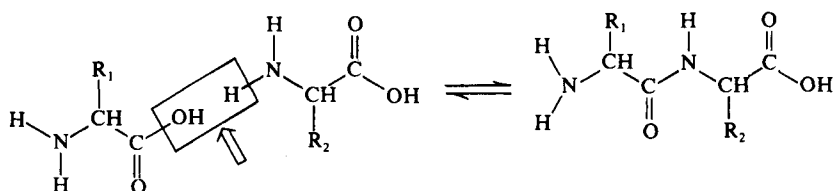


Cholesterol is a constituent of cell membranes. It is also the basic molecule from which various steroid hormones, such as the adrenal cortical hormones, and the gonadal hormones oestrogen and testosterone, are synthesised. Under certain conditions the body can manufacture vitamin D from a cholesterol-type precursor. The recently discovered and rapidly metabolised class of hormones known as prostaglandins also have a sterol-based structure. The role of one of these hormones is indicated on p. 178.

1.4 Proteins

1.4 Proteins

Proteins are very complex organic molecules containing carbon, hydrogen and oxygen, and less commonly sulphur and phosphorus. All proteins are formed by the condensation of amino acids to give peptide chains. On hydrolysis the peptide linkages in this chain break as shown below:



Although some 80 amino acids are known only 22 of these are commonly found in proteins, the great variety of proteins being due to the very large number of possible sequences of amino acids.

A possible classification of the common amino acids gives us six groups:

1. Monoamino (one $-\text{NH}_2$ group) and monocarboxylic (one $-\text{COOH}$ group)

e.g. glycine	leucine
alanine	isoleucine
valine	

2. Monoamino, monocarboxylic but also include a hydroxyl ($-\text{OH}$) group

e.g. serine
threonine

3. Monoamino, dicarboxylic

e.g. aspartic acid	glutamic acid
asparagine	glutamine

4. Diamino, monocarboxylic

e.g. lysine
hydroxylysine
arginine

5. Sulphur-containing

e.g. cysteine
cystine

6. Aromatic and cyclic

e.g. phenylalanine	histidine
tyrosine	proline
tryptophan	hydroxyproline

Proteins vary considerably in size. They range from small ones, such as insulin which has some 50 amino acids and a molecular weight of 6,000,

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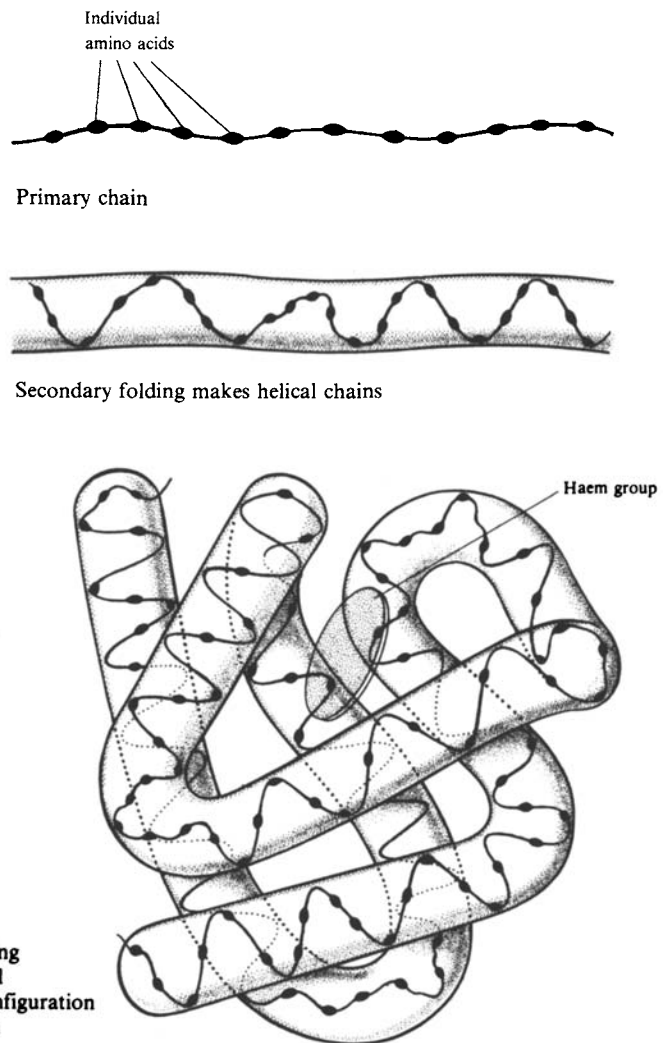


Fig. 1.3.
 Stages in the formation
 of a tertiary protein
 such as myoglobin.

Tertiary folding
 produces final
 molecular configuration
 of the protein

through those of intermediate size, such as haemoglobin with a molecular weight of around 66,000, to the largest, such as fibrinogen with a molecular weight of nearly half a million. Their structures are further complicated by the fact that the primary chains of amino acids become folded into helices or lattices (secondary structure) and that these in turn take up tertiary arrangements. Fig. 1.3 shows these stages in the formation of a myoglobin molecule. Quaternary structure results from the joining of two, three or more molecules to form dimers, trimers or even larger conglomerates, respectively.

The various foldings of proteins are stabilised by the formation of cross-linkages between adjacent amino acid chains. These may be strong covalent links, as with the $-S-S-$ bonds between cysteines, or may be weaker hydrogen bonding. Besides the amino acid sequences proteins