5) Cellulose molecules are insoluble in water, due to their size and structure. In cellulose, glucose units are linked to each other by β-1,4 linkages to form large linear polymers. Human beings do not possess the enzyme required to hydrolyse this bond. Amylase present in human saliva and pancreatic juice are suited for the hydrolysis of α-1,4 glucosidic bonds only. Hence, the glucose present in cellulose is unavailable to human beings as an energy source.

6) Structures of maltose, lactose and sucrose are given in section 2.4. Sucrose is the major disaccharide present in sugarcane, lactose is present in milk and maltose is a product obtained during incomplete (enzymatic) hydrolysis of starch, glycogen or dextrins and is present naturally in barley malt.

7) Polysaccharides can be classified on the basis of their composition as homopolysaccharides (starch) and heteropolysaccharides (Peptidoglycan of cell wall). Functionally, two types of polysaccharides are distinguished, namely, storage polysaccharides like starch and glycogen, and structural polysaccharides, like cellulose and chitin.

UNIT 3 : LIPIDS

Structure

3.1 INTRODUCTION

In Unit 2 we described carbohydrates, an important class of biomolecules, which are a source of energy for the cell. These molecules also form part of the structure of the cell. Another class of biomolecules, namely lipids, which are extremely hydrophobic in nature, are essential constituents of all living cells. You will recall that we briefly introduced you to the structure of membranes in Unit 1. You learnt that lipids form part of the structure of cell membranes. These molecules also store energy for the cell, and, in addition, perform some other tasks also. In Unit 3 we will describe the biological importance of lipids and classify them into various types. We will also illustrate their chemical composition. Besides this you shall learn more about the structure and function of biomembranes. In the next unit we will describe nucleic acids. Like carbohydrates, nucleic acids are biopolymers and are important components of the cell.

Objectives

After studying this unit you should be able to:

- describe the main functions of lipids in the organism,
- classify lipids into various groups,
- describe the essential structural features and major functional roles of various classes of lipids, and
- describe the role of lipids in the formation and functioning of biomembranes.

3.2 BIOLOGICAL IMPORTANCE OF LIPIDS

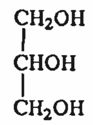
Lipids constitute a very heterogeneous group of biological compounds, which have a common property of being sparingly soluble in water but being freely soluble in organic (lipophilic) solvents, such as ether, chloroform and benzene. They include such diverse compounds as fatty acids, acylglycerols, phosphoglycerides, steroids, terpenes and prostaglandins. Triacylglycerides, the most predominant form of natural lipids, serve as important dietary constituents, because of their high calorific value (9.3 kcal/gm or 38.8 kJ g-1) as compared to proteins or carbohydrates (4.1 kcal/gm or 17.1 kJ g-1). Phospholipids are essential structural components of all biological membranes and serve to compartmentalise the cells. Some lipids are also important precursors of hormones and vitamins. The cell also synthesises prostaglandins from lipid molecules. Prostaglandins act as defences against many sorts of changes in the cell.

We shall now describe the general classification of lipids and then learn in detail about the various types of these lipids.

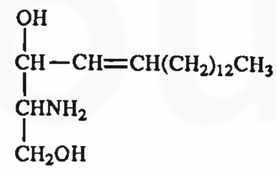
3.3 CLASSIFICATION OF LIPIDS

Lipids can be classified into three main classes. These are simple lipids, complex lipids and derived lipids.

Simple lipids are esters of fatty acids with alcohols, such as glycerol. Oils and fats are common examples of this class of lipids. **Fats** are generally esters of fatty acids with glycerol and a fat in the liquid state is known as an **oil**. **Waxes** are also simple lipids and are esters of fatty acids with high molecular weight monohydric alcohols.



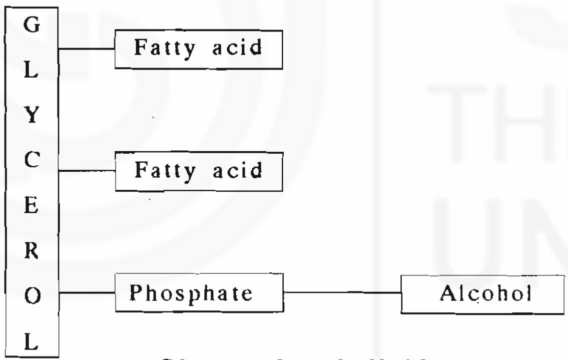
Glycerol



Sphingosine

Complex lipids are also esters of fatty acids with alcohol. However, in addition, they contain other groups, such as a phosphate group or a carbohydrate moiety. This group comprises of the following types of lipids.

a) **Phospholipids** These complex lipids contain a phosphate group, in addition to fatty acids and an alcohol. They frequently have nitrogen containing bases and other substituents as well. Phospholipids, that contain glycerol as the alcohol are known as glycerophospholipids and those containing sphingosine as the alcohol are known as sphingophospholipids.



Glycerophosphollpids

b) **Glycolipids** These lipids contain a carbohydrate group, in addition to a fatty acid and an alcohol. You should note that the main difference between a phospholipid and a glycolipid is that the former contains a phosphate group, whereas the latter contains a sugar group instead. The sugar group in glycolipids is usually galactose. Glucose is present in these lipids less frequently. The alcohol is either sphingosine or glycerol.

c) **Other Complex Lipids** This category comprises of lipids such as, sulpholipids, aminolipids and lipoproteins.

Derived lipids are the third major class of lipids, besides simple and complex lipids. These are obtained from the above mentioned groups by hydrolysis and include fatty acids (saturated as well as unsaturated), glycerol, steroids, lipid soluble vitamins and prostaglandins.

We shall now describe some of the important types of lipids and examine their structural features and importance.

3.3.1 Fatty Acids

Fatty acids are long chain hydrocarbons containing a terminal carboxyl group. They are obtained by the hydrolysis of fats. Most of the fatty acids, especially those which occur in natural fats, contain an even number of carbon atoms (usually more than fourteen C-atoms). These are generally straight chain compounds and the chain may be saturated, i.e., without any double bond, or unsaturated, i.e., with one or more double bonds. Fatty acids normally occur as their esters in natural fats and oils. However, they do occur in the unesterified form as free fatty acids in the plasma, bound to certain proteins.

Fatty acids are generally named after the parent hydrocarbon, with **-oic** being substituted for the final **-e** in the name of the hydrocarbon. Thus saturated fatty acids end in **-anoic** acid, as in octanoic acid ($CH_3 - (CH_2)_6 - COOH$). Similarly unsaturated fatty acids with double bonds end in **-enoic** acid, as in octadecenoic acid ($(CH_3) - (CH_2)_7 - CH = CH - (CH_2)_7 - COOH$, oleic acid). The carbon atoms are numbered from the carboxyl carbon, which is designated as carbon atom no. 1. The carbon atom adjacent to the carboxyl carbon is known as carbon atom no. 2 or α-carbon. Similarly carbon atom no. 3 is also known as β-carbon, and the terminal methyl carbon is known as the ω-carbon or *n*-carbon atom. For indicating the number and position of the double bonds in unsaturated fatty acids, various conventions are used. For example, Δ^9 indicates a double bond between carbon atoms 9 and 10 in the hydrocarbon chain. Similarly, ω-9 indicates a double bond on the 9th carbon atom, counting from the ω-carbon. We shall illustrate this by taking oleic acid, as an example. A number of 18:1; 9 or 18:1; Δ^9 would suggest an 18-carbon chain with a double bond at C-9, counting from the carboxyl carbon.

$$\overset{18}{C}H_3(CH_2)_7\overset{10}{C}H = \overset{9}{C}H(CH_2)_7\overset{1}{C}OOH$$

The oleic acid molecule can also be represented by ω-9, C18:1 or n-9, C 18:1

$$\underset{\omega}{\overset{1}{C}}H_3\overset{2}{C}H_2\overset{3}{C}H_2\overset{4}{C}H_2\overset{5}{C}H_2\overset{6}{C}H_2\overset{7}{C}H_2\overset{8}{C}H_2\overset{9}{C}H = CH(CH_2)_7COOH$$

In this case the carbon no. 9 is counted from the ω-carbon. The digit 1 after 18 in both the cases, denotes one unsaturated bond in the molecule. We have presented the systematic names, common (trivial) names, structure and occurrence of the more frequently occurring saturated and unsaturated fatty acids in Tables 3.1 and 3.2, respectively.

Table 3.1 : Commonly occurring saturated fatty acids

Common name	Systematic name	Structure	Source
Butyric acid	Tetranoic acid	$CH_3(CH_2)_2COOH$	Butter fat
Lauric acid	Dodecanoic acid	$CH_3(CH_2)_{10}COOH$	Palm kernel and coconut oils
Myristic acid	Tetradecanoic acid	$CH_3(CH_2)_{12}COOH$	Coconut, nutmeg and palm kernel oils
Palmitic acid	Hexadecanoic acid	$CH_3(CH_2)_{14}COOH$	Present in all animal and
Stearic acid	Octadecanoic acid	$CH_3(CH_2)_{16}COOH$	plant fats
Arachidic acid	Eicosanoic acid	$CH_3(CH_2)_{18}COOH$	Peanut oil

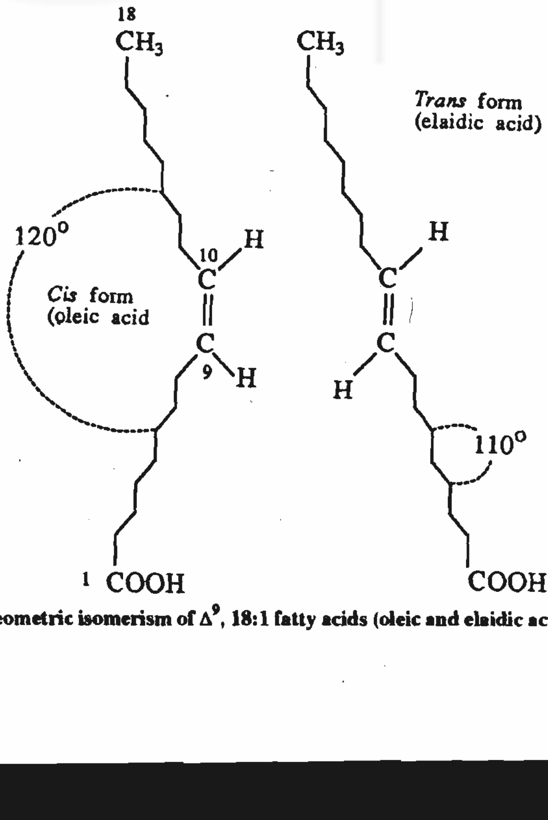
Table 3.2 : Unsaturated fatty acids of biological importance

Common name	Systematic name	Structure	Source
Palmitoleic acid	9-Hexadecenoic acid	$CH_3(CH_2)_5CH = CH(CH_2)_7COOH$	All fats
Oleic acid	9-Octadecenoic acid	$CH_3(CH_2)_7CH = CH(CH_2)_7COOH$	All fats
Linoleic acid	9,12-Octadecadienoic acid	$CH_3(CH_2)_4CH = CHCH_2-CH = CH(CH_2)_7COOH$	Corn, peanut,
Linolenic acid	9,12,15-Octadecatrienoic acid	$CH_3CH_2CH = CHCH_2CH = CHCH_2CH = CH(CH_2)_7COOH$	Frequently found with linoleic acid
Arachidonic acid	5,8,11,14-Eicosatetraenoic acid	$CH_3(CH_2)_4CH = CHCH_2CH = CHCH_2CH = CHCH_2CH = CH(CH_2)_3COOH$	Peanut oil

While most of the fatty acids have either 16, 18 or 20 carbon atoms, fatty acids with lesser number of carbon atoms (4- 8) are present in milk fat, whereas those of intermediate chain length (10-14), and between 16-20 C atoms are found in most of the animal and vegetable fats.

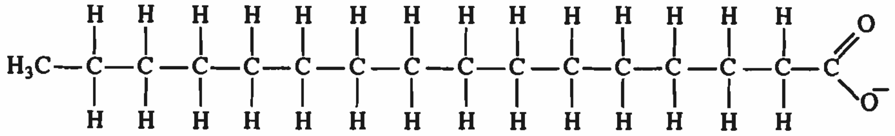
Saturated fatty acids do not contain any double bond. The unsaturated fatty acids, containing one double bond are called **monounsaturated fatty acids**. Those unsaturated fatty acids having two or more double bonds are known as **polyunsaturated fatty acids** (PUFA). Some of the PUFAs, such as linolenic, linoleic and arachidonic acids are not synthesised by higher animals and man. These have to be supplied through dietary sources, as they are essential for normal health and well being of the organism. Such fatty acids are known as **essential fatty acids** (EFA).

The carbon chain of a saturated fatty acid forms a zig-zag pattern, when fully extended. In unsaturated fatty acids, a *cis-trans* geometric isomerism occurs, depending upon the orientation of atoms or groups around the axis of the double bonds. When the acyl and alkyl groups are on the same side of the double bonds, it is *cis*, as in most PUFAs. If the acyl and alkyl groups are on the opposite sides, it is *trans* configuration. This is illustrated for oleic and elaidic acids below:



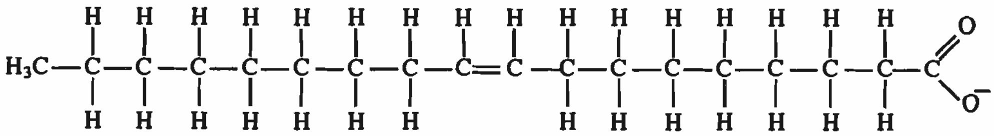
Geometric isomerism of Δ^9, 18:1 fatty acids (oleic and elaidic acids)

You would observe from the above structures that a *cis* double bond produces a bend in the molecule. This would be more conspicuous with increasing unsaturation. Therefore, you should picture unsaturated fatty acids as bulky groups, occupying a large space due to the bends in their hydrocarbon chains. In Fig. 3.1 we have shown a space filling model of a saturated fatty acid, palmitate, and an unsaturated fatty acid, oleate. The latter shows the resulting bend, due to unsaturation, in the molecule.



Plalmitate

(iorised form of palmitate acid)



Oleate

((ionisd form of oleic acid)

Fig. 3.1 : Space-filling models of (a) palmitate (C_{16}, saturated) an (b) oleate (C_{18}, unsaturated). The *cis* double bond in oleate produces a bend in the hydrocarbon chain

Naturally occurring unsaturated fatty acids are always of the *cis* configuration. The molecules being bent at 120° at the double bond. Increase in the number of double bonds in a fatty acid leads to a number of spatial configurations of the molecule. For example, arachidonic acid which has four double bonds, assumes almost a U shape.

The melting points of even carbon fatty acids, increase with carbon chain length, and decrease with increasing unsaturation. For example, triacylglycerols containing saturated fatty acids of 12 carbons or more only, are solids at body temperature. However, if the fatty acids in them are 18:2, i.e., a carbon chain of 18 atoms with two double bonds, they are liquids below 273 K. Naturally occurring triacylglycerols contain a mixture of fatty acids that serve their functional roles. For example, lipids found in membranes are more unsaturated than the storage lipids.

SAQ 1

Tick [√] mark the following statements as True or False.

a) Most of the naturally occurring fatty acids contain odd number of carbon atoms [True/False]

b) Glycolipids lack a phosphate group and, instead, contain a sugar group [True/False]

c) The double bonds in naturally occurring unsaturated fatty acids are always in *cis* configuration [True/False]

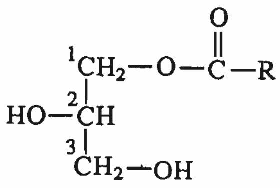
d) A triacylglycerol having all the three fatty acids as 18:2, is a solid at body temperature [True/False]

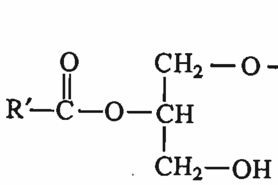
In the foregoing lines we mentioned about triacylglycerols. We will now describe these molecules in the next subsection.

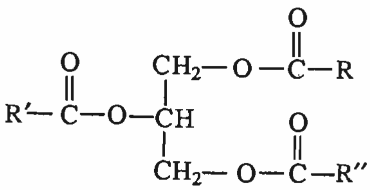
3.3.2 Acylglycerols

Acylglycerols are the most abundant group of naturally occurring lipids. They are the esters of fatty acids with the trihydroxy alcohol, glycerol. Either one, two or all the three hydroxyl groups of glycerol can undergo esterification to yield **mono –**, **di –**, and **triacylglycerols,** respectively. Triacylglycerols, the so called neutral fats as they do not carry a charge, are also known as **triglycerides.**

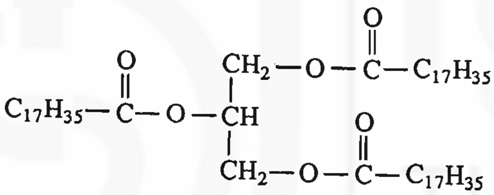
We have illustrated below, the general structures of the three acylglycerols, wherein R, R′ and R″ represent the fatty acid residues.


Monoacylglycerol

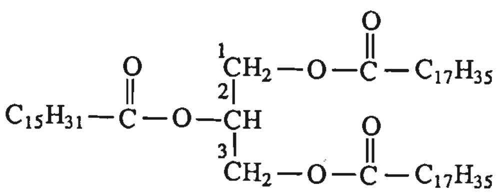

Diacylglycerol

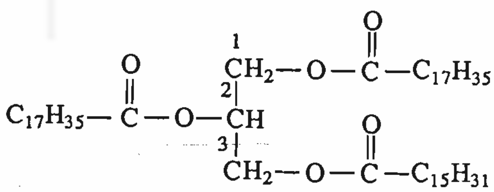

Triacylglycerol

While most of the naturally occurring lipids are all triacylglycerols, the mono- and diacylglycerols are formed as intermediates in the metabolism of lipids. Triacylglycerols generally contain different fatty acids in the three ester positions i.e., they are **mixed acylglycerols**. We shall illustrate the structure and nomenclature of a few triacylglycerols:


Tristearin

The above fat molecule is known as tristearin, since it consists of three stearic acid residues which are esterified with glycerol.


1,3-Distearopalmitin


1,2-Distearopalmitin

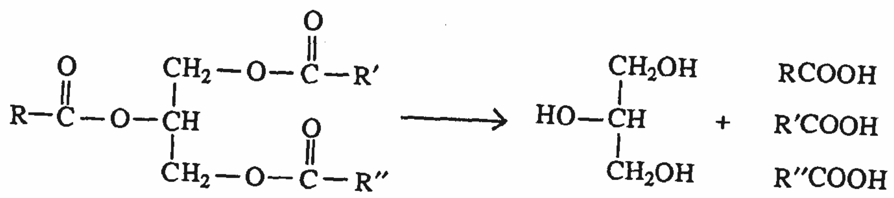
The above two molecules are examples of mixed acylglycerols as they contain two stearic acid and one palmitic acid residues esterified with glycerol.

We shall now briefly describe some of the properties of acylglycerols. Triacylglycerols from animal sources normally contain a higher percentage of saturated fatty acids and are solids at room temperatures. These are generally known as **fats**, while those from vegetable sources are rich in unsaturated fatty acids, and are generally liquids at room temperature. They are known as **oils**. Pure oils and fats are colourless, odourless and tasteless. They are insoluble in water but can form emulsions in the presence of emulsifying agents, such as soaps and bile salts. This process of emulsification usually occurs during the digestion of fats and oils in the small intestine, in which bile salts aid in emulsification process.

Let us now examine the effect of hydrolysis on acylglycerols.

Hydrolysis of Acylglycerols

When a triacylglycerol is subjected to hydrolysis, the ester bonds are hydrolysed. Three molecules of fatty acids and one molecule of glycerol are obtained. This reaction can be catalysed by acids, alkalies or enzymes (lipases):



Triacylglycerol **Glycerol** **Fatty acids**

Lipases are secreted along with digestive juices in an animal and are responsible for digestion of fats in the stomach. Alkaline hydrolysis of a fat is also called **saponification**, since the fatty acids liberated would be present as their salts, i.e. soaps. An oil or fat can be characterised by the **saponification number**, which is the weight in milligrams of KOH required to completely saponify one gram of fat or oil. This is a measure of the fatty acid component in a fat and a higher value indicates presence of mostly short chain fatty acids.

We shall briefly describe the importance of unsaturation in oils and fats.

Unsaturation in Oils and Fats

The unsaturated fatty acid present in an oil or a fat can be catalytically reduced in the presence of hydrogen (hydrogenation). They can also be halogenated with bromine or iodine. This addition of halogen (**iodine number**) is used to determine the degree of unsaturation of an oil or a fat. Iodine number, of a fat is defined as the weight in grams of iodine that can be taken up by 100 grams of fat or oil. Higher the iodine number, greater is the degree of unsaturation present in the fat. Oils with higher iodine number are thus preferred, as their nutritional value is higher. The iodine number of coconut oil is about 8, while that of butter fat is about 36, compared to 81 for olive oil, 93 for groundnut oil and 145 for safflower oil.

Another property of unsaturated fats is their easy oxidation. Many oils and fats when allowed to stand in contact with air, become rancid and develop unpleasant odours. This is attributed to the oxidation of the double bonds, yielding short chain aldehydes and keto acids. This oxidative **rancidity** of oils and fats can be prevented by the addition of antioxidants, like vitamin E. Rancidity of fats can also occur due to partial hydrolysis of the ester linkage, giving rise to free fatty acids.

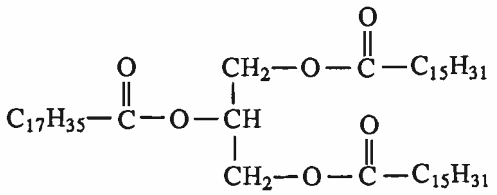
The process of autooxidation of fats, called **peroxidation**, can also occur within the body due to free radicals that are generated during metabolism. Lipid peroxidation can become a chain reaction, so that further peroxidation is continued:

$$\underset{\text{Lipid}}{LH} \xrightarrow{H\cdot} \underset{\text{Lipid free radical}}{L\cdot} \xrightarrow{O_2} \underset{\text{Lipid peroxide}}{LOO\cdot} \xrightarrow[-L\cdot]{LH} \underset{\text{Lipid hydroperoxide}}{LOOH}$$

Lipid peroxidation of unsaturated fatty acid chains in membranes could be quite damaging to the integrity of cell membranes and leads to membrane damage.

SAQ 2

Tick [√] mark the name which correctly describes the acylglycerol shown below:



a) Monostearodipalmitin [ ]
b) 1,3 Distearopalmitin [ ]
c) Dipalmitomonostearin [ ]
d) Stearodipalmitin [ ]

In the preceding section you learnt about lipids, formed by esterification of fatty acids with a trihydric alcohol. Let us now describe this esterification with monohydric alcohols, and find out what kind of molecule is thus formed.

3.3.3 Waxes

When a fatty acid undergoes esterification with a monohydric alcohol of high molecular weight, **waxes** are formed. In general waxes are complex mixtures of esters of long chain fatty acids (e.g. palmitic acid, $C_{15}H_{31}-COOH$) with long chain monohydric alcohols like cetyl alcohol ($C_{15}H_{31}-CH_2OH$) and myricyl alcohol ($C_{30}H_{61}-CH_2OH$). They are widespread in nature, as many of them serve a protective function on fruit and leaf surfaces. Being highly insoluble in water, and having no double bonds in their hydrocarbon chains, they are chemically inert and thus protect leaves from water loss.

Waxes are different from paraffin wax, which is a complex mixture of high molecular weight hydrocarbons.

SAQ 3

Fill in the blanks with appropriate words

a) Bile salts .... triacylglycerols and other fats.

b) Triacylglycerols are hydrolysed by .... present in digestive juices

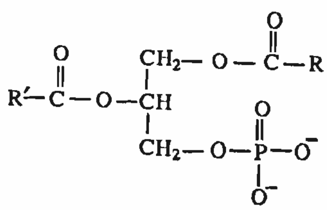
c) Iodine number of fat is used to determine the degree of .... present in a fat

d) Lipid .... can become a chain reaction

Let us now describe phospholipids, which are an important class of lipids.

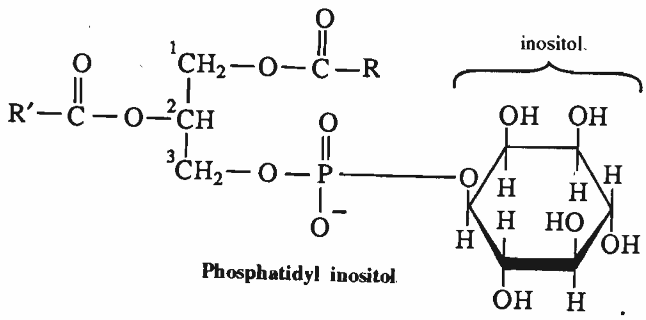
3.3.4 Phospholipids

Phospholipids are the major lipid components of all biological membranes, about which you will know more in Section 3.4. Phospholipids are so named because they contain a phosphate group. In addition, glycerol, fatty acids and nitrogenous bases are the key components of these molecules. Phospholipids are termed **amphipathic** molecules since they possess both polar phosphate groups (heads) and nonpolar hydrocarbon groups (tails). You would have seen a diagrammatic representation of a phospholipid in Unit 1 (Section 1.5.1, Fig. 1.6).

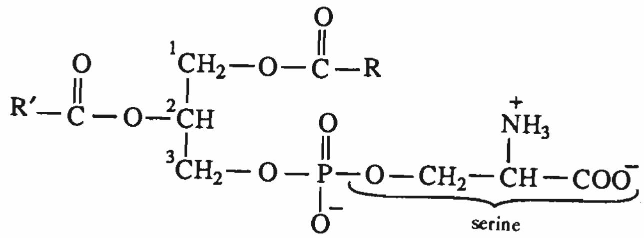


Phosphatidic acid

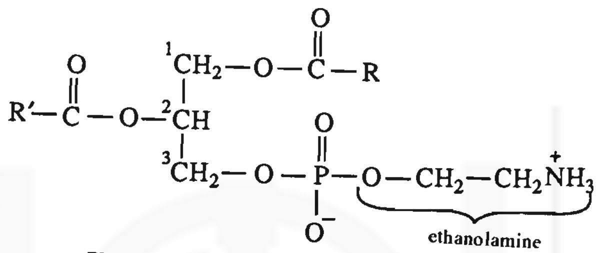
The phospholipids are further classified on the basis of the nature of the polar group, other than the phosphate group in the molecule. They include (a) phosphatidic acid and phosphatidyl glycerols, (b) phosphatidyl choline, (c) phosphatidyl ethanolamine, (d) phosphatidyl inositol, (e) phosphatidyl serine, (f) lysophospholipids, (g) plasmalogens, and (h) sphingomyelins. All these molecules are phosphoglycerides, except sphingomyelins, which do not contain glycerol but a complex amino alcohol, namely sphingosine. All the phosphoglycerides may be considered as derivatives of phosphatidic acid, in which the phosphate group is esterified with the hydroxyl of a suitable alcohol. The structures of some of these are shown below:



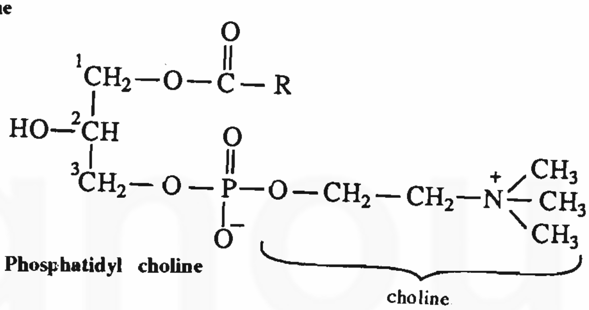
Phosphatidyl inositol



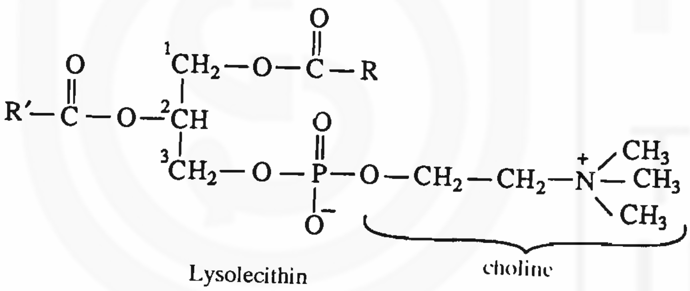
Phosphatidyl serine



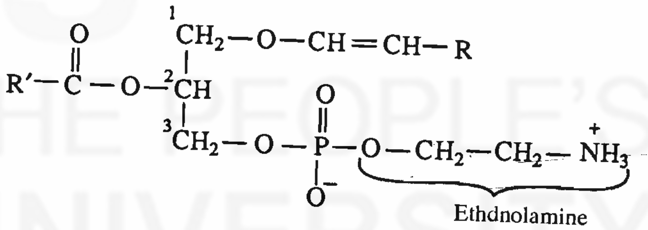
Phosphatidyl ethanolamine



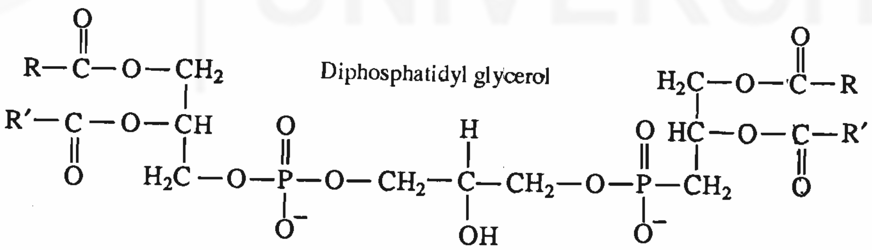
Phosphatidyl choline



Lysolecithin



Plasmalogen (phosphatidal ethanolamine)



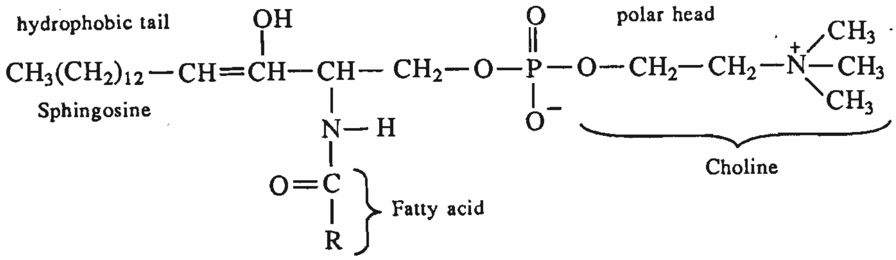
Diphosphatidyl glycerol

Structures of some phospholipids

Diphosphatidyl glycerol or cardiolipin is a major phospholipid present in mitochondrial membranes. Phosphatidyl choline or lecithin is the most abundant phospholipid in cell membranes, and represents a large portion of the body's stores of choline, which is important in transmission of nerve impulses. Phosphatidyl inositol is also an important constituent of cell membranes and its 4,5 bisphosphate acts as a second messenger, and is important in cell signalling mechanisms. Plasmalogens are phospholipids containing an , α, β unsaturated alcohol in an ether linkage rather than a fatty acid in ester linkage on C-1 of glycerol 3-phosphate.

Plasmalogens contain either ethanolamine, choline or serine and constitute as much as 10% of the phospholipids in brain and muscle.

Sphingomyelins are phospholipids that do not contain glycerol but instead contain the complex amino alcohol, sphingosine. The structure of a sphingomyelin is shown below:



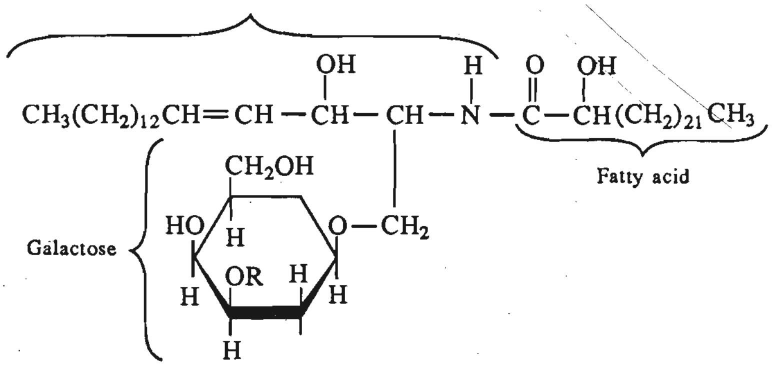
A sphingomyelin

Sphingomyelins are found in large quantities in brain and nerve tissue. The membrane sheath that surrounds and electrically insulates many nerve cell axons is particularly rich in sphingomyelins. On hydrolysis of sphingomyelin, a fatty acid, phosphoric acid, choline and sphingosine are formed. The combination of sphingosine and fatty acid is known as ceramide, a structure also found in glycolipids.

We shall now describe glycolipids, which form the other major class of complex lipids.

3.3.5 Glycolipids

Glycolipids are widely distributed in most tissues of the body and particularly in the nervous tissue, such as the brain. In the plasma membrane they contribute to cell surface carbohydrates, which function as cell membrane receptors, and are involved in recognition mechanisms. The major glycolipids of the animal tissues are the **glycosphingolipids**. They contain ceramide and one or more sugars. Two simple examples are galactosylceramide and glucosylceramide, and the structure of the former is shown below:



Structure of galactosylceramide (galactocerebroside, R = H), and sulfogalactosylceramide (a sulphatide, R = SO_3^-)

Galactosylceramide has a characteristic 24 carbon fatty acid, as a constituent part. You would observe from the above structure that the sugar molecule can be sulphated in some cases. These sulphated glycolipids are known as **sulphatides**. Some highly complex glycosphingolipids are derived from glucosylceramide, and are called **gangliosides**. These are present in nerve tissues.

We shall describe an important member from the **other-complex lipids group**, namely , lipoproteins.

3.3.6 Lipoproteins

Lipids, being insoluble in water, cannot be transported in the free form in circulating blood plasma. Hence they are transported in association with proteins, and such protein complexes are called **lipoproteins.** Lipoproteins are water miscible, and consist mainly of triacylglycerols, phospholipids, cholesterol, and one or more protein compounds called the a**polipoproteins**. Depending upon the composition and density of the lipoprotein four major groups of lipoproteins have been identified. They are the chylomicrons, very low density lipoproteins (VLDL), low density lipoproteins (LDL) and high density lipoproteins (HDL). The composition of some of these different lipoproteins is shown in Table 3.3.

Table 3.3 : Source and Composition of Some Lipoproteins

Source	Type pf Lipoprotein	Molecular weight	Percentage of components (%)			
			Protein	Phospholipid	Cholesterol (free + ester)	Triacyl glycerol
Blood serum	Chylomicron	$10^9 - 10^{10}$	2	7.5	10	80
	Very low density	$(5 - 10) \times 10^6$	8	19	18	55
	Low density	2×10^6	21	28	41	10
	High density	$(1 - 4) \times 10^5$	58	25	12	6
Egg yolk	β-Lipovitellin	4×10^5	78	12	1	9
Milk	Low density	4×10^6	13	52	0	35

The apolipoprotein content of HDL is as high as 60%, while in that of chylomicrons it is as low as 2%. We have illustrated the generalised structure of a typical lipoprotein in Fig. 3.2.

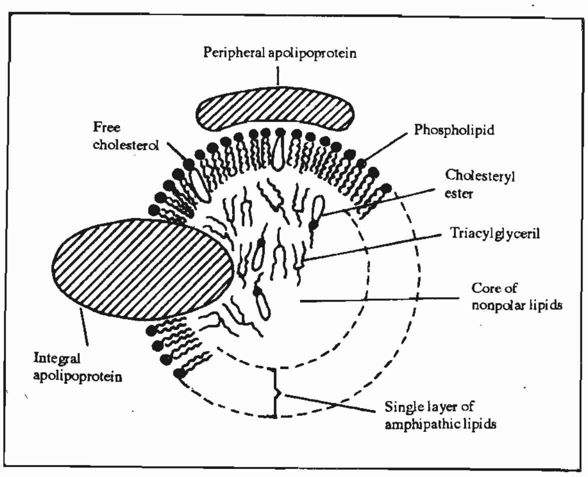


Fig. 3.2 : Generalised structure of a lipoprotein

Chylomicrons and VLDL consist of a lipid core of mainly nonpolar triacylglycerols and cholesteryl ester, surrounded by a single layer of phospholipids and cholesterol molecules. The apolipoprotein is present either on the surface of the lipid core or it could be an integral part of the complex. Free fatty acids are released in the tissues from the lipoproteins, by the action of the enzyme **lipoprotein lipase**. Dietary triglycerides are partially hydrolysed in the small intestines mostly to 2- acylglycerols which are absorbed together with the free fatty acids in an emulsified form. These are reconverted into triacylglycerols and transported to liver as part of chylomicrons. In the liver they are processed into other higher density lipoproteins. They are then transported to the extrahepatic tissues. Different lipoproteins are recognised by different tissues by specific receptors found in the cells. Various abnormalities of lipid metabolism occur at the sites of production and utilisation of lipoproteins, causing various hypo or hyperlipoproteinemias. Hypercholesterolemia and atherosclerosis are two such disorders seen in humans.

SAQ 4

Tick [√] mark the statement which correctly describesthe function of lipoproteins.

a) Lipid solubilisation [ ]

b) Increase in density of lipoproteins [ ]

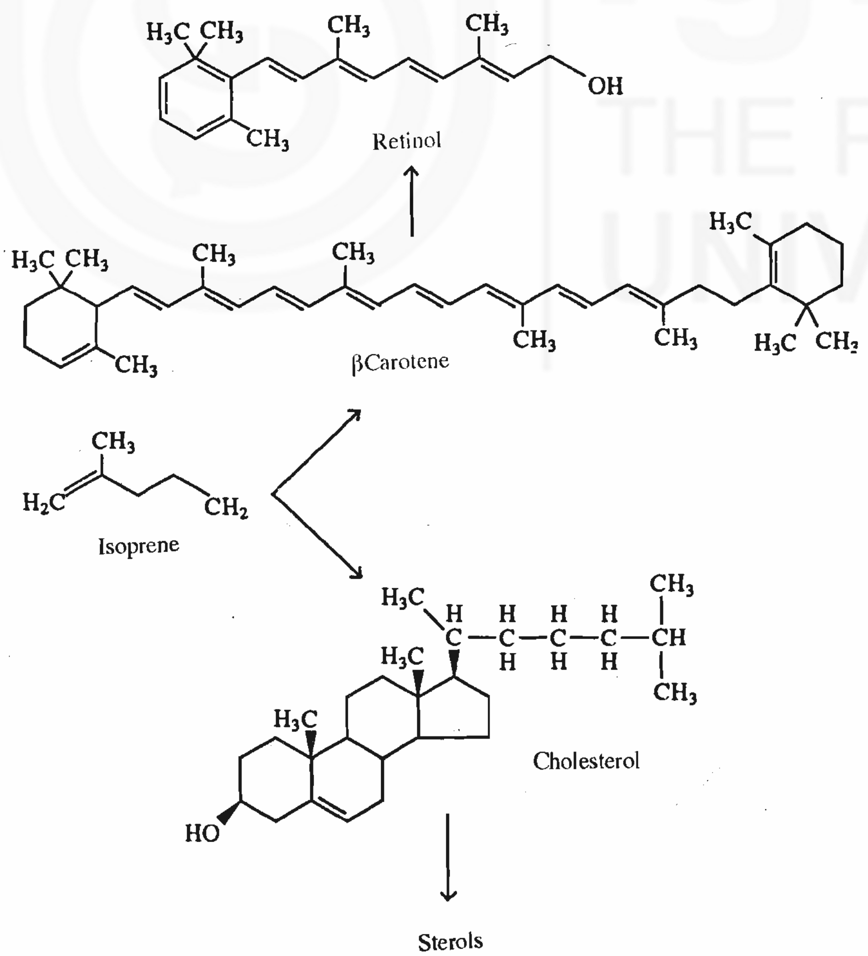
c) Stability of lipids [ ]

d) Carrier of lipids [ ]

We shall now describe some members from the **derived lipid** group.

3.3.7 Terpenoids

Terpenoids are another large group of lipids which are made up of repeating "isoprenoid units". These molecules are derived by the condensation of isoprene



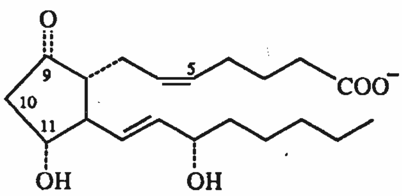
units, which gives rise to such important compounds as carotenoids, from which vitamin A is derived, and cholesterol, from which several steroid hormones, bile acids and vitamin D are derived:

Cholesterol is widely distributed in body cells and is a major constituent of the plasma membrane and plasma lipoproteins.

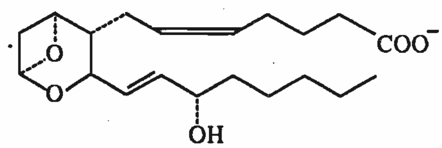
As mentioned earlier, prostaglandins are a class of derived lipids. These act as defences against many sorts of changes in the body. Let us learn more about these molecules.

3.3.8 Prostaglandins

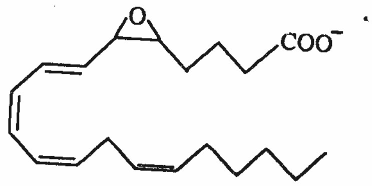
PUFAs, which we described in subsection 3.3.1, are essential for animal and human nutrition, because they are precursors to a class of compounds collectively called **eicosanoids**. These comprise prostaglandins, thromboxanes and leukotrienes. They are derived from arachidonic acid, which contains four double bonds. The structures of these three eicosanoids are depicted below:



Prostaglandin E_2 (PGE_2)



Thromboxane A_2 (TXA_2)



Leuktriene A_4 (LTA_4)

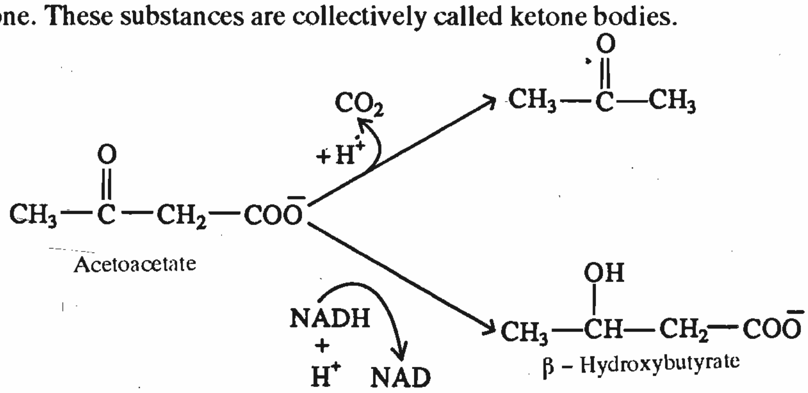
Structures of eicosanoids

The prostaglandins have a cyclopentane ring and are so called because they were first isolated from the secretions of the prostrate gland. They exist in all tissues and act as local hormones, and exert important physiological and pharmalogical effects. Some important actions of prostaglandins are their effects on blood pressure, blood clotting, gastric secretions, contraction of the uterine muscles and reproduction. Thromboxanes, first discovered in platelets, have a six membered ether ring called the oxane ring, and are derived from prostaglandins. They have potent effects on arterial walls of blood vessels and are implicated in several cardiovascular disorders. Leukotrienes, the third group of eicosanoids, first found in leukocytes, are characterised by the presence of three conjugated double bonds. Leukotrienes cause vascular permeability. They attract and activate leukocytes and are important regulators of many diseases involving inflammatory reactions, such as asthma.

Lastly, we shall briefly describe a group of derived lipids, which are known as ketone bodies.

3.3.9 Ketone Bodies

Under certain metabolic conditions such as starvation, associated with a high rate of fatty acid oxidation, the liver produces considerable quantities of acetoacetate and β-hydroxybutyrate. Acetoacetate undergoes spontaneous decarboxylation to yield acetone. These substances are collectively called ketone bodies.



Ketone bodies producton

Ketone body production is characteristic of starvation and diabetes mellitus. Presence of higher than normal quantities of ketone bodies in blood and urine constitute ketonemia and ketonuria, respectively, and the overall condition is called ketosis.

In the preceeding section you learnt about the various types of lipids. Now we shall discuss the role of some of the lipids in the formation of biomembranes. You will recall from Unit 1 that membranes control the chemical environment of the space they enclose, by keeping out certain compounds and selectively transporting other molecules through the membrane. The chemical composition of the membranes allows cell to cell recognition. In addition, membranes contain receptors for many hormones. Let us now learn more about membranes.

SAQ 5

Match the lipid functions in I with appropriate lipids in II.

I	II
a) Protection	a′) Isoprenoids
b) Muscle contraction	b′) Leukotrienes
c) Precursor	c′) Prostaglandins
d) Inflammatory reponse	d′) Waxes

3.4 LIPIDS AND BIOMEMBRANES

You will recall from Unit 1 (Section 1.5) that all living cells are enveloped by a surface or plasma membrane, composed primarily of lipids and proteins. Because of its diverse functions, the plasma membrane plays a central role in cellular biology. Even cellular organelles, such as mitochondria, nucleus, lysosomes and chloroplasts are bound by membranes. The membranes thus give individuality to cells, separating them from the environment and permitting compartmentalisation of cellular functions. You will learn about the composition, structure and functions of membranes in the next subsections.

3.4.1 Composition of Biomembranes

As we mentioned earlier, membranes are mainly composed of lipids and proteins. Although most membranes contain approximately equal amounts of proteins and lipids, their ratio varies depending upon the tissue or organelle. Protein and lipid composition of several membranes is given in Table 3.4.

Table 3.4 : Lipid and protein composition of some membranes

Membranes	% Dry weight	
	Protein	Lipid
Myelin	18	79
Human RBC	49	43
Retinal rods	51	49
Mitochondria (Outer)	52	48
Mitochondria (inner)	76	24
Gram positive bacteria	75	25

The erythrocyte and retinal rod membranes have a protein to lipid ratio of 1:1, while in the myelin membrane of nerve cells it is 1:4, and the inner mitochondrial membrane has a ratio of 3:1. Phospholipids are the most abundant lipid material in membranes, and in addition small amounts of cholesterol and glycolipids are also present. The predominant phospholipids of membranes are phosphatidylcholine, phosphatidylethanolamine, phosphatidylserine and sphingomyelin. Cholesterol is found exclusively in eukaryotic membranes and is absent in bacterial membranes. In contrast to the relatively few kinds of lipids in membranes, many different kinds of proteins are present. These proteins are mainly involved in various cellular functions, such as, enzymic, transport, receptor and other specialised functions.

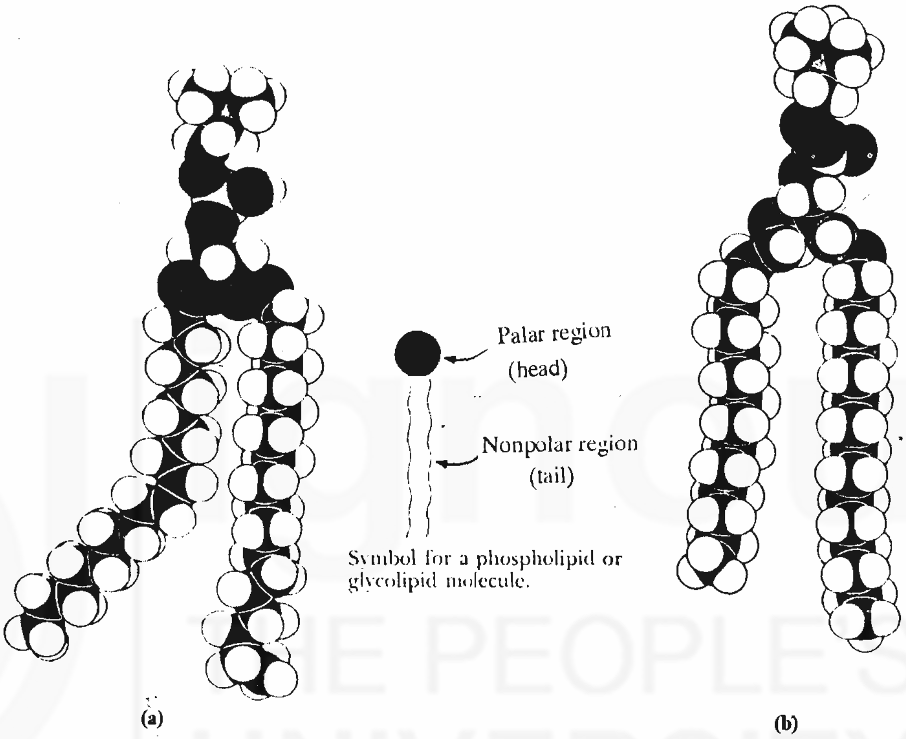


Fig. 3.3 : (a) Space filling model of a phosphatidyl choline molecule
(b) Space filing model of a sphingomyelin molecule

3.4.2 Membrane Structure

We have briefly described the membrane structure in Unit 1. In this subsection you will learn some more details about membrane structure. The structure of the membrane is intimately associated with the amphipathic nature of phospholipids, which constitute the major component of the membrane. The amphipathic nature of the membrane lipids makes them organise themselves into stable structures at a water phase.

The polar head groups and nonpolar tails may be represented as shown in Fig. 3.3 above, and because of this character they organise themselves into unique assemblies as illustrated in Fig. 3.4.

A micelle is a structure wherein the hydrophobic regions are shielded from water, while the hydrophilic polar groups are exposed to the aqueous environment. The

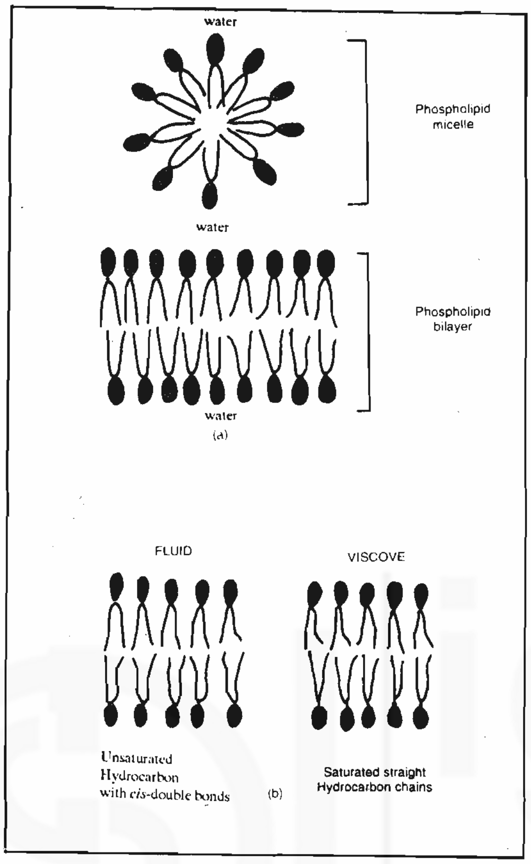


Fig. 3.4. : a) A phsopholipid micelle and a phospholipid bilayer seen in cross section. Phospholipid molecules form such structures spontaneously in water.
b) Double bonds in unsaturated hydrocarbon chains increasse the fluidity of a phospholipid bilayer by making it more difficult to pack the chains together.

phospholipids more often form a "lipid bilayer", and satisfy the thermodynamic requirements of amphipathic molecules in an aqueous environment. The lipid bilayer recognised nearly 60 years ago by Gorter and Grendel exists as a sheet in which hydrophobic region of the phospholipids are protected from the aqueous environment, while the hydrophilic regions are exposed to water. The lipid bilayer provides one of the essential properties to the membrane, in that it acts as a barrier to the entry of water soluble molecules, since they are insoluble in the hydrophobic core of the bilayer. You will recall from Section 1.5 that one of the most widely accepted model of the membrane is the one proposed by S.J. Singer and G.L. Nicolson in 1972 called the **"fluid mosaic model"**. ccording to this model the membranes are two dimensional solutions of oriented proteins and lipids. The membrane phospholipids are arranged in a bilayer in which proteins are dispersed. Fig. 1.5 (Unit 1) and Fig. 3.5 show a diagrammatic representation of the model of a membrane.

The membrane is a quasi fluid structure and the different components are held merely by noncovalent interactions. The lipid and protein molecules are free to perform lateral movements within the overall bilayer. The fluidity of the membrane

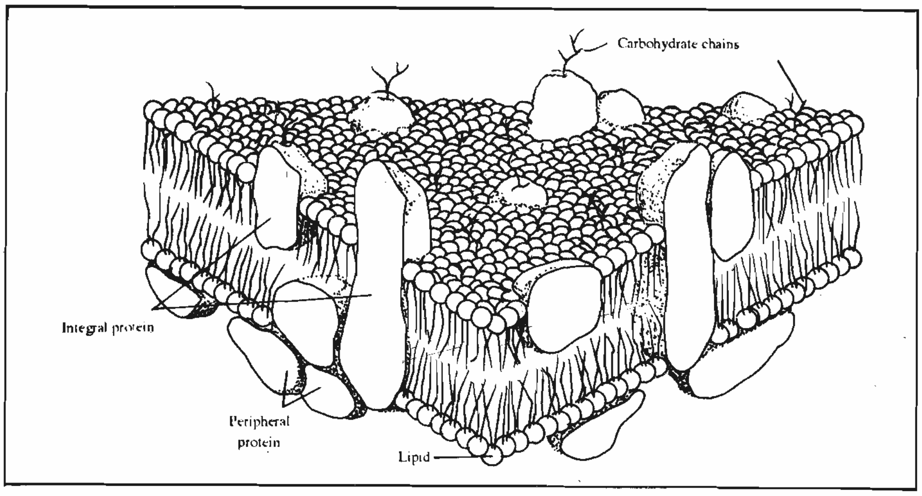


Fig. 3.5 : Fluid mosaic model of biomembranes

is regulated by the cholesterol content, and the unsaturated fatty acid content of the phospholipids. The unsaturated fatty acid residues disrupt the highly ordered packing of fatty acid chains, and thus increase fluidity. This is illustrated in Fig. 3.6 in the space filling models of C_{18} saturated and unsaturated fatty acids.

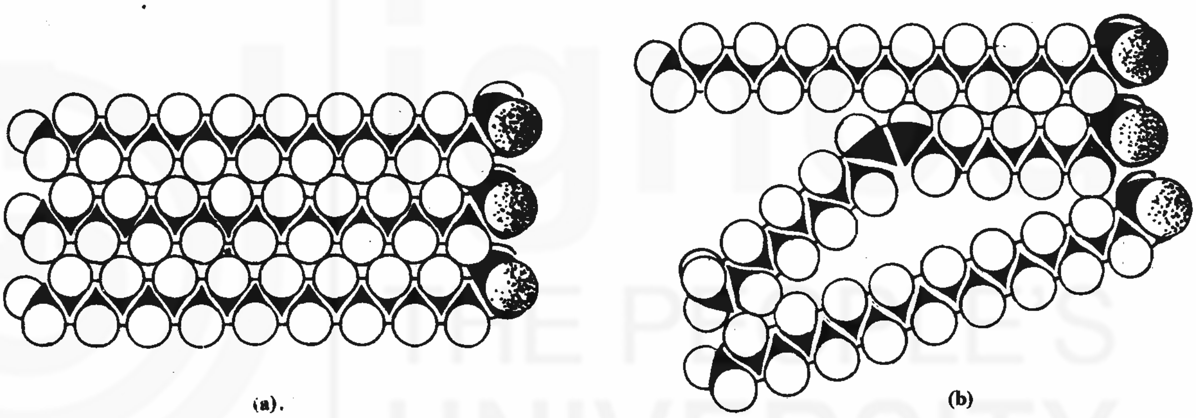


Fig. 3.6 : The highly ordered packing of fatty acid chains is disrupted by the presence of *cis* double bonds. These space filling models show the packing of (a) three molecules of stearate (C_{18}, saturated) and (b) a molecule of oleate (C_{18}, unsaturated) between two molecules of stearate.

3.4.3 Functions of Biomembranes

While the cell membrane is responsible for many of the functions associated with the cell, some of the main and distinguishing functions are as follows:

a) The cell membrane forms a selective barrier between cells and their environment, and regulates the entry and exit of substances across the cell membrane. Thus, it is responsible for the maintenance of the internal environment, whose composition is strikingly different from that of the outside. This is accomplished by the presence of specific transport proteins and transport channels that act as selective gates for the entry and exit of molecules. While some substances move by passive diffusion, other molecules, like glucose, are transported by facilitated diffusion. These mechanisms do not require energy. Some substances e.g. most of the biomolecules are transported against a concentration gradient by active transport, a process that needs energy, as in the absorption of amino acids across the intestines.

b) The cell membrane is also reponsible for cell-cell communication and recognition. The cell surface proteins function as receptors recognising specific molecules such as hormones and other second messengers.

c) Membranes also carry out specialised functions, such as membranes of the mitochondria and the chloroplast, which act as energy transducers. Retinal rod cell membrane proteins, for instance, act as photoreceptors.

SAQ 6

Make appropriate corrections in the following statements and write the correct versions in the space provided.

a) Proteins exhibit free mobility in the lipid bilayer.

....

....

b) Lipid bilayers and micelles are formed by free fatty acids in water.

....

....

c) Membranes possess specific pores for transport of molecules.

....

....

d) Cholesterol is exclusively found in bacterial membranes.

....

....

3.5 SUMMARY

- Lipids are hydrophobic biomolecules, that are insoluble in water and soluble in various organic solvents. They include fatty acids, acylglycerols, phosphoglycerides, eicosanoids and sterols.
- Lipids are important dietary constituents and form major storage forms of energy, because of their high calorific value. Lipids are major and essential components of all biological membranes.
- Fatty acids are essential structural elements of most lipids, and may be either saturated or unsaturated. Most fats usually contain fatty acids with an even number of carbons. The unsaturated fatty acids always have the *cis* configuration. The polyunsaturated fatty acids are nutritionally essenial for humans and animals, because they are the precursors of eicosanoids which are a class of biomolecules of high activity. The eicosanoids represented by prostaglandins, thromboxanes and leukotrienes have profound effects in different tissues.
- Most naturally occurring fats and oils are triacylglycerols with different constituent fatty acids and are hydrolysed by lipases to glycerol and free fatty acids. Polyunsaturated fatty acids (PUFAs) in membranes are prone to lipid peroxidation, leading to membrane damage.
- Lipids are transported in plasma as lipoproteins, which are protein lipid complexes. Lipoproteins vary in their size and composition, and are classified

into four different types. Defects in the synthesis and utilisation of various lipoproteins lead to disorders, such as atherosclerosis and hypo or hyper lipoproteinemias.

- Phospholipids are the most important lipid constituents of biomembranes and their amphipathic character contributes to most of the properties of the membranes. The protein component of the membranes gives them their individuality. They are important in recognition mechanisms and carry out specific transport functions. Phospholipids are especially abundant in nervous tissue, such as the brain.
- Derived lipids such as carotenoids and cholesterol are important precursors to various physiologically important biomolecules, such as vitamins and hormones.

3.6 TERMINAL QUESTIONS

1) A fat has low iodine number and a high saponification number. What do you infer from that?
2) What are the different types of naturally occurring fatty acids?
3) Name the different types of lipoproteins found in plasma. What is their functional role?
4) What are eicosanoids and what are their physiological activities?
5) What are the differences between a sphingolipid and a phospholipid?
6) What is the fluid mosaic model and how does it explain the membrane permeability?
7) What are essential fatty acids and why are they essential?
8) What are the characteristics that affect membrane fluidity?
9) Name some important functions of membrane proteins.

3.7 ANSWERS

Self Assessment Questions

1) a) False; b) True; c) True; d) False
2) b
3) a) emulsify; b) Lipases; c) Unsaturation d) peroxidation
4) d
5) a) d′; b) c′ c) a′ d) b′
6) a) Proteins exhibit lateral mobility in the lipid bilayer.
   b) Lipid bilayers and micelles are formed by phospholipids.
   c) Membranes possess specific carrier proteins for transport of molecules.
   d) Cholesterol is exclusively found in eukaryotic membranes.

Terminal Questions

1) The iodine number of a fat indicates the degree of unsaturation in it. A low iodine number of a fat, thus, indicates that the unsaturated fatty acid content of

the fat is low. A high saponification number shows that the fat is composed of short chain fatty acids (low molecular weight). Thus, the fat contains mostly short chain fatty acids, with a low degree of unsaturation.

2) Fatty acids are of two types; saturated and unsaturated. Most naturally occurring fatty acids have 16-20 carbon atoms but short chain fatty acids are also present occassionally. The naturally occurring unsaturated fatty acids are alwlays of the *cis* configuration, and PUFAs are generally present in vegetable fats. Saturated fatty acids are often found in animal fats.

3) The plasma lipoproteins are distinguished on the basis of their composition and density into four types, namely, chylomicrons, VLDL, LDL and HDL. Lipoproteins represent the principal form, in which the lipids are transported to tissues by plasma. The protein portion (apolipoproteins) of the complex are recognised by tissue specific receptors, wherein they are further utilised.

4) The eicosanoids are 20 carbon atom lipids derived from the tetraenoic acid, arachidonic acid. They include prostaglandins, thromboxanes and leukotrienes. They generally have profound effects, such as smooth muscle contraction, mediation of hormonal effects, increase in blood pressure, blood clotting and inflammatory responses.

5) Sphingolipids are also phospholipids, except that the alcohol in the former is the C_{18} amino alcohol, sphingosine, whereas the latter term also includes phosphoglycerides derived from the trihydroxy alcohol, glycerol. The phosphate group in both lipids is on the primary alcohol group. The fatty acids in phospholipids are esterified to the two alcohol groups of glycerol, while in sphingolipids they are attached by an amide bond, to the amino group of sphingosine.

6) Singer and Nicolson model for biomembranes proposes that proteins are dispersed in the phospholipid bilayer as a mosaic. While the exterior of the bilayer sheet is hydrophilic, the interior is hydrophobic, so that water soluble molecules cannot freely pass through the bilayer. The lipid and protein molecules are capable of lateral movement within the plane of the bilayer. The different proteins present in the membrane carry out both active and passive (facilitated) transport of molecules.

7) Essential fatty acids are those fatty acids that contain more than one double bond and cannot be synthesised by the body. Arachidonic, linolenic and linoleic acids are important polyunsaturated fatty acids that are required by animals and humans for proper nutrition. They are precursors of an important class of lipids, namely the eicosanoids.

8) Membrane fluidity is influenced by the lipid composition, primarily by cholesterol and unsaturated fatty acid content of the membranes. Because of the *cis* double bonds in unsaturated fatty acids, a bend is produced in the molecule and the highly ordered packing of fatty acids in the bilayer is disrupted, leading to increased fluidity.

9) Membrane proteins could be both peripheral and integral. These proteins perform several functions such as, enzymic, receptor, transport, cell communication and energy transduction.

UNIT 4 : NUCLEIC ACIDS

Structure

4.1 INTRODUCTION

In Unit 3, we described lipids, which are a class of biomolecules grouped together mainly on the basis of common solubility properties. You also learnt about the structure of biomembranes. You will recall that membranes are an important part of cell structure, and are vital for living organisms. In Unit 4, we shall study another type of vital biomolecule, namely the nucleic acids. These biomolecules, like polysaccharides, are biopolymers, and are important components of living organisms. In this unit you will learn about the biological importance of nucleic acids. We shall also describe nucleotides, which are the building blocks of nucleic acids. Besides, you shall learn about the types of nucleic acids and the helical structure of DNA. Nucleic acids (RNA) play an important role in the biosynthesis of proteins and polypeptides, and Unit 5 shall deal with the study of proteins. These are complex biomolecules, constituting half the solid mass of a cell. We shall describe their structural organisation first, and then you will learn about their role as biocatalysts in Unit 6.

Objectives

After studying this unit, you should be able to:

- explain the functions of nucleic acids,
- describe the structure of nucleic acids,
- distinguish between ribonucleic acids and deoxyribonucleic acids,
- describe the role of various types of RNAs, and
- explain the double helical structure of DNA.