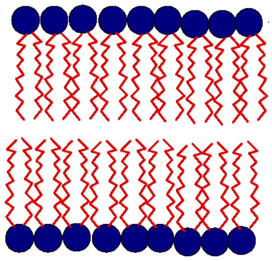


Lipid bilayer

UNIT 10

MEMBRANE LIPIDS

Structure

10.1 INTRODUCTION

In the previous unit, you learnt that lipids are heterogeneous group of compounds which perform diverse functions. We discussed about their classification, common building blocks and their properties with suitable examples. We explained classification of lipids based on their functions such as storage lipids, membrane lipids and others with specialized functions. Among the energy storage lipids, we described the structure and important reactions of triacylglycerols and wares in the previous unit.

In this unit, we shall discuss about another class of lipids; membrane lipids. As evident from their name, these serve as structural component of biological membranes. Lipids in this class include phospholipids, galactolipids and sulpholipids, sphingolipids and cholesterol. These lipids along with proteins not only provide structural support to the biological membrane but also help it to maintain fluidity. Let us learn about structure and specific functions of membrane lipids in detail.

Objectives

After studying this unit you should be able to:

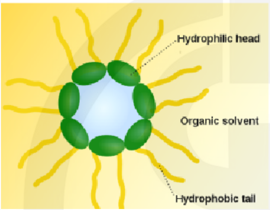
- identify structural features of different types of phospholipids and their derivatives;
- discuss importance of galactolipids and sulpholipids;
- classify sphingolipids and explain their biological importance;
- dxplain structure and importance of cholesterol; and
- write about structure and composition of biological membranes.

10.2 STRUCTURAL LIPIDS IN MEMBRANES

You know from your school biology that all living cells are bound by a membrane. In addition to the outer cell membrane, cell organelles such as mitochondria, chloroplast, nucleus, golgi bodies and endoplasmic reticulum present in eukaryotic cells are also bound by their own membranes. All biological membranes are composed of a lipid bilayer and proteins and serve as barrier for polar molecules and ions.

Amphipathic means a molecule has both polar/ hydrophilic and non polar/ hydrophobic ends.

Lipids present in the biological membranes are amphipathic in nature. You learnt about the amphipathic nature of soaps in the last unit, which are salts of fatty acid under alkaline conditions. Hydrocarbon chain is the hydrophobic part while the carboxylic group forms the hydrophilic or polar part. When exposed to aqueous environment, hydrophobic chains of the amphipathic lipids tend to stay together excluding water and their hydrophilic ends are oriented towards polar environment. Such ordered arrangements result in formation of micelles or sheets (Fig. 10.1). In case of soap, polar head and single fatty acid chain form wedge like structure which is more stable by forming micelles. However, most of the membrane lipids have one polar head and two fatty acid chains giving rise to cylindrical shape. Such shape is more stable to make sheet like structure as observed in the biological membranes.



This is the arrangement you will see if a drop of water is added to oil.

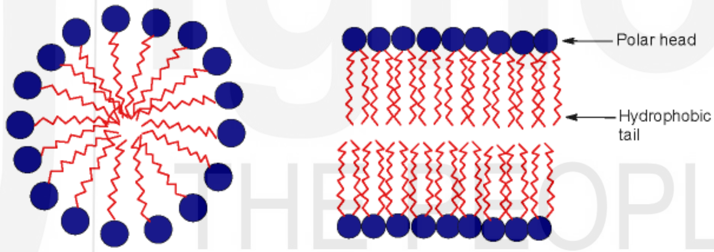


Fig. 10.1: Micelles and lipid bilayers arrangements of amphipathic lipids when exposed to aqueous environment.

In this section, we shall discuss about five different types of membrane lipids: **Glycerophospholipids, galactolipids, sulfolipids, sphingolipids and sterols**. Except for sterols, all membrane lipids are sponifiable because of the presence of fatty acid chains.

10.2.1 Glycerophospholipids

Glycerophospholipids are also known as phosphoglycerides. These lipids constitute the most abundant class of membrane lipids throughout animal, plant and bacterial kingdom and are derivatives of phosphatidic acid. Phosphatidic acid is composed of a glycerol backbone (Fig. 10.2) with fatty acids esterified at positions 1 and 2 and phosphoric acid at position 3.

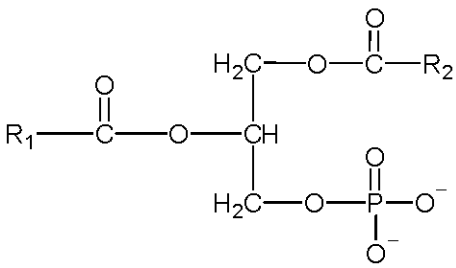
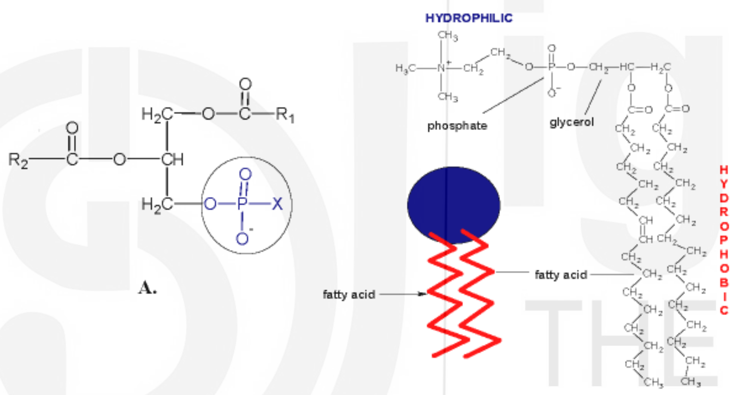


Fig. 10.2: Chemical structure of phosphatidic acid, the parent compound of glycerophospholipids. R1 and R2 are fatty acids.

Different substituents are esterified to phosphoric acid giving rise to different glycerophospholipids. These substituents are highly polar or charged groups which are attached to glycerol via phosphoric acid. As phosphoric acid makes two ester bonds; one with glycerol and second with the substituent, it is known as phosphodiester bond. Thus, we can say that **glycerophospholipids are membrane lipids in which two fatty acids are attached in ester linkage to the first and second carbons of glycerol and a highly polar or charged group is attached through a phosphodiester linkage to the third carbon** (Fig. 10.3a).

Note in Fig. 10.3b that each glycerophospholipid is an amphipathic molecule having: (i) **polar region** constituted by phosphate group with attached polar head group **(X),** and (ii) **non polar region** consisting of hydrocarbon tails of fatty acids **R1 and R2.** In most cases, R1 is a C16 or C18 saturated fatty acid and R2 is an unsaturated fatty acid with chain length of C18 or C20. These features are depicted by a cartoon showing polar head group and non polar tails (Fig. 10.3b).



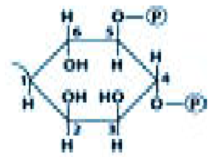
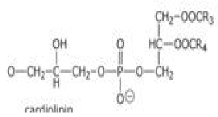
(a) (b)

Fig. 10.3: (a) General structure of a glycerophospholipids, where R1 and R2 are hydrophobic fatty acid chains and X is the polar substituent, generally an alcohol. (b) Cartoon depicting amphipathic nature of a glycerophospholipid molecule.

These phosphoglycerides are not only important component of cell membranes but also participate in other cell functions. Table 10.1 lists some common glycerophospholipids, the polar substituents (X) that are attached to phosphatidic acid and their chemical formula and biological roles these play in the cell.

Table 10.1: Polar substituent groups present in different phosphoglycerides and their biological roles.

Name of the phospho-glyceride	Polar Substituent group (X)	Formula of the substituent group (X)	Significance
Phosphatidyl choline (Lecithin)	Choline	HO-CH_2-CH_2-N^+ $(CH_3)_3$	Major component of cell membranes, source of choline, a form of vitamin B, important for brain and liver function, precursor of acetylcholine, a neurotrans-mitter, component of bile which helps in fat digestion

Phosphatidyl Ethanolamine (Cepahlin)	Ethanolamine	HO-CH_2-CH_2-N^+H_3	Important component of cell membranes in plants, animals as well as microbes, helps in assembly of proteins and orientation of enzymes in membranes
Phosphatidyl serine	Serine	HO-CH_2-CH(COOH)-N^+H_3	Important component of cell membranes; important for brain and nerve function
Phosphatidyl inositol-4,5-bisphosphate	*myo*-inositol-4,5-bisphosphate		Relatively less in cell membranes compared to other phosphoglycerides, important in signal transduction, source of arachidonic acid
Cardiolipin	Phosphatidyl glycerol		Major component of mitochondrial inner membrane

Let us look at the structure of phosphatidyl choline (Fig. 10.4) to get an idea how this group is linked to phosphoric acid in a phosphoglyceride.

Phospholipids are important for proper functioning of cell membranes as well as optimal brain health.

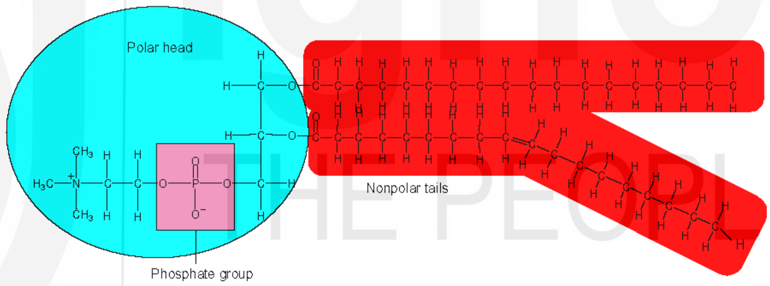


Fig. 10.4: Structure of phosphatidyl choline

Ether glycerophospholipids: Some animal tissues and unicellular organisms are rich in ether lipids. In such lipids one of the two acyl chains is linked to glycerol by ether instead of ester linkage. Ether linked chain can be saturated or unsaturated. Two important examples in this category are platelet activating factor (PAF) and plasmalogens.

Platelet activating factor (PAF), a mediator in inflammation and allergic reactions, is released from basophils and causes platelet aggregation and dilation of blood vessels. It consists of a long alkyl chain which is ether linked at C1 of glycerol. C2 of glycerol is ester linked to acetic acid. This acetic acid group makes PAF more water soluble than other lipids. C3 is linked to the polar head choline by phosphodiester bond (Fig. 10.5).

Plasmalogens contain unsaturated chain with double bond between its C1 and C2. It is ether linked to C1 of glycerol, C2 is esterified to a fatty acid and C3 is linked to a polar group (X) by phosphodiester bond. Based on the type of X, plasmalogens are referred to as phosphatidyl choline (Fig. 10.5), Phosphatidyl ethanolamine and Phosphatidyl serine. Vertebrate heart tissue is rich in ether lipids with more than 50% constituted by plasmalogens. Their function is however unknown.

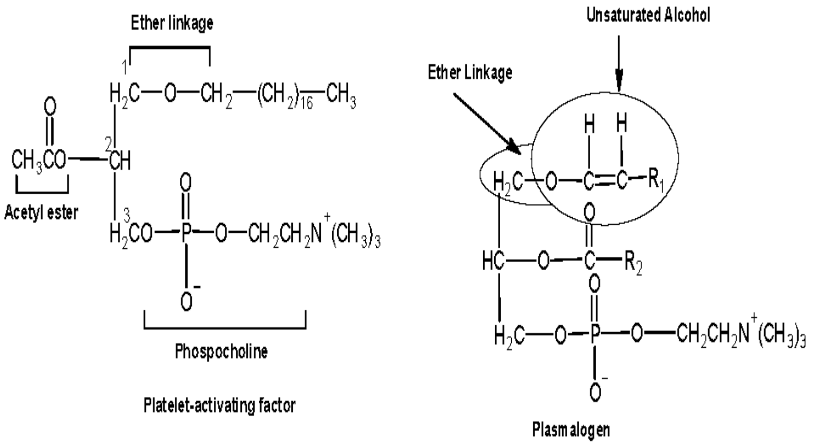


Fig. 10.5: Structures of PAF and phosphatidyl choline, a plasmalogen with reference to the phospholipid.

10.2.2 Galactolipids and Sulpholipids

Galactolipids are the membrane lipids found mainly in plant cells. They have one or two galactose residues linked to C3 of diacylglycerols by a glycosidic linkage (Fig. 10.6 a, b). They are present in thylakoid membranes of chloroplasts and make up 70-80% of the total membrane lipids in vascular plants. Thus galactolipids are probably the most abundant membrane lipids in biosphere.

Phosphate is a limiting nutrient on soil. Therefore probably during evolution, plants preferred to make phosphate free lipids and conserving it for more important roles.

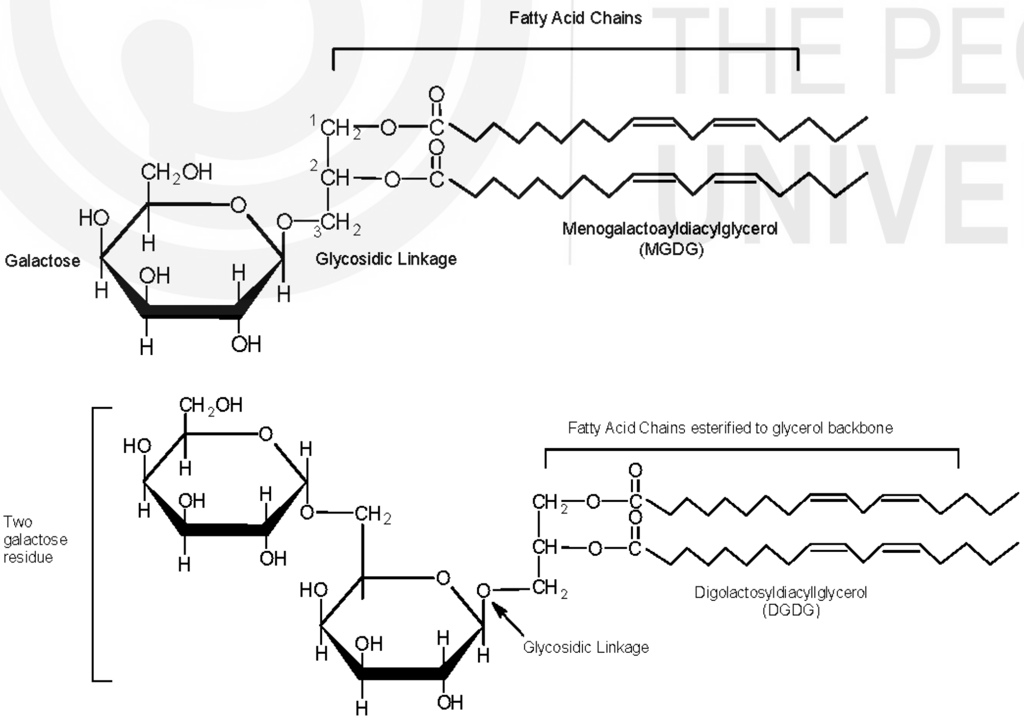


Fig. 10.6: Structures of galactolipids –(a) monogalactosyldiacylglycerol; (b) digalactosyldiacylglycerol

Sulfolipids contain a sulfonated glucose residue attached to diacylglycerol by a glycosidic linkage. The sulfonate group carries negative charge (Fig. 10.7).

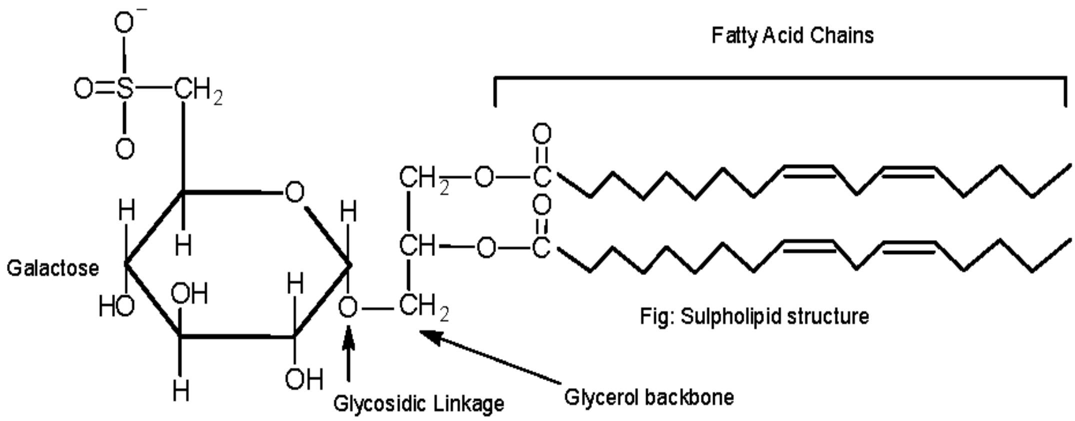


Fig. 10.7: Structure of sulfolipid

SAQ 1

a) **Match the followings:**

i)	Lecithin	a)	Ethanolamine
ii)	Galactolipids	b)	Ether lipid
iii)	Plasmalogen	c)	choline
iv)	Cardiolipin	d)	phosphatidyl glycerol
v)	Cephalin	e)	plant lipids

b) **Name the structural conponents of the following:**

i) Phosphatidyl choline

ii) Phosphatidyl serine

iii) Phosphatidyl ethanolamine

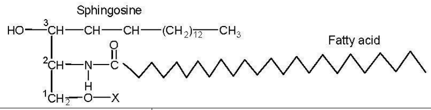
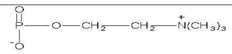
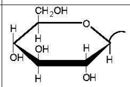
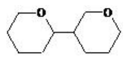
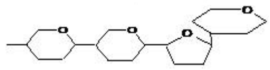
10.2.3 Sphingolipids

The structure of sphingosine includes a long hydrophobic tail so it requires addition of only one fatty acid chain to make it suitable as membrane lipid.

Sphingolipids are also important constituent of some biological membranes. Like glycerophospholipids, they also have a polar head and non polar tails. However, they differ from glycerophospholipids and galactolipids as they do not have glycerol. Instead, they contain a long chain amino alcohol, sphingosine. Sphingosine is part of ceramide, which is the parent molecule of sphingolipids. We mentioned about ceramides in the last unit in section 9.3.3.

Different derivatives of ceramide are formed by reaction with hydroxyl group present at C1resulting in three subclasses: **sphingomyelins, glycosphingolipids and gangliosides**. Table 10.2 shows the general structure of a sphingolipid and different chemical groups present in different sub classes of sphingolipids.

Table 10.2: The general structure of a sphingolipid and different chemical groups.

Sphingolipid (general structure)	 	
Name of Sphingolipid	**Name of X-O**	**Formula of X**
Ceramide	——	H
Spingomyelin	Phosphocholine	
Neutral glycolipids Glucosylcerebroside	Glucose	
Lactosylceramide (a globoside)	Di - tri - or tetrasaccharide	
Ganglioside GM2	Complex oligosaccharide	

Sphingomyelin: Sphingomyelins contain a phosphocholine or phosphoethanolamine group esterified to C1 group of ceramide. They are important component of nervous tissue in higher animals and are predominantly found in the myelin sheath of neurons. They are clinically important molecules as their deposition in brain leads to *Niemann Pick disease* which results in brain damage and early death.

Glycosphingolipids: They consist of one or more sugar residues attached by glycosidic linkage at C1 of ceramide. These are of two types- cerebrosides and globosides.

Cerebrosides contain a single glucose or galactose residue attached to ceramide. Galactosyl cerebrosides are generally found in neural membranes while glucosyl cerebrosides are present in membranes of non neural tissues. Globosides contain two or more sugar residues; which usually include D-glucose, D- galactose or N- acetyl- D- galactosamine. Cerebrosides and globosides are sometimes known as neutral glycolipids as they are uncharged at pH 7.

Glycosphingolipids are largely found at the outer surface of plasma membrane where they act as recognition sites. Carbohydrates of certain glycosphingolipids define blood groups and therefore determine the type of blood that individuals can receive in blood transfusions.

Gangliosides: They are the most complex sphingolipids that contain an oligosaccharide and one or more residues of N- acetyl neuraminic acid, a sialic acid (refer to section 5.4.3 of Unit 5 in block 2). Presence of sialic acid gives gangliosides negative charge at pH 7 that distinguishes them from neutral glycolipids.

Based on the number of sialic acid residues, gangliosides are assigned different series. Gangliosides with one, two, three and four sialic acid residues belong to GM (M- mono), GD (D- di), GT (T-tri) and GQ (Q-quadra) series, respectively. They are concentrated on the cell surface where they act as point of recognition for neighboring cells or extracellular molecules. However, specific functions of many sphingolipids are not known and they are the topic of current research by many researchers. Fig. 10.8 shows different members of GM series.

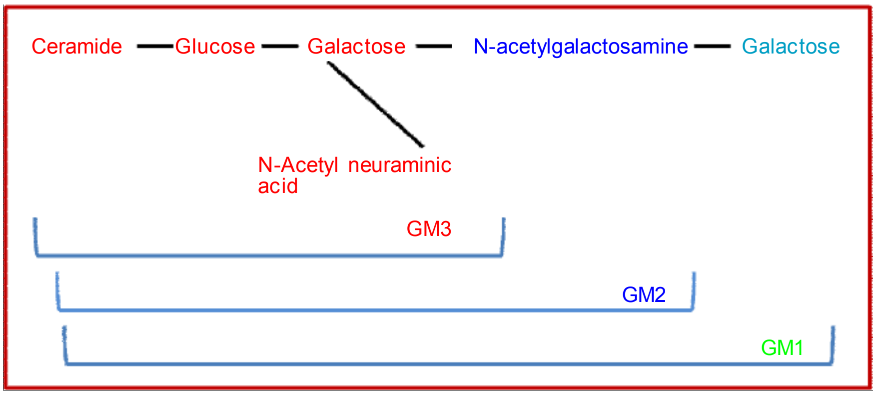


Fig. 10. 8 : Structures of members of GM gangliosides: GM1, GM2 and GM3 where G denotes ganglioside, M is a single sialic acid; and the subscript 3 is a number assigned on the basis of chromatographic migration. The simplest of these is GM3, which contains ceramide, one molecule each of glucose, galactose, and NANA. GM1, the more complex ganglioside derived from GM3, is of considerable biologic interest, as it is known to be the receptor in human intestine for cholera toxin.

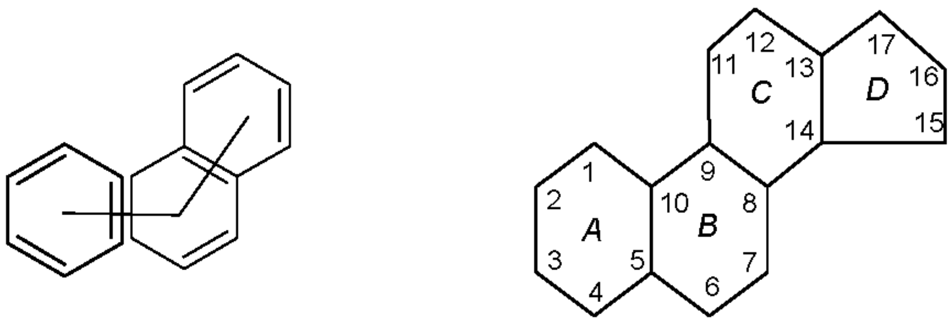
SAQ 2

Name three classes of sphingolipids and their polar head groups.

10.2.4 Sterols

These are the cyclic lipids which lack fatty acid chain and therefore, are *nonsaponifiable*, *i.e.*, cannot be hydrolyzed by heating with alkali to yield soaps. (Recall section 9.4.1). They are derived from **four** fused and fully saturated rings called **cyclopentanoperhydrophenanthrene** or **sterane**. This system consists of 3 cyclohexane rings (A, B and C) fused in nonlinear or phenanthrene manner and a terminal cyclopentane ring (D). The sterane nucleus along with the conventional numbering of the carbon atoms is shown in the Fig. 10.9. Molecules containing sterane ring are known as steroids.

Cholesterol literally means 'solid alcohol from bile'; *chole*-bile and *stereos*-solid. It was first isolated in 1784 from human gallstones which consist almost entirely of cholesterol and hence its name.



Phenanthrene

Cyclopentanoperhydrophenanthrene or sterane nucleus

Fig. 10.9: Parent compounds of steroids- A: Phenanthrene B: Sterane

Steroids containing hydroxyl groups (hydroxy steroids) are often referred to as **sterols**. One of the commonly known sterol is cholesterol, which is an important constituent of many biological membranes.

The structure of cholesterol was determined by the German chemist, Adolph Windaus who received Nobel Prize in Chemistry in 1928. Since its discovery it has occupied a central stage in the area of biology. As many as thirteen Nobel Prizes have been awarded to the scientists who devoted most of their career working on cholesterol.

Cholesterol is a 27 carbon compound derived from sterane with molecular formula $C_{27}H_{45}OH$. You may be quite familiar with this name as high levels of cholesterol in blood are widely associated with the cardiovascular disease. The hydroxyl group of cholesterol constitutes its polar head; the rest of the molecule is hydrophobic making it weakly amphipathic. Structure of cholesterol is shown in Fig. 10.10.

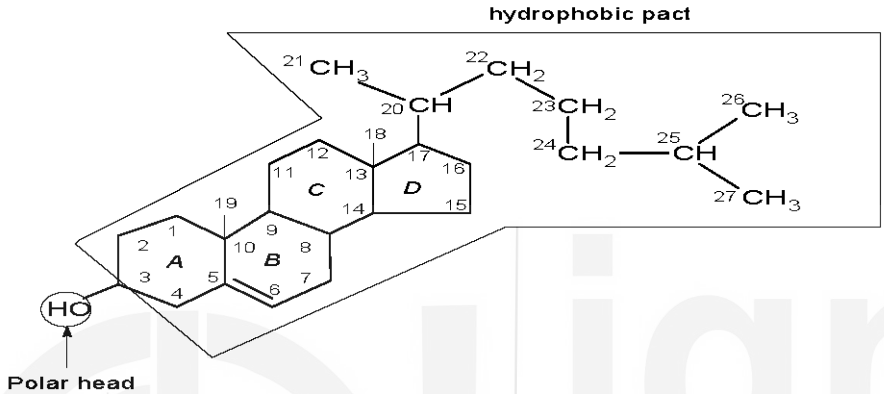


Fig. 10.10: Structure of cholesterol (mark polar and non polar parts)

It is quite evident from the Fig. 10.10 that cholesterol is a bulky rigid structure as compared to other hydrophobic membrane lipids. Therefore, it tends to disrupt the regular packing of fatty acid tails in the membrane structure. This property of cholesterol has quite an impact on the membrane fluidity as cholesterol constitutes 25% or more of the total lipid content in some of the membranes.

It is primarily an animal fat as it is absent in plants. It is not only an important component of some cell membranes and plasma lipoproteins but also the precursor of many other biologically important steroids, such as bile acids and various steroid hormones. It is the major sterol of higher animals and is especially abundant in nerve tissues and gallstones. It occurs either free or as fatty esters in all animal cells. Similar sterols exist in other eukaryotes, for example; stigmasterol in plants and ergosterol in fungi. We shall discuss about some of these sterols in the next unit.

SAQ 3

State whether the following statements about cholesterol are true or false?

i) Cholesterol is a sponifiable lipid.

ii) Cholesterol lack fatty acid chains.

iii) Cholesterol is also present in plants.

iv) Parent compound of cholesterol is sterane.

v) Cholesterol has no effect on membrane fluidity as it has a rigid structure.

So far we discussed the structures and roles of different types of membrane lipids. We observed that they all share a common feature; amphipathic nature. Due to this feature, when they come in contact with aqueous environment, they arrange themselves to form variety of structures. Moreover, their distribution also varies depending on the localization and function of the membrane. In the next section, you will learn about these aspects.

10.3 COMPOSITION AND ROLE OF BIOLOGICAL MEMBRANES

Amphipathic membrane lipids form various types of aggregated structures in contact with aqueous environment. All these structures expose hydrophilic polar head towards aqueous medium and maximize the contact among hydrophobic lipid chains, for example, soaps. Lets us look at these arrangements.

10.3.1 Ordered Structures of Lipids in Water

Membrane lipids arrange themselves into monolayers, micelles, liposomes or bilayers when exposed to an aqueous environment. Fig. 10.11 shows these arrangements.

Monolayers are formed when few lipid molecules are added to aqueous solution. This single layer formed at water- air interface exposes polar head towards water and hydrophobic tails towards air.

Micelles are spherical structures that contain anywhere from a few dozen to a few thousand amphipathic molecules. These molecules are arranged with their hydrophobic tails aggregated in the interior, where water is excluded, and their hydrophilic/polar head groups are at the surface, in contact with water (Fig. 10.11a). Amphipathic molecules form micelles at or above a specific concentration. This concentration is known as **critical micelle concentration** (CMC). Below CMC, these molecules exist as individual molecules.

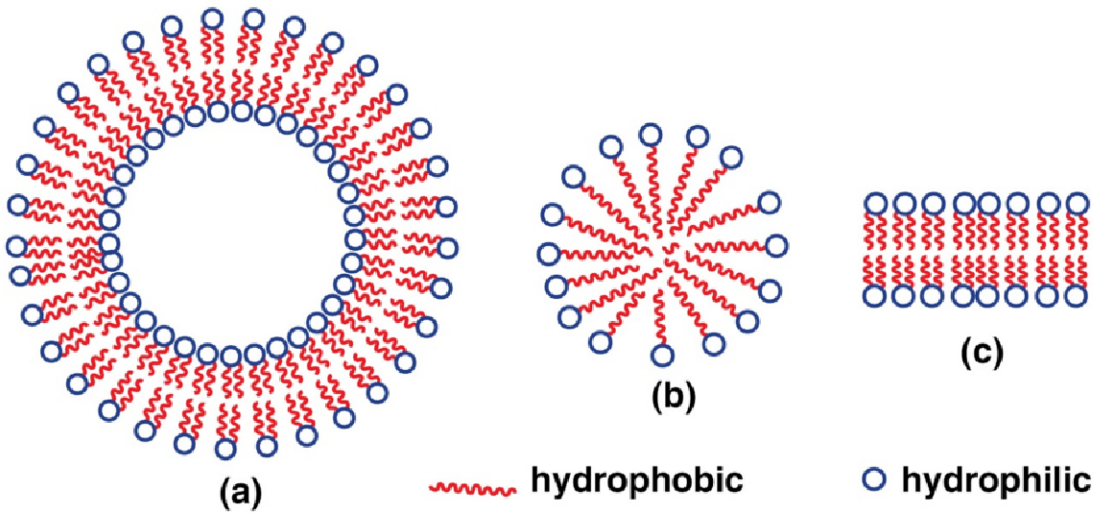


Fig. 10.11: Aggregation of lipids as a. Micelles, b. Bilayer c. Liposome

Bilayer is another type of lipid aggregate in water in which two lipid monolayers are arranged back to back to form a two-dimensional sheet. The hydrophobic portions in each monolayer interact with each other (Fig. 10.11b). The hydrophilic head groups interact with water at each surface of the bilayer. Because the hydrophobic regions at its edges are transiently in contact with water, the bilayer sheet is relatively unstable and spontaneously forms a third type of aggregate: it folds back on itself to form a hollow sphere, a vesicle or liposome.

It is likely that the precursors to the first living cells resembled liposomes, their aqueous contents segregated from the rest of the world by a hydrophobic shell.

Liposomes are the closed self sealing solvent filled vesicles bound by a single bilayer (Fig. 10.11c). By forming liposomes, bilayers lose their hydrophobic edge regions, achieving maximal stability in the aqueous environment. These bilayer vesicles enclose water, creating a separate aqueous compartment. Liposomes have been widely used as models to study properties and functions of biological membranes. They are also used a vehicle for drug delivery since they are absorbed by many cells through fusion with the plasma membrane.

Liposomes can be prepared artificially by using a suspension of phospholipids and different solvents on the inner side

10.3.2 Biological Membranes

Biological membranes exist as lipid bilayers and play active role in the life of a cell. Their basic functions include:

1) Separation: Membranes provide a closed compartment around the cells as well as within the cell. This permits separation of one cell from the other so that they can maintain their individuality. Compartmentalization within the cell helps to shape many of the morphologically distinguishable organelles, such as mitochondria, endoplasmic reticulum, golgi complexes, secretory granules, lysosomes and the nucleus.

2) Exchange: Membranes are characterized by providing cells with selective permeability which means they allow entry and exit of specific substances across them. This helps in maintaining differences in composition between the inside and outside of the cell. They enable the transport and translocation of cellular metabolites and macromolecules.

3) Metabolism: Cell membranes are integral part of metabolic pathway organization. They contain many enzymes involved in energy harvesting pathways such as photosynthesis and respiration.

4) Communication: Cell membranes also mediate cell to cell communication, recognition and interaction between cells and propagation of electrical and chemical signals

Many different models have been proposed to explain the structure and functions of the membranes. The most widely accepted model is by S.J. Singer and G.L. Nicolson in 1972which is known as **Fluid mosaic model of biological membranes**. The model emphasizes two basic characteristics of all cell membranes: mosaic sheet of lipids and proteins and their dynamic fluid properties. This models can very well explain most of the structural and functional features of biological membranes. Let us discuss some of the characteristic features of this model:

1) Biological membranes are formed of a bilayer of lipids constituted mainly by phospholipids. The lipid bilayer is organized in such a way that the hydrophilic part of phospholipids is on the exterior of the lipid bilayer in contact with the water, while their hydrophobic tails face inward.

2) Importance of transverse asymmetry can be understood from the example that appearance of phosphatidyl serine in the outer monolayer of plasma membrane triggers cell death and is seen in aging erythrocytes so that they are removed from the blood circulation.

   Proteins embedded in this bilayer are of two types: integral and peripheral. An **integral membrane protein** (IMP) or **intrinsic protein** is a protein molecule or assembly of proteins permanently attached to the biological membrane. **Peripheral membrane proteins or extrinsic proteins** adhere only temporarily to the biological membrane. These molecules attach to integral membrane proteins or penetrate the peripheral regions of the lipid bilayer (Fig. 10.12).

3) Integral membrane proteins span the membrane; they are involved in forming pores that transport many molecules, such as ions and polar molecules, across the membrane.

4) Peripheral proteins perform diverse function as enzymes, membrane-targeting domains, structural domains, carriers of hydrophobic molecules.

5) Many integral membrane proteins and some lipids are attached to oligosaccharides; these are known as glycoproteins and glycolipids respectively. These oligosaccharides are important for cell recognition; these allow cells to recognize other cells and interact with each other.

6) Lipids and some proteins in the lipid bilayer are not stationary. They frequently move laterally (side-to-side, about 10^7 times per second) and transversely (flip-flopping, only about once per month). This fluid bilayer of membrane lipids containing milieu of proteins and carbohydrates constitutes the "fluid mosaic model".

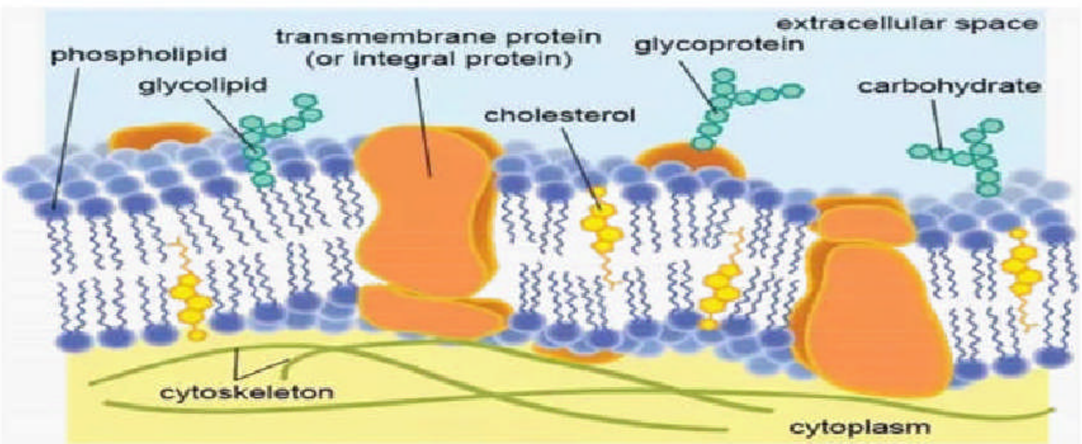


Fig. 10.12: Structure of a typical membrane.

Role of biological membranes depend on their composition. Type and distribution of different types of lipids influences their properties which are more suited to perform specific functions. Therefore, it is important to study their composition.

Composition of biological membranes: An important feature of biological membranes is their modular structure. Proteins and lipids in membranes interact through non covalent bonding, therefore, can be inserted, extracted and rearranged independently and in unlimited variations. They can fine tune their composition and redistribution of their components. It allows rapid adjustment in the structure and composition in response to changing demands of the cell or influences of the environment.

Membranes vary in their composition; some of these may have as much as 75- 80% of proteins and only 20-25% of lipids while others may contain 80-85% lipids and 15-20% proteins (Table 10.3). This variation in structural composition is reflected in their functions. Generally the membranes which carry out enzyme catalyzed reactions and transport activities such as mitochondrial and chloroplast membranes are rich in proteins. The membranes which carry out less protein based activities are rich in lipids such as myelin sheath in neurons.

Membranes have an interesting feature: self renewal. Just as cells come from cells, cell membranes also come only from the cell membranes. They stay intact throughout the life of a cell.

Biological membranes are **asymmetric** as the monolayers of a lipid bilayer do not have same composition. This variation in lipid and protein composition in the two monolayers of a bilayer membrane is termed as **transverse asymmetry**. For example, phosphatidyl choline comprises 29% of the total phospholipid in erythrocyte membrane. Of this amount, 76% is found in the outer monolayer and only 24% is present in the inner monolayer. Transverse asymmetry gives sidedness or direction to the membrane structure and is important for its functions that occur in a particular direction such as transport of different ions and molecules across membrane, action of hormones at the surface and recognition of a cell by signals present at the surface. Fig. 10.13 shows distribution of membrane lipids in a typical erythrocyte membrane.

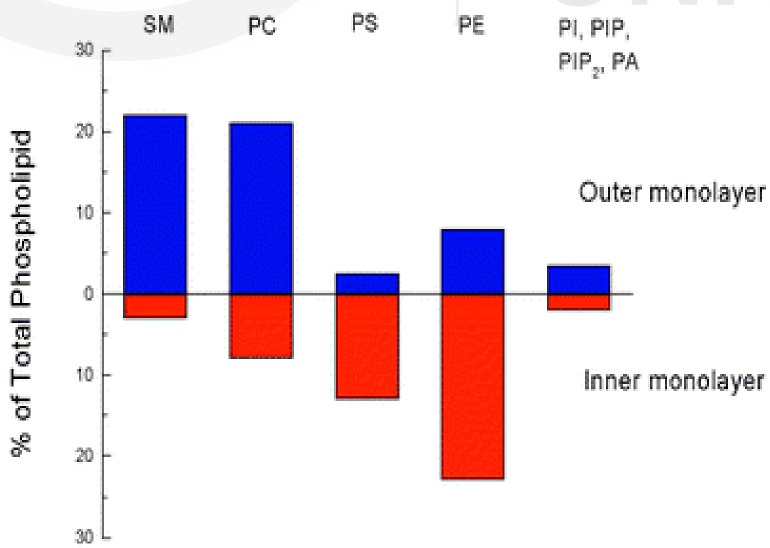


Fig. 10.13: Distribution of membrance lipids in a typical erythrocyte membrane

10.4 SUMMARY

1) Five different types of membrane lipids: Glycerophospholipids, galactolipids, sulfolipids, sphingolipids and sterols.

2) Glycerophospholipids are the compound lipids which constitute the most abundant component of cell membrane and are derivatives of phosphatidic acid. They are made up of glycerol, phosphoric acid and fatty acids. They are amphipathic molecules and are named after the type of polar group these are attached to: phosphatidyl choline, phosphatidyl ethanolamine, phosphatidyl serine, phosphatidyl inositol and cardiolipin.

3) Phospholipids are important for proper functioning of cell membranes as well as optimal brain health.

4) Some animal tissues and unicellular organisms are rich in ether glycerophospholipids. In such lipids one of the two acyl chains is linked to glycerol by ether instead of ester linkage. Platelet activating factor (PAF) and plasmalogens belong to this group.

5) Galactolipids and sulfolipids are the membrane lipids found mainly in plant cells. These are phosphate free lipids and contain galactose or sulfonated glucose, respectively which attach t diacylglycerol chain through glycosidic bonds.

6) Sphingolipids are also important constituent of some biological membranes and are derived from ceramide. They do not have glycerol, instead, they contain a long chain amino alcohol, sphingosine which is part of ceramide.

7) Different derivatives of ceramide result in three subclasses: **sphingomyelins, glycosphingolipids and gangliosides**.

8) Sphingomyelins contain a phosphocholine or phosphoethanolamine group esterified to ceramide. They are important component of nervous tissue in higher animals and are predominantly found in the myelin sheath of neurons. Their deposition in brain leads to *Niemann Pick disease* which results in brain damage and early death.

9) Glycosphingolipids consist of one or more sugar residues attached by glycosidic linkage to ceramide. These are of two types- cerebrosides and globosides.

10) Gangliosides are the most complex sphingolipids that contain an oligosaccharide and one or more residues of N-acetyl neuraminic acid, a sialic acid.

11) Steroids are the cyclic lipids which lack fatty acid chain and therefore, are nonsaponifiable. They are derived from fused and fully saturated ring system called cyclopentanoperhydrophenanthrene or sterane. Steroids containing hydroxyl groups are often referred to as sterols. One of the commonly known sterol is cholesterol. It is a 27 carbon compound derived from sterane with molecular formula $C_{27}H_{45}OH$.

12) Membrane lipids are amphipathic molecules. Except for cholesterol, all have a polar head group and two hydrophobic chains which prefer to aggregate as bilayers when exposed to the aqueous environment.

13) Bilogical membranes have been found to have a bilayers structure in which two lipid monolayers are arranged back to back to form a two-dimensional sheet. The hydrophobic portions in each monolayer interact with each other. The lipid bilayers has proteins associated with it.

14) Cholesterol is a bulky rigid structure tends to disrupt the regular packing of fatty acid tails in the membrane structure. This property of cholesterol has quite an impact on the membrane fluidity.

15) A bilayer model for biomembranes called Fluid mosaic model was put forward by S.J. Singer and G.L. Nicolson (1972) and is so far the most widely accepted model as it can very well explain most of the structural and functional features of biomembranes.

10.5 TERMINAL QUESTIONS

1) What are phospholipds? Explain structural components of phospholipids and their derivatives.

2) Draw structure of cholesterol and discuss its biological significance.

3) Draw a neat diagram of Fluid Mosaic Model of a biological membrane and explain its important features.

10.6 ANSWERS

Self-Assessment Questions

1) a) (i) (c); (ii) (e); (iii) (b); (iv) (d); (v) (a)

   b) Structural components of:

      i) Phosphatidylcholine-Glycerol, two fatty acid chains, phosphoric acid and choline

      ii) Phosphatidylserine-Glycerol, two fatty acid chains, phosphoric acid and serine

      iii) Phosphatidylethanolamine-Glycerol, two fatty acid chains, phosphoric acid and ethanolamine.

2) Sphingomyelins- phosphocholine or phosphoethanolamine

   Glycosphingolipids- one or more monosaccharides such as glucose, galactose, N-acetyl glucosamine and

   Gangliosides-complex oligosaccharides and N-acetyl neuraminic acid

3) (i) False; (ii) True; (iii) False; (iv) True; (v) False.

Terminal Questions

1) Glycerophospholipids are membrane lipids in which two fatty acids are attached in ester linkage to the first and second carbons of glycerol and a highly polar or charged group is attached through a phosphodiester linkage to the third carbon. Please refer to section 10.2.1 for the detailed information their derivatives.

2) Cholesterol is a 27 carbon compound derived from sterane with molecular formula $C_{27}H_{45}OH$. It is primarily an animal fat as it is absent in plants. It is not only an important component of some cell membranes and plasma lipoproteins but also the precursor of many other biologically important steroids, such as bile acids and various steroid hormones. It is the major sterol of higher animals and is especially abundant in nerve tissues and gallstones.

3) Please refer to the section 10.12.

10.7 FURTHER READINGS

1. Albert L. Lehninger: Principles of Biochemistry, Worth Publishers, Inc. New York, 1984.
2. Harper's Illustrated Biochemistry, 29e. Robert K. Murray, David A Bender, Kathleen M. Botham, Peter J. Kennelly, Victor W. Rodwell, P. Anthony Weil, USA.
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6. Thomas M. Devlin: Textbook of Biochemistry, John Wiley and Sons, Inc.Danvers, MA, USA.