River Valley High School
2025 JC1 H2 Biology

Lecture Topic 4: Biomolecules of Life - Lipids

Name: ________________________ ( ) Class: 25J__ Date: ___________

References

Title	**Authors**
Biology (9th Edition)	Campbell and Reece
Longman A-Level Course in Biology: Core Syllabus Volume 1	Hoh
Biological Science 1. Organisms, Energy and Environment (3rd Edition)	Taylor, Green, Stout and Soper
Understanding Biology for Advanced Level (4th Edition)	Toole and Toole

H2 Biology Syllabus 9477 (2025)

Candidates should be able to use the knowledge gained in the following section(s) in new situations or to solve related problems.

Related Topics	**Concepts**
Biomolecules of Life and Cellular Transport	The structure of carbohydrates, lipids and proteins and their roles in living organisms
Transformation of Energy between the Environment and Organisms	The need for energy in living organisms

Learning Outcomes

1B. Biomolecules of Life and Cellular Transport

g. Describe the structure and properties of the following monomers:
  i. α-glucose and β-glucose (in carbohydrates)
  ii. glycerol and fatty acids (in lipids)
  iii. amino acids (in proteins) (chemical formulae of specific R-groups of different amino acids are not required)

h. Describe the formation and breakage of the following bonds:
  i. glycosidic bond
  ii. ester bond
  iii. peptide bond

i. Describe the structures and properties of the following biomolecules and explain how these are related to their roles in living organisms:
  i. starch (including amylose and amylopectin)
  ii. cellulose
  iii. glycogen
  iv. triglyceride
  v. phospholipid

For practical, candidates should be able to:

- carry out the emulsion test for lipids.

Lecture Outline

I. **Importance of Lipids**

II. **Nature of Lipids**

III. **Fats**

IV. **Phospholipids**

V. **Glycolipid**

VI. **Cholesterol**

I. Importance of Lipids

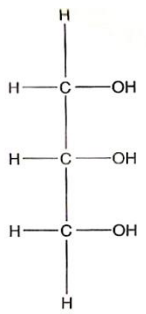
Lipids are a heterogonous group of compounds inclusive of fats, oils, waxes, steroids and phospholipids.

In general, lipids perform three biological functions (although certain lipids apparently serve more than one purpose in some cells):

1. Lipids containing hydrocarbon chains serve as energy stores.
2. Lipid molecules in the form of lipid bilayers are essential components of biological membranes.
3. Many intra- and intercellular signaling events involve lipid molecules.

II. Nature of Lipids

- Lipids are a group of **organic** compounds whose molecules contain atoms of **carbon**, **hydrogen**, and **oxygen** only.
- General formula: No general formula but the ratio of hydrogen atoms to oxygen atoms is always **much greater than 2:1**. For example, tristearin: $C_{57}H_{110}O_6$.
- Structure-Property Relationship:
  - Although lipids are not polymers, they are large molecules assembled from smaller molecules by **condensation** reactions. Most lipids are **esters** of **an alcohol** and **fatty acids**.
  - Lipids comprise of two components:

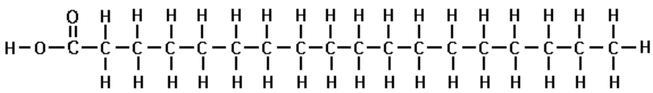


▲ **Figure 3.11** Glycerol.

1. ________
   * Glycerol is an alcohol.
   * It has **3 hydroxyl groups**: each hydroxyl group may be used to form an ester bond with a separate fatty acid, forming a triglyceride.

2. __________

   A fatty acid consists of a **hydrocarbon chain** and a **carboxyl group**. Its general formula is **RCOOH**, where R is the hydrocarbon chain.
   * A hydrocarbon chain consists of a chain of carbon atoms to which hydrogen atoms are attached.
   * Fatty acids may be **saturated** or **unsaturated**.



Stearic Acid

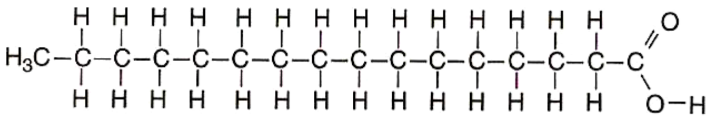
   * The hydrocarbon tail is **hydrophobic** and causes lipids to be **insoluble in water**.
   * The effect of the non-polar hydrocarbon chain is enough to overcome the polarity of the carboxyl group, so most fatty acids have low solubility in water.

* The length of the hydrocarbon chain differs from one fatty acid to another. Those most frequently found in living organisms have 15-17 carbon atoms.

- Lipids are **insoluble in water** but are **soluble in organic solvents** such as ethanol, ether and trichloromethane (chloroform).

SATURATED FATTY ACIDS

- In saturated fatty acids, each carbon atom in the chain is joined to the next by single covalent bonds (i.e. does not contain carbon-carbon double bonds) – it thus has the maximum possible number of hydrogen atoms.
- E.g. palmitic acid and stearic acid.



▲ **Figure 3.9** Palmitic acid is a saturated fatty acid.

Source: Longman A-Level Course in Biology: Core Syllabus Volume 1. pp.60

UNSATURATED FATTY ACIDS

- The hydrocarbon chain of unsaturated fatty acids has one or more double covalent bonds (i.e. contains carbon-carbon double bond(s)).
- Pronounced kinks (bends) occur in the hydrocarbon chain where double bonds exist.
- The kinks prevent the molecules from packing together closely enough to solidify at room temperatures.
- E.g. Oleic acid.

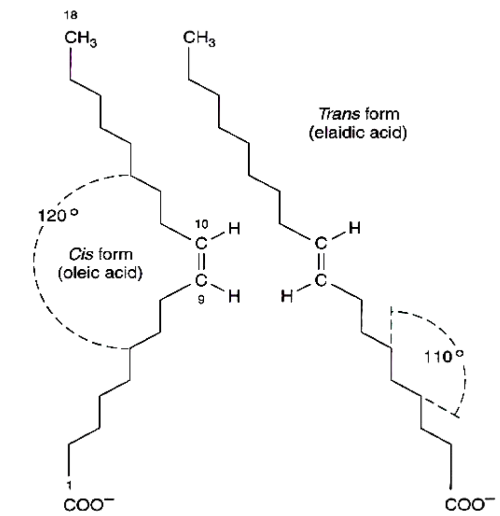


Figure 15–5. Geometric isomerism of Δ^9, 18:1 fatty acids (oleic and elaidic acids).

Geometric isomerism occurs in unsaturated fatty acids. If the hydrocarbon chains are on the same side of the double bond, it is a *cis* fatty acid. E.g. Oleic acid has 18 carbon atoms and contains one carbon-carbon double bond.

Naturally occurring unsaturated fatty acids are nearly all of the *cis* configuration, leading to kinks in the structure.

* Classification of Lipids:

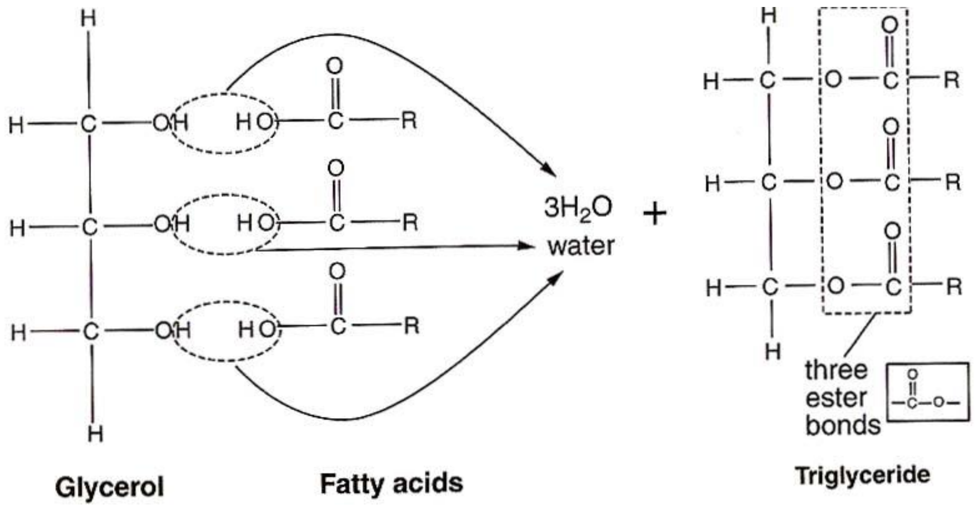
Simple Lipids	Complex Lipids	Steroids and Sterols
Are esters of fatty acids with various alcohols	Consist of both lipid and non-lipid components	Consists of four rings of carbon atoms interconnected to form the main skeleton, with side chains of variable length.
Examples: 1. **Fats** are esters of fatty acids with glycerol. **Oils** are fats in the liquid state. E.g. monoglycerides, diglycerides, and triglycerides. 2. **Waxes** are esters of fatty acids with high molecular weight alcohols. E.g. waxes found in the cuticle of leaves and exoskeleton of insects	Examples: 1. **Phospholipids** contain a phosphate group (i.e. the non-lipid component) in addition to fatty acids and glycerol. 2. **Glycolipids** contain a carbohydrate group as the non-lipid component.	Example: 1. **Cholesterol** is an important cell membrane component and a precursor of all other steroids.

III. Fats

* Fats are the simplest and commonest lipid molecules in nature.
* They are large molecules but are NOT polymers.
* Structure:
    - The components of fats are fatty acids and glycerol.
    - Examples of fats - monoglyceride, diglyceride and triglyceride and the reactions for their formation are represented by the following equations:

1 Fatty acid	+	Glycerol	→	Monoglyceride	+	Water
2 Fatty acids	+	Glycerol	→	Diglyceride	+	2 Water
3 Fatty acids	+	Glycerol	→	Triglyceride	+	3 Water

* Synthesis of a triglyceride:
    - **3 fatty acid molecules** combine with **1 glycerol molecule**.
    - each **hydroxyl group** (-OH) in the glycerol molecule reacts with the **carboxyl group** of a fatty acid.
    - in this reaction, an **ester bond** is formed between the glycerol and fatty acid, with the **removal of a molecule of water** – this is a **condensation reaction**.
    - since glycerol has 3 hydroxyl groups, 3 fatty acids attach themselves to the glycerol molecule and hence, 3 molecules of water are removed.



Source: Longman A-Level Course in Biology: Core Syllabus Volume 1. pp.61

Fats and oils are of the same basic chemical structure, the difference between them being their physical state at 20°C.

- Triglycerides made from saturated fatty acids and having longer hydrocarbon chains are solids or fats at room temperature.
- Triglycerides made of fatty acids with shorter hydrocarbon chains and containing one or more double bonds are oils or soft fats at room temperature.

- Relating structure to function:

1. As ____________________

Structure-Property	Significance
S: Triglyceride molecules are large and uncharged **P:** This makes them insoluble in water	Being insoluble, they can be stored in large amounts without having any great effect on the water potential of the cells. They are also prevented from leaving the cells.
S: Triglyceride molecules contain a larger number of hydrogen atoms per gram compared to carbohydrates. **P:** Triglyceride has higher calorific value (38 kJ / g) than carbohydrates (17 kJ / g) upon oxidation.	For an equivalent amount of energy stored, triglycerides have about half the mass of carbohydrates. This makes triglycerides especially useful: i. for animals in which locomotion requires the body mass to be kept to a minimum ii. in seeds where dispersal by wind or insects makes small mass a necessity.
P: Triglycerides are oxidised **only after carbohydrates are depleted**.	Triglycerides can be used as a long-term energy store - this is important to hibernating animals.

2. As ______________________

Structure-Property	Significance
S: An unit mass of a triglyceride contains about 2-fold more hydrogen atoms as compared to an unit mass of carbohydrate. **P:** The hydrogen part of the triglyceride and carbohydrate molecules yields water upon oxidation, **triglycerides release twice as much water as do carbohydrates** during cellular respiration.	Water produced from oxidation of food is called metabolic water, which is extremely important to desert animals.

3. As ________

Structure-Property	Significance
P: A good thermal insulator. It prevents excessive loss of heat.	This is especially important for animals living in cold climate, e.g. a layer of fat beneath the skin in whales and seals.
P: As electrical insulator.	Triglycerides are the components of the myelin sheath of nerve cells. This allows for rapid transmission of impulses along myelinated neurones.

4. For mechanical protection

Structure-Property	Significance
P: Triglyceride forms a natural buffer that absorbs shock.	This helps to cushion fragile internal organs (e.g. kidney) from impact and physical damage.

5. For buoyancy

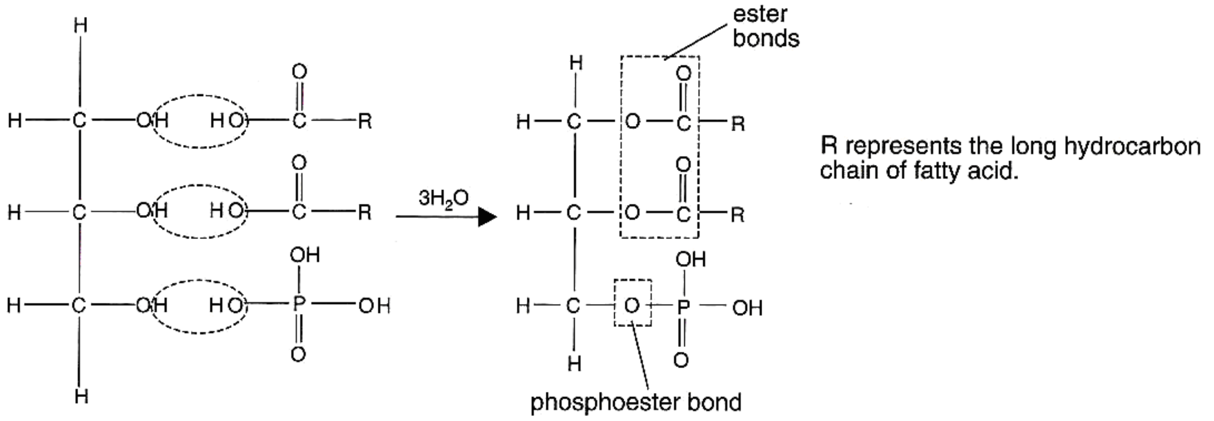
Structure-Property	Significance
P: Triglyceride is less dense than water.	Therefore is able to provide aquatic mammals (e.g. whales) with buoyancy.

V. Phospholipids

- Phospholipids are lipids that contain a phosphate group.

- Structure:
  - The simplest phospholipid is **phosphatidic acid** and is synthesised from 1 glycerol, 2 fatty acids and 1 phosphoric acid (H_3PO_4).

- Synthesis of phosphatidic acid:
    - phosphoric acid reacts with one of the three hydroxyl groups of glycerol.
    - the other two hydroxyl groups of glycerol react with fatty acid as in the formation of triglyceride



▲ **Figure 3.13** Formation of phosphatidic acid

Source: Longman A-Level Course in Biology: Core Syllabus Volume 1. pp.61

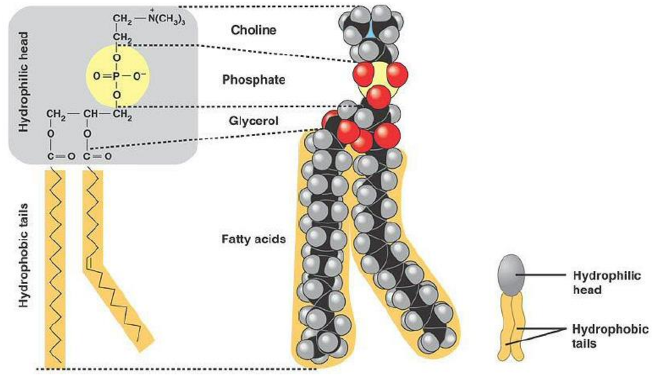


Fig. 5.12 Structure of a phospholipid and symbol for a phospholipid.

Source: Biology (9th Edition). Pp. 122

- Property:
    - The phosphate group of the phosphatidic acid forms the **hydrophilic (i.e. water-loving) "head"** of the molecule whilst the hydrocarbon chains of the fatty acid moieties form the **hydrophobic (i.e. water-hating) "tails"** of the molecule. Such molecules are described as being **amphipathic**.

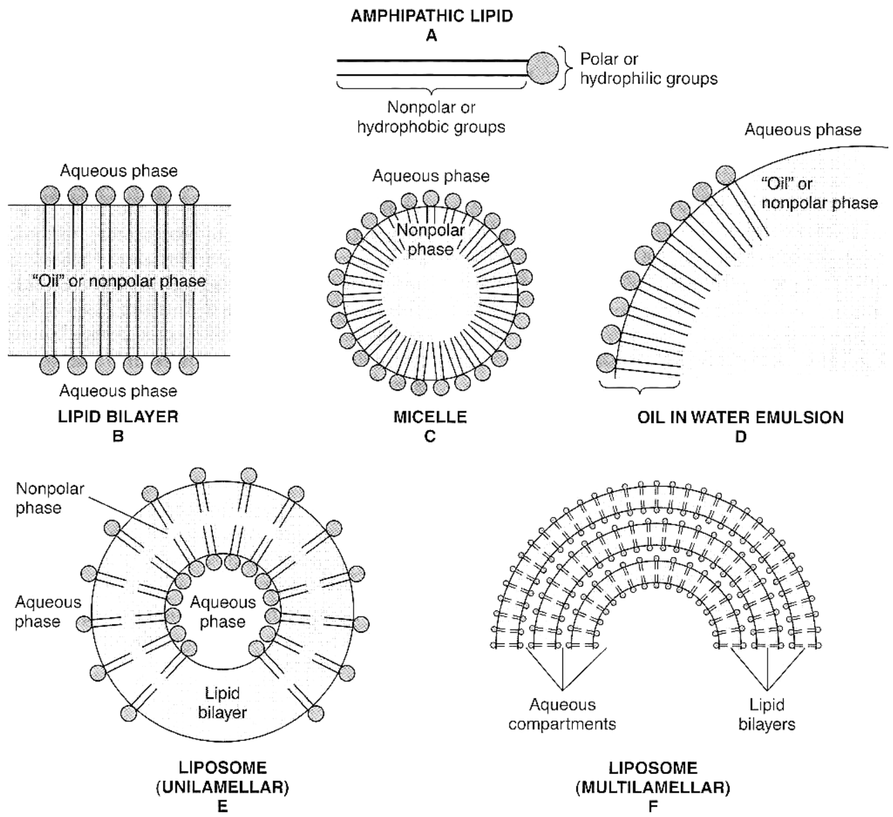


Figure 15–22. Formation of lipid membranes, micelles, emulsions, and liposomes from amphipathic lipids, eg, phospholipids.

Source: Harper's Illustrated Biochemistry. 27th Edition. pp.117

- Function:
  - The internal environment of the cell (i.e. cytoplasm) and its external environment are both aqueous. In an aqueous environment, phospholipid molecules assemble themselves into a **phospholipid bilayer**. They are responsible for the **selectively permeable** property of membrane.

- Relating structure to function:

<table>
<tr><th>Structure-Property</th><th>Significance</th></tr>
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S: A phospholipid molecule consists of a phosphate group and two hydrocarbon chains.

P: The phosphate group of the phospholipid is **hydrophilic** whilst the hydrocarbon chains of the fatty acid moieties are **hydrophobic**. Such molecules are described as being **amphipathic**.

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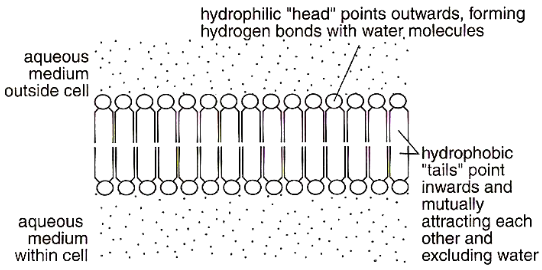
In an aqueous environment, phospholipid molecules assemble themselves into a **phospholipid bilayer**. The hydrophobic region of the bilayer forms a barrier between the aqueous interior and exterior of the cell, responsible for the **selectively permeable** property of membrane.



▲ **Figure 3.16** Formation of a phospholipid bilayer.

Source: Longman A-Level Course in Biology: Core Syllabus Volume 1. pp.65

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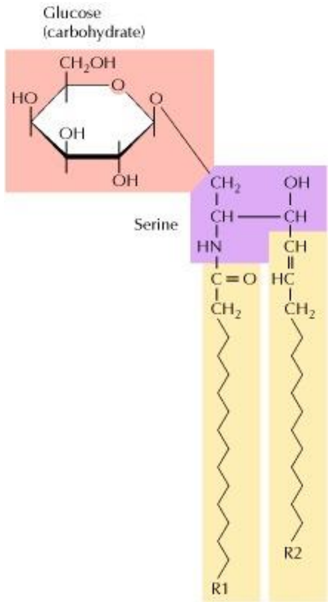
V. Glycolipid

- Glycolipids are lipids combined with carbohydrate.



- Structure:
  - Glycolipids are formed when a carbohydrate chain associates with the phospholipid in the cell surface membrane.
  - They are thus similar to the phospholipids in their general organization as amphipathic molecules.
  - These carbohydrate chains are found on the extracellular surface of all eukaryotic cell membranes.

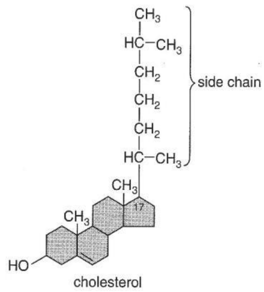
Figure 2.8 Structure of glycolipids
Two hydrocarbon chains are joined to a polar head group formed from serine and containing carbohydrates (e.g. glucose).

Source: The Cell: A Molecular Approach (2nd Edition)

- Functions:
  1. Involved in cell-cell recognition – the carbohydrate chain functions as a marker that distinguishes one cell from another;
  2. Involved in cell-cell adhesion – to bind cells together into tissues.
  3. Act as receptor sites for chemical signals e.g. hormones.

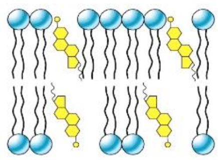
VI. Cholesterol

- Cholesterol is an example of steroid.



- Structure:
  - A carbon skeleton consisting of 4 fused rings of carbon and hydrogen atoms.
- Functions:

1. ____________________________________
   - Cholesterol disrupts the close and orderly packing of phospholipid molecules in cell membranes, hence they are important for **increasing membrane fluidity**.



2. As precursors of other biomolecules
   - Cholesterol is used in the synthesis of steroid hormones, e.g. testosterone, oestrogen and progesterone.

Ethanol Emulsion Test for Lipids

Principle: Lipids are soluble in organic solvents such as ethanol, but not in water, with which they form **emulsions** on vigorous shaking.

Method:

1. Grind test item (if it is a solid) and pour it into a test tube. Use only two drops of the test item if it is a liquid.
2. Add 2 cm^3 of ethanol and mix well. Allow any solid particles to settle.
3. Decant the ethanol into another test tube containing 2 cm^3 of water. Mix well (or shake vigorously) and look for cloudiness.

Observations:

4. If lipid is present, it dissolves in ethanol to form a homogenous solution, which then forms an emulsion with water.
5. If lipid is absent, a homogenous solution is still formed with ethanol, which remains homogenous when water is added.

Annex

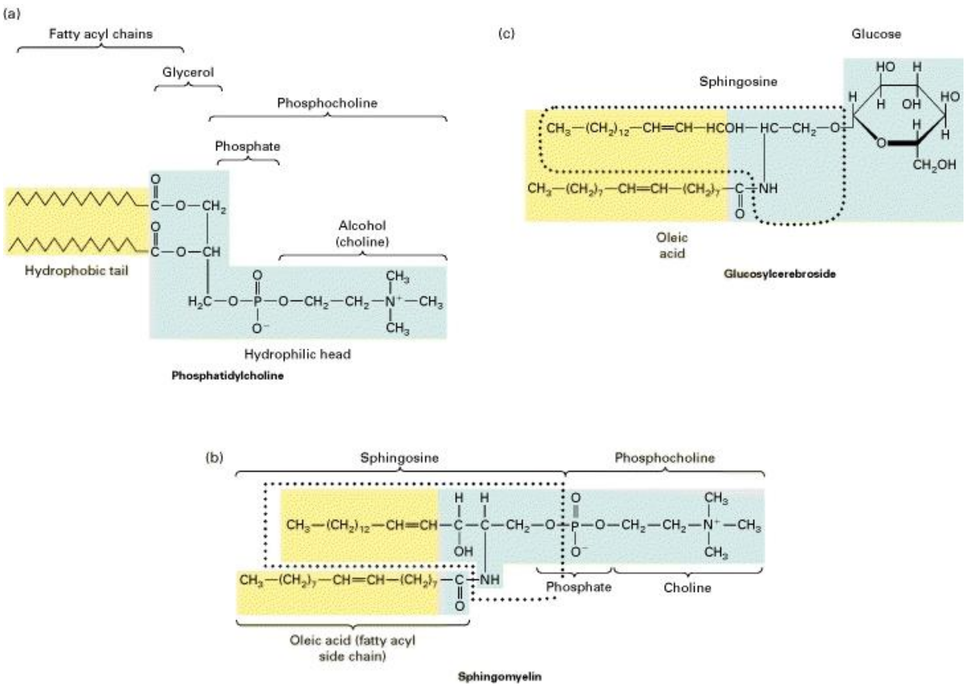


Figure 5-27 Structures of two types of phospholipids and a glycolipid. The hydrophobic portions of all molecules are shown in yellow (lighter grey); the hydrophilic, in green. (a) Phosphatidylcholine is a typical phosphoglyceride. The fatty acyl side chains can be saturated, or they can contain one or more double bonds. Common alcohols found in these phospholipids are shown in Figure 5-28. (b) Sphingomyelins are a group of phospholipids that lack a glycerol backbone; a sphingomyelin may contain a different fatty acyl side chain than oleic acid (shown here). Linkage of sphingosine (outlined by black dots) to a fatty acid via an amide bond forms a ceramide. (c) Glucosylcerebroside, one of the simplest glycolipids, consists of the ceramide formed from sphingosine and oleic acid linked to a single glucose residue. This glycolipid is abundant in the myelin sheath.

Source: Molecular Cell Biology (4th Edition)