



The Structure and Biological Functions of Lipids

This factsheet covers the relevant AS syllabus content of the major examining boards.

By studying this Factsheet candidates will gain a knowledge and understanding of:

- the general nature and structure of lipids as triglycerides (fats and oils) and waxes, including ester bonds and their formation.
- the nature of saturated and unsaturated fatty acids and fats and their implications for human health.
- the structure and properties of phospholipids.
- the roles of phospholipids, cholesterol and glycolipids in cell membranes.

Introduction

All lipids contain the elements carbon, hydrogen and oxygen but have a lower proportion of oxygen in the molecule than carbohydrates. With the exception of glycerol they are insoluble in water, but dissolve in organic solvents such as ether, chloroform and benzene. They are lighter (less dense) than water. They show a wide range of molecular structures, properties and biological functions and this diversity has been utilised by living organisms in a large variety of ways. The major functions of lipid types referred to in AS syllabuses are shown in Table 1.

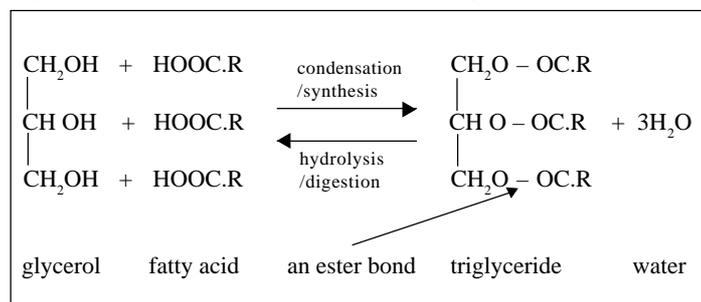
Table 1. Major functions of lipids

Function	Lipid type
Energy source as soluble, mobile respiratory substrate	glycerol, fatty acids.
Energy store as insoluble respiratory substrate	fats in animals, oils in plants (seeds)
Thermal insulation against heat loss via body surface	fats
Buoyancy in aquatic mammals	fats
Cushioning and protection against knocks	fats
Waterproofing on surfaces of leaves, insects, skin	waxes
Solvent, enabling storage and transport of fat soluble vitamins (A, D, E and K)	fats and oils
Major components of cell membranes	phospholipids, cholesterol and glycolipids

Glycerol, fatty acids and triglyceride structure

Glycerol is a three carbon alcohol which contains three hydroxyl (-OH) groups. Its molecular structure can be seen in Fig 1. Each of the three hydroxyl groups can condense with a fatty acid to form an ester. The combination of one molecule of glycerol with three molecules of fatty acid forms a lipid molecule known as a triglyceride (fat). An equation showing the formation of fat can be seen in Fig 1.

Fig 1. The formation and breakdown of triglycerides



Remember – an ester bond is formed by condensation between an alcohol group and an acid group. In this case the alcohol groups are on the glycerol and the acid groups belong to the fatty acids

Fatty acids contain the acidic (-COOH) group. They have the general formula R-COOH where the side chain, R, is hydrogen or an alkyl-group, such as -CH₃ or -C₂H₅, and so on. They increase in molecular length by -CH₂ for each successive member of the series. Most fatty acids have an even number of carbon atoms, usually between 14 and 22. These long hydrocarbon tails mean that fatty acid molecules are insoluble in water (the tails are referred to as hydrophobic or 'water-hating').

Biological functions of triglycerides

The digestion of triglycerides is catalysed by lipase enzymes which are found, for example, in animal digestive systems, in germinating seeds, in the lysosomes inside cells and in the secretions of saprophytic bacteria and fungi. The synthesis of triglycerides takes place in fat storage depots, for example, in liver cells, in the adipose cells of mammals, which make up adipose connective tissue (found under the skin, between the skeletal muscles, around the kidneys and in the yellow bone marrow), in the fat body of insects and also in the food reserves and endosperm of seeds. The energy content of triglycerides is higher than that of carbohydrate or protein. 1g of fat will yield around 37kJ of energy on complete oxidation whereas 1g of carbohydrates yields 16kJ and 1g of protein yields 17kJ. Triglycerides form compact food reserves which do not upset the osmotic balance of cells. When oxidised triglycerides also yield water which may be useful to desert animals such as the kangaroo rat and camel. These store fat specifically for its metabolic water content.

Triglycerides are poor conductors of heat so that fat laid down under the skin can help to prevent heat loss. This is particularly important in aquatic mammals such as whales, seals and walrus which build up huge deposits of blubber to protect them from heat loss in cold Arctic or Antarctic seas. Since the blubber is less dense than water it also provides buoyancy enabling the animals to stay near the surface.

A thick layer of fat around the mammalian kidneys helps to protect them from damaging knocks.

Remember – condensation is the joining of molecules by the removal of water and is important in synthetic reactions. The reverse, hydrolysis, is the splitting of molecules by the addition of water and is important in digestion.

Saturated and unsaturated fatty acids and fats

Fatty acids frequently contain double bonds (C=C) in their side chains(R) resulting from the absence of some hydrogen atoms. If a fatty acid has a full complement of hydrogen atoms - so it has no double bonds - it is said to be **saturated**. The general formula of a saturated fatty acid is $C_nH_{2n+1}COOH$. Examples are palmitic acid ($C_{15}H_{31}COOH$) and stearic acid ($C_{17}H_{35}COOH$). If a fatty acid has some hydrogen atoms missing - resulting in the presence of double bonds - it is referred to as **unsaturated**. The general formula of an saturated fatty acid may be $C_nH_{2n-1}COOH$ or $C_nH_{2n-3}COOH$ or $C_nH_{2n-5}COOH$. Examples are oleic acid ($C_{17}H_{33}COOH$), linoleic acid ($C_{17}H_{31}COOH$) and linolenic acid ($C_{17}H_{29}COOH$).

Exam Hint – examiners expect you to be able to recognise and manipulate formulae but you will not be asked to reproduce formulae from memory.

In combination with glycerol, saturated fatty acids form saturated fats which are solid at normal atmospheric temperatures, and is more common in the fats of animals. Unsaturated fatty acids in combination with glycerol give oils. These are liquid at normal atmospheric temperatures and tend to be more characteristic of plants, particularly in oily seeds and fruits, such as castor oil seeds, sunflower seeds and coconuts. However, oils do occur in animals, for example the fish liver oils of cod and halibut, and in red fish such as sardines, pilchards, mackerel, salmon, tuna, eels and trout which are referred to as ‘oily fish’.

Oleic acid in combination with glycerol forms olive oil. Linolenic and linoleic acids in combination with glycerol are found in linseed oil and in corn oils. Linoleic and linolenic acids are examples of ‘essential fatty acids’ because they are required in small quantities for normal health but cannot be made by the body.

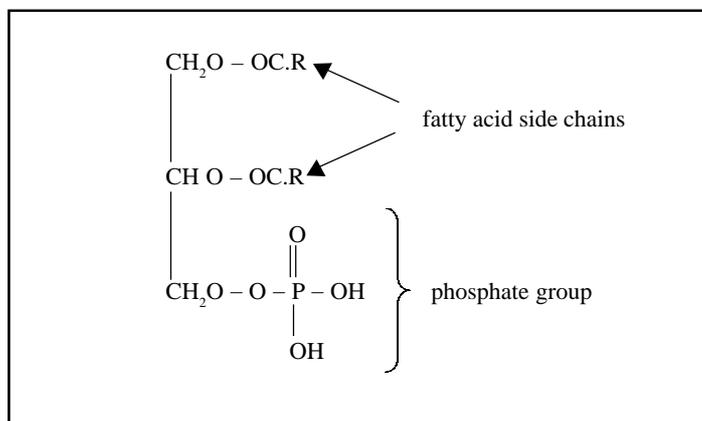
Waxes

These are esters of fatty acids with long chain alcohols such as cetyl alcohol ($C_{16}H_{33}OH$) or cholesterol. They are hard and form protective waterproof coverings on biological surfaces, for example, the cuticle of arthropod exoskeletons, leaves, fruits, seeds, mammalian skin, fur, feathers. Beeswax is used to build the honeycomb of bees. Lanolin is a waxy substance that coats mammalian hair.

Phospholipids

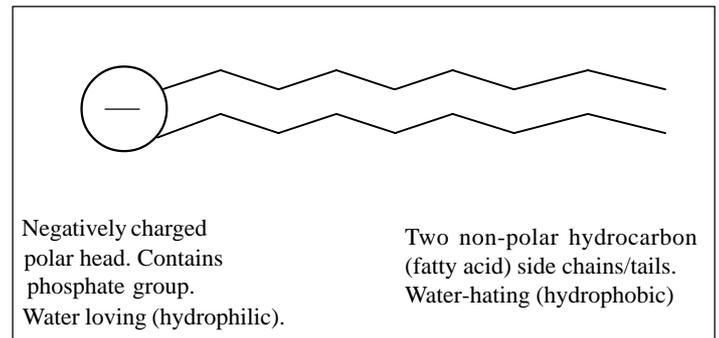
Most of these involve the alcohol glycerol. The glycerol forms ester links with two fatty acid molecules and with one phosphate group. The general structural formula is shown in Fig 2.

Fig 2. General structure of a phospholipid



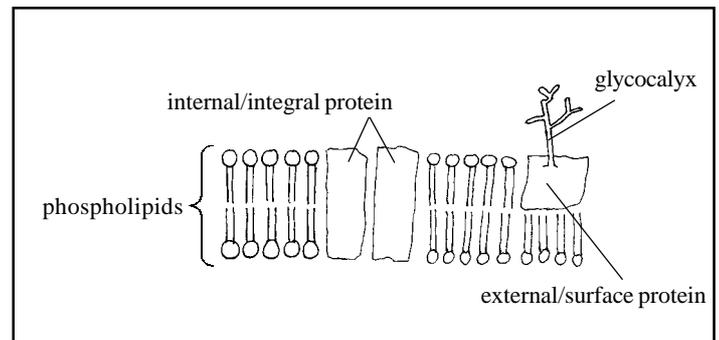
The phosphate group can ionise (become polarised) and so becomes water soluble but the fatty acid tails are non polar and remain water insoluble. A commonly used representation of a phospholipid is shown in Fig 3.

Fig 3. Diagram of a phospholipid



The possession of both hydrophilic and hydrophobic groups is a very important biological property, since if placed in water the only stable form that the molecules can achieve is to form a double membrane with the polar heads to the outside, facing the water and the non-polar tails to the inside, hidden from the water. This forms the basis of biological membranes, such as the cell membrane. The general structure of the cell membrane, consisting of phospholipids and associated molecules is shown in Fig 4.

Fig 4. Vertical section through a cell membrane (fluid mosaic model)



The phospholipid bilayer is dynamic (fluid) since the individual molecules can move sideways and exchange places in their own row. This enables the membrane to be self sealing if punctured and also allows the taking in of materials by forming vacuoles around them (pinocytosis or cell drinking and phagocytosis or cell eating). It also enables movement of the protein components of the membrane. Since the non-polar tails within the phospholipid bilayer are water hating, transport of water soluble substances across the membrane is restricted to via the protein components. However, fat soluble substances can cross the membrane via the phospholipid components.

In many cell membranes the complex lipid cholesterol is present between phospholipid molecules. This is thought to make the membranes stronger and less flexible, but may also reduce permeability. Glycolipids (molecular complexes of lipid and polysaccharides) are found on the outside of cell membranes as the glycolyx. This is involved in cell to cell recognition and communication, particularly during growth and development. They may also be used as infection sites by viruses and bacteria.

Importance of lipids to human health

Lipids are an essential component of a balanced diet since they have many roles in the body. However, if too much lipid is taken into the body it can lead to the development of medical problems. Surplus dietary triglycerides are laid down as storage fat in the adipose tissue and this can cause obesity. This can cause a strain on the heart, due to the carriage of extra body weight and due to the need to pump blood through all the extra capillaries of the additional adipose tissue. Surplus triglycerides, phospholipids, some lipoproteins and cholesterol may also be laid down, in and on cells of the inner surface of blood vessels, forming plaques or atheromas. This can also impede blood flow and thus impose an extra workload on the heart.

Cholesterol may be taken in via the diet or may be synthesised in the liver from saturated fats, (which are found in high levels in beef, pork, butter, whole milk, eggs, cheese, palm oil and coconut oil). For this reason a high intake of saturated fats should be avoided, particularly in individuals with high cholesterol levels. On the other hand, unsaturated fats (found in many plant oils) are thought to reduce cholesterol levels in the blood and so should be preferred in the diet rather than saturated fat.

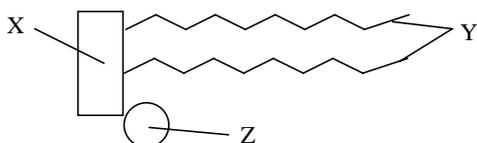
In the liver, triglycerides and cholesterol are made water soluble (allowing blood transport) by combination with proteins, forming lipoproteins. There are two major types of these:

- **low density lipoproteins (LDLs)**. These pick up blood cholesterol and deposit it inside cells, including in the smooth muscle cells of arteries. Because of this, high blood levels of LDLs may increase the risk of developing coronary artery disease.
- **high density lipoproteins (HDLs)**. These gather up cholesterol from cells and transport it to the liver for excretion. Thus high levels of HDLs in the blood reduce the risk of developing coronary artery disease. Red (oily) fish are good dietary sources of HDLs

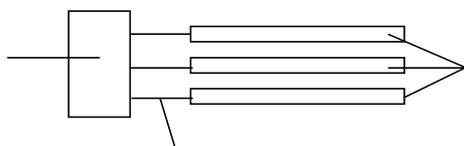
Dietary intake of unsaturated fatty acids known as omega-3 fatty acids are known to reduce the levels of cholesterol and LDLs in the blood, and thus reduce the risk of developing heart disease. Omega-3 fatty acids are found in oily (red) fish and in shellfish and should be a regular component of a balanced diet.

Practice Questions

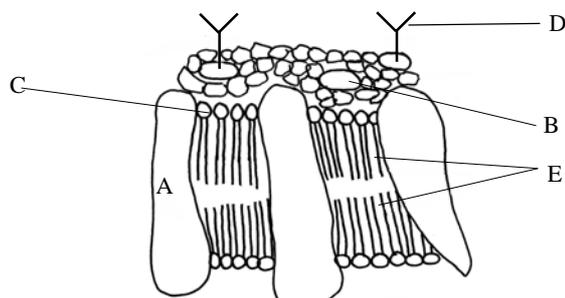
1. The diagram represents a phospholipid.
 (a) Name the parts of the molecule X, Y and Z. 3



- (b) Comment on the role of phospholipids in the transport of molecules through the cell membrane. 2
2. Stearic acid is a saturated fatty acid with the formula $C_{17}H_{35}COOH$. Oleic acid is an unsaturated fatty acid with the formula $C_{17}H_{33}COOH$.
 (a) (i) What do the terms saturated and unsaturated mean? 2
 (ii) In what ways do the properties of saturated and unsaturated fats differ? 2
 (b) Why are triglycerides useful as storage molecules? 3
 (c) (i) Name the parts of the triglyceride shown below



- (ii) In what way would the structure of a phospholipid differ from this triglyceride? 1
3. The diagram below shows part of a cell membrane.



- (a) Which two structures would yield fatty acids on hydrolysis? 2
 (b) Why is the membrane referred to as 'a fluid mosaic' membrane? 2
 (c) (i) Describe the composition of structure D. 2
 (ii) State a function of structure D. 1

Answers

1. (a) X = glycerol; Y = fatty acid tails/chains; Z = phosphate; 3
 (b) enables transport of lipid/fat soluble molecules in/out of cell; prevents/restricts transport of water soluble molecules in/out of cell; 2
 2. (a) (i) saturated means that the molecule contains the maximum number of hydrogen atoms; unsaturated means that the molecule contains fewer hydrogen atoms than it might/ contains double bonds; 2
 (ii) unsaturated fats have lower melting points than saturated fats; unsaturated fats form oils but saturated fats are solid; 2
 (b) Any three of:
 don't dissolve in water/body fluids/
 therefore don't affect osmotic balance of cells/tissues/
 have higher calorific value than carbohydrates/ can yield more energy per gramme on oxidation/
 reference to other useful properties/buoyancy/insulation;;; 3
 (c) (i) 3
 (ii) one of the fatty acid molecules would be replaced by a phosphate molecule; 1
 3. (a) E; D; 2
 (b) because the phospholipid molecules can move sideways into new positions; this enables the protein components to move about also; ref to analogy of proteins as 'icebergs' floating about in a 'sea' of phospholipids; max 2
 (c) (i) made of glycolipid; which consists of polysaccharide joined to lipid; 2
 (ii) cell recognition/cell communication; 1

Acknowledgements;

This Factsheet was researched and written by Martin Griffin

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