Lesson 2

LIPIDS & PROTEINS

Aim

Explain the characteristics of major biochemical groups including carbohydrates, lipids and proteins.

CARBOHYDRATE

Carbohydrates are compounds that contain carbon combined with hydrogen and oxygen. They are one of the most significant groups of organic compounds that are made (synthesised) by living systems (within the tissues of plants or animals). Carbohydrates are significant both in terms of both quantity made and the importance of their use in living organisms.

Carbohydrates are compounds which, when analysed, give empirical formulae which are multiples of the simple formula CH_2O. Chemically, carbohydrates are defined as polyhydroxy (poly = many, hydroxyl refers to the OH groups which are bonded to the carbon atoms of the molecules backbone) aldehydes or ketones (depending on the location of a double bonded oxygen atom (refer to the structural diagrams in the previous lesson. A saccharide aldehyde is an aldose, a saccharide ketone is a ketose. Saccharides typically exist as cyclic molecules. Examples of carbohydrates include sugars, starch, glycogen, cellulose and chitin. Carbohydrates are made or synthesised in plants by the process of photosynthesis.

Types of Carbohydrate

Carbohydrates may be broken down into three groups:

Monosaccharides

These are the simplest carbohydrates. They are made up of a chain of carbon atoms to which hydrogen and oxygen atoms are attached in the proportion of 1 carbon atom to 2 hydrogen atoms to 1 oxygen atom (CH_20). Monosaccharides can not be hydrolysed to give smaller molecules, they are as small as saccharides get, and are considered to be one saccharide unit, hence the name mono (meaning 1) saccharide. (Hydrolysis is the process of splitting one molecule into two by the addition of H^+ and OH^- ions of water and is depicted in the diagram at the end of this section).

Glucose is a monosaccharide and is the form of sugar which is most often transported through animal systems. A combination of glucose and fructose forms sucrose, which is the form that plants use.

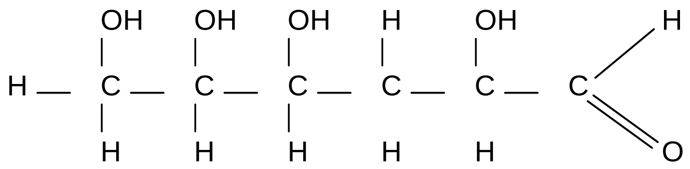
There are four common monosaccharides found in nature:

- Glucose -Contains six carbon, six oxygen and twelve hydrogen atoms; it is a building block for many other compounds, and is one of the most common compounds on earth.

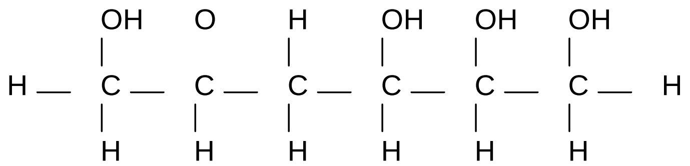
- Fructose -Contains six carbon, six oxygen and twelve hydrogen atoms, the same as glucose, but arranged or bonded together in a different pattern; found together with glucose in honey and fruit juices.

- Ribose -occurs naturally as part of vitamin B_{12} and the ribonucleic acids (RNA)

- 2-Deoxyribose -occurs naturally as part of DNA (Deoxyribonucleic acid) which is an essential part of the genetic material found in all living organisms.



Glucose



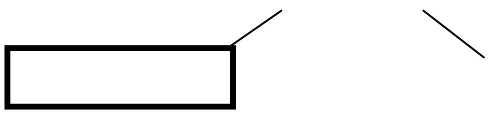
Fructose

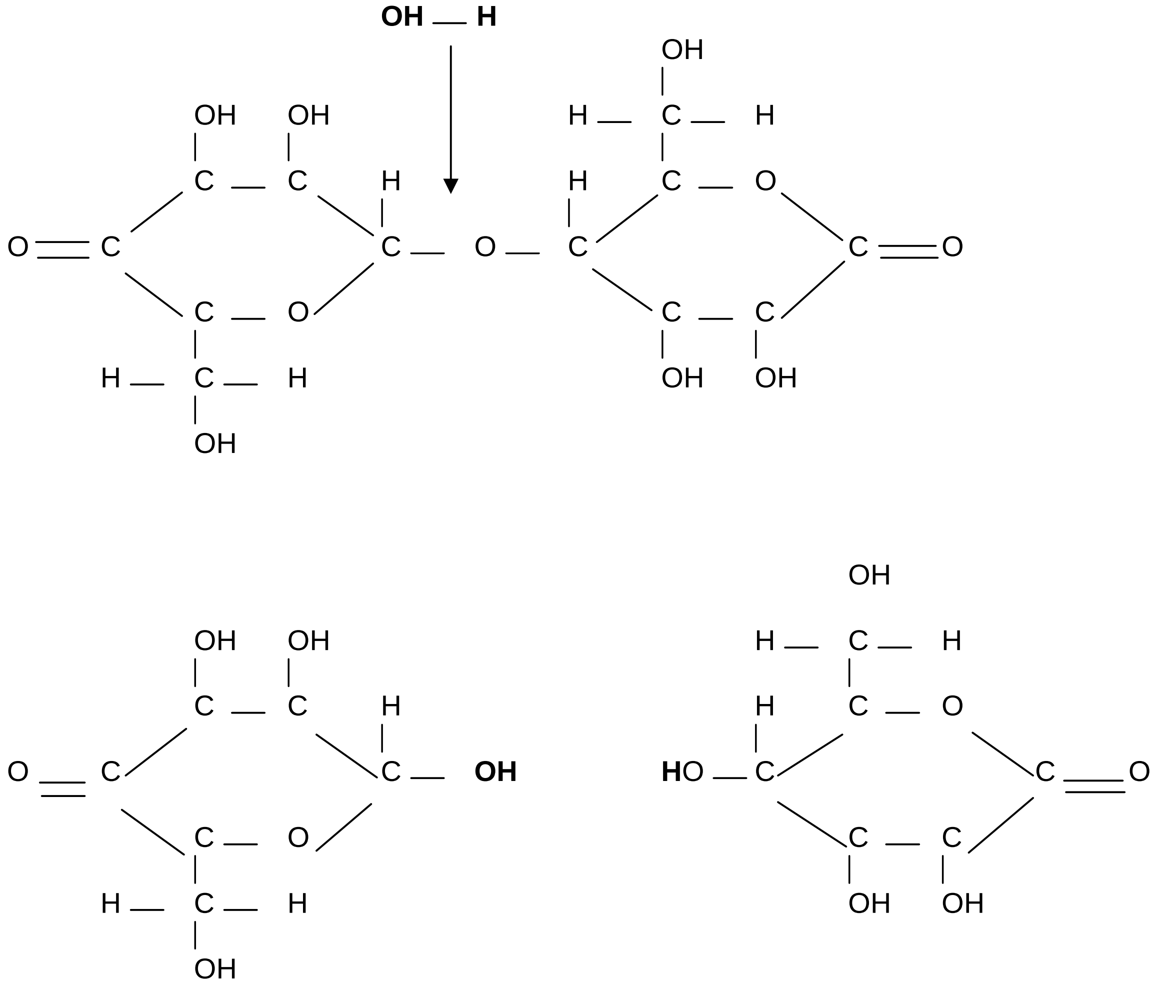
While they have the same chemical formula, glucose is an aldose and fructose is a ketose. This affects how the body metabolises each, and fructose takes much longer to metabolise than glucose.

Oligosaccharides
These are compound sugars which, when hydrolysed, will yield two to six saccharide molecules. Disaccharides for example, are oligosaccharides which yield two monosaccharide molecules when they are hydrolysed.

Polysaccharides
These are made up of monosaccharides linked together in long chains. They yield a large number of monosaccharides when they are hydrolysed. Starch, which is made of many glucose molecules, is the main storage form of sugar in plants. (Glycogen is the common storage form of sugar in animals.) They must be hydrolysed before they can be used as energy sources for living systems.

Hydrolysis of a disaccharide to give two monosaccharides:





Hydrolysis of a Disaccharide
The glycosidic bond joining the two monosaccharides is shown in the box. Water attacks this bond, and is itself 'added' across it, with the hydroxide ion bonding to one of the carbons and the remaining H+ ion bonding to the oxygen molecule which remains attached to the other carbon.

Carbohydrate Function

- Carbohydrates store energy from light in plants.

During photosynthesis light energy is accepted by the plant cell and transformed into a chemical energy which is used to bond atoms of hydrogen, oxygen and carbon together to produce sugars. The hydrogen, oxygen and carbon come from water (extracted from the soil) and carbon dioxide (extracted from the air). Plants can build up complex carbohydrates and store them as starch in their tissues. Humans cannot do this. Starch must be broken down into simple sugars before being used by human tissue.

- Carbohydrates release energy.

The photosynthesis explained above can be reversed in a plant in order to supply energy (with by products of carbon dioxide and water). This process is called plant respiration.

- Energy Supply in Animals/Humans

Carbohydrates are a major energy source for most animals. They can be metabolised; (transformed into usable end products by chemical reactions in living cells) breaking down chemical bonds making large compounds into smaller compounds, and in the process releasing energy. This energy is then used by the cell as a power source, allowing it to perform required functions.

LIPIDS

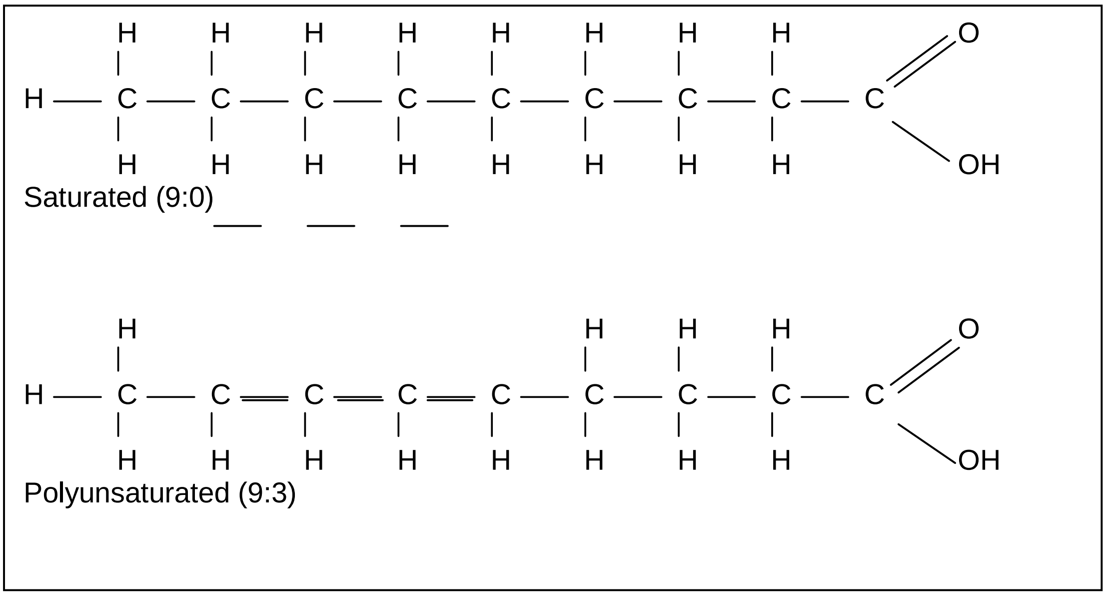
Lipids are organic fats and oils. Group of biomolecules that are grouped under this classification based on their solubility properties – they are all water insoluble, or at least partially insoluble in water, however they are readily soluble in organic solvents, such as hot alcohol, benzene or ether. Lipids occur in both plants and animals, and are among other things, used to store chemical energy. Fats and oils are distinguishable by their melting points, fats (such as lard and butter) are solid at room temperature, and oils (canola, olive etc) are liquid. Some common lipid biomolecules that are found in animals are described below including fatty acids, triglycerides, phospholipids and sterols.

Fatty Acids

These are carboxylic acids with long hydrocarbon chains tails. They may be saturated (all single bonds between the carbon atoms of the backbone) or unsaturated (double or triple bonds between the carbon atoms). Monounsaturated means there is only one double or triple bond in the hydrocarbon tail, polyunsaturated means there is more than one double bond on the hydrocarbon tails. When a hydrocarbon chain is saturated (no double bonds) it lies straight. This means that the molecules in a saturated fat can pack in tight to each other. This is why saturated fats are commonly found to be hard at room temperature. In either a mono or polyunsaturated fat, the hydrocarbon tails are kinked and they cannot pack in closely to each other. This is why these types of oils are commonly found to be liquid at room temperature.

The head of the fatty acid, the carboxylic acid is very hydrophilic (water hating). The hydrocarbon chain (the tail) is very hydrophobic (water hating). A molecule like this, which is both water hating and loving is called amphipathic. This property is extremely important in the structure of cell membranes.

Fatty acids are typically written with the number of carbons, followed by a colon (:) and then the number of double bonds in the molecule. So, 18:1 means the fatty acid has 18 carbons, with one double bond (oleic acid). The general structure of a saturated and polyunsaturated fatty acid is shown in the following diagram.

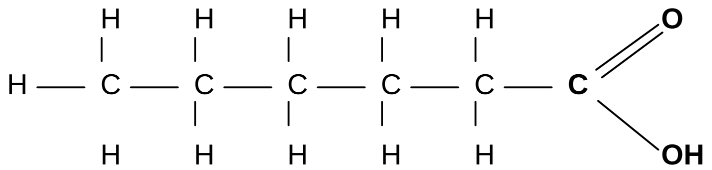


Triglycerides

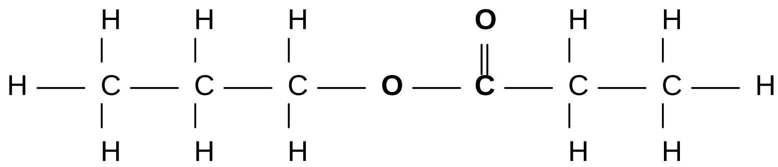
You will also see these referred to as triacylglycerols. A triacylglycerol is a compound comprised of glycerol with three fatty acids attached. The glycerol and the fatty acids about joined by ester bonds. An ester bond (or esterification as the process is called) is where H from the carboxylic acid (-COOH) found on the fatty acid is replace by a bond to the glycerol.

The diagram below shows the structure for both an ester and a carboxylic acid so you can compare the difference, along with the more complex structure of a triglyceride.

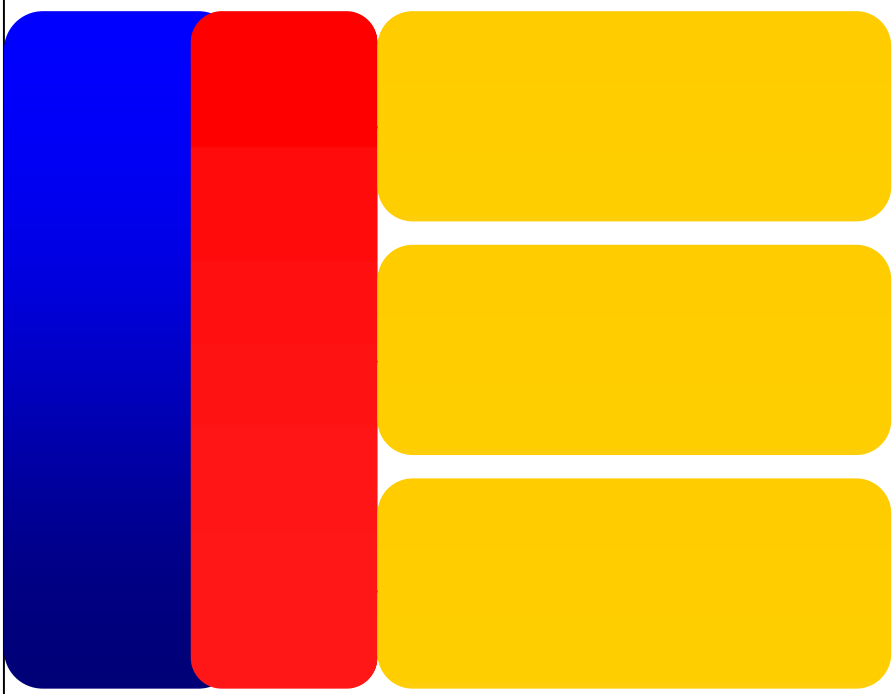
The fatty acids tails in one triacylglycerol molecule could all be the same as each other, or they could all be different. Triglycerides are a source of energy in living systems. They are stored primarily in the fat tissue and the body can get more than twice as much energy from a molecule of triacylglycerol than it can from a carbohydrate or protein molecule.



Carboxylic acid



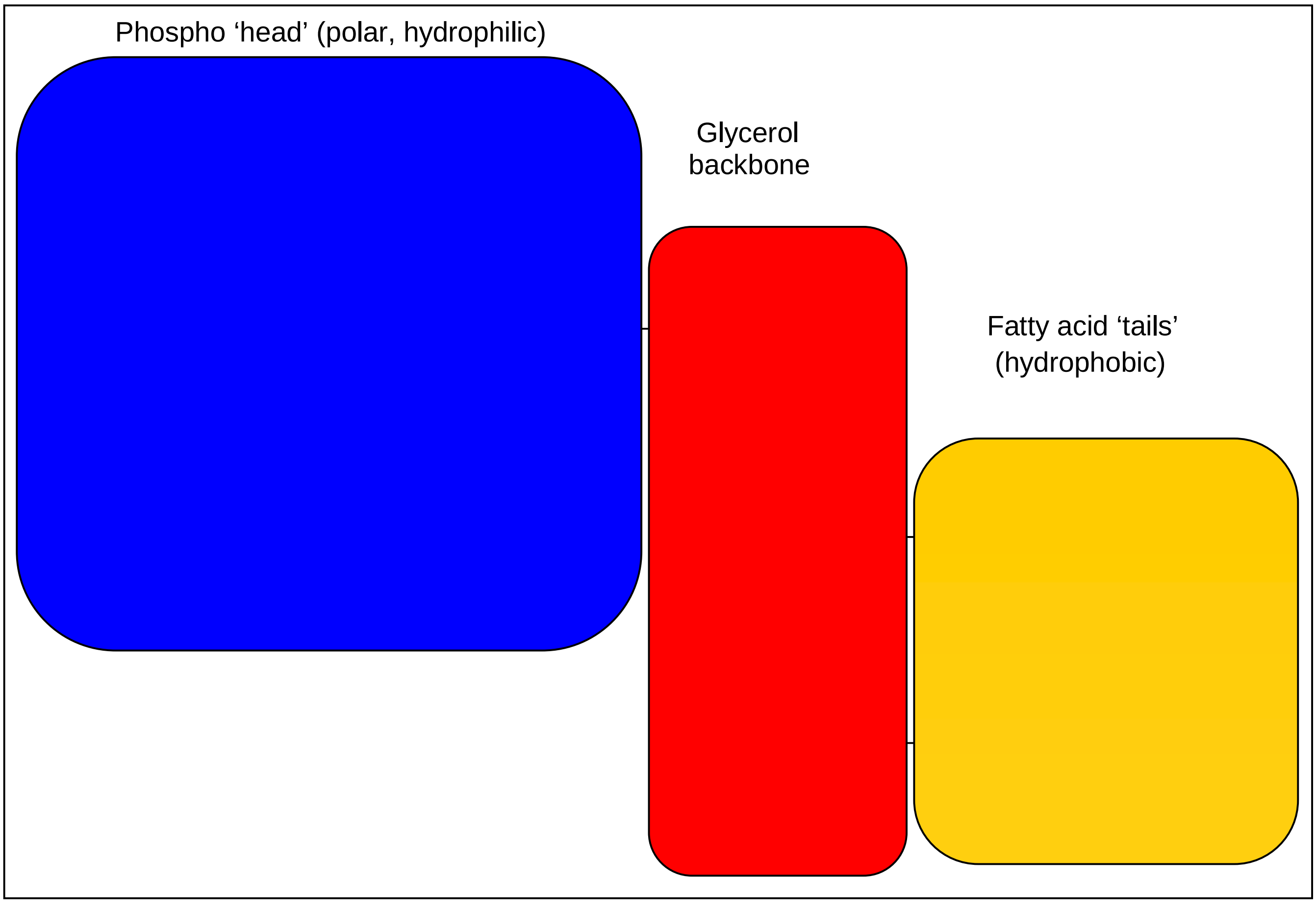
Ester



Triacylglycerol

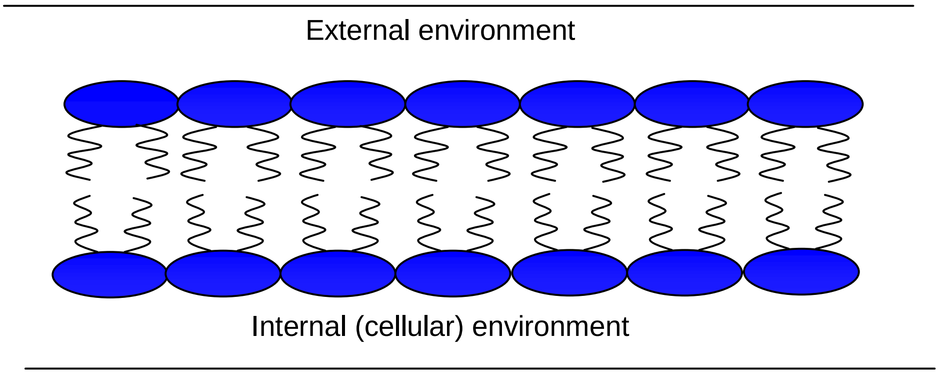
(glycerol – blue)
(ester bonds – red)
(fatty acids – yellow)

Phospholipids
Phospholipids are amphipathic molecules. This means they are hydrophobic at one end and hydrophilic at the other. A general diagram showing phospholipid structure is below:



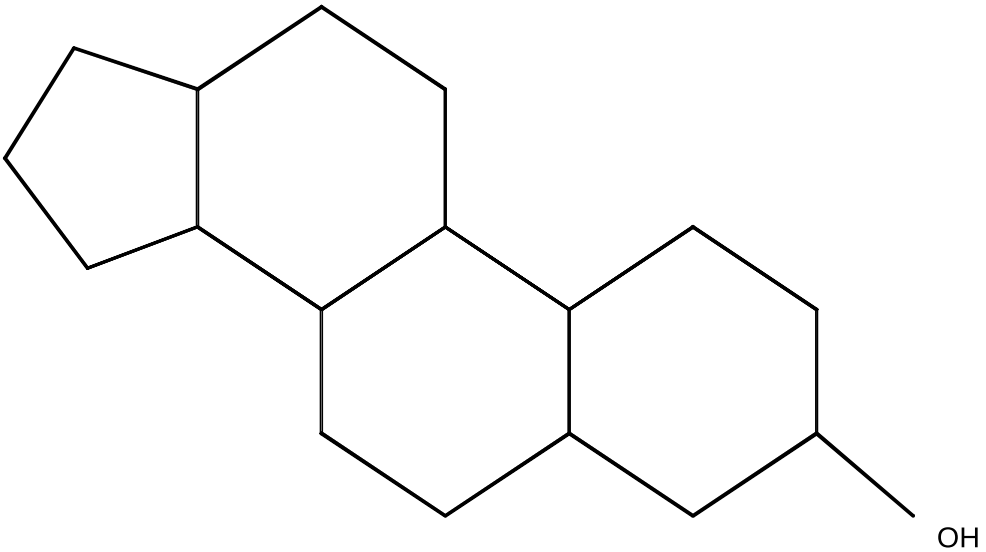
Phospholipids are the main constituent of cellular membranes, the semi-permeable barrier that isolates the inside of a cell from the external environment. The phospho head groups, being hydrophilic, face out to the water based external environment, and the tails face away. Another phospholipid lies behind the first; with its fatty acid tails faces those of the first phospholipid and the phospho head group faces into the internal cellular environment. This means you have two watery fluids, that outside the cell and that inside (the cytoplasm) separated from each other by a membrane that is lipid on the inside. The lipid interior of the membrane means hydrophilic molecules are trapped either inside or outside the cell as they cannot move across the lipid interior of the membrane. These types of membranes are known as phospholipid bilayers.

Phospholipid bilayer



(Phospho head groups are shown in blue, fatty acid tails are the zig zagging lines)

Sterols
These molecules are made up of an alcohol and a steroid. They are amphipathic – the alcohol hydroxyl group (-OH) is polar and hydrophilic and the steroid part is hydrophobic. A general diagram showing sterol structure is shown below. Cholesterol is a sterol that is found in animals (but not in plants). It is found in the blood steam as well as being an important component of cell membranes where the steroid group is buried in the lipid interior of the membrane and the polar alcohol group is projected out of the membrane to associate with the watery extracellular fluid.



General sterol structure

Terminology

Term	Meaning
Glyco – and – ose	Carbohydrate
Lipo –	Lipid
Phospho-	Phosphate
Hydroxy- or -ol	An OH group is present
Hydrophobic	Literally, water fearing
Hydrophilic	Literally, water loving
Lipophobic	Literally, lipid fearing
Lipophilic	Literally, lipid loving
Functional group	Often denoted –R in structural diagrams, this is the group, or in some molecules, groups, of atoms that confer the key properties of the molecule (polarity, acid/base, hydrophobicity, hydrophilicity etc) also known as a side chain
Amphipathic	A molecule that is in one region hydrophobic and in another hydrophilic
Polar	A molecule that carries a charge or charges either positive or negative

COMMERCIALLY USEFUL FATS AND LIPIDS

Drying Oils (in paints & lacquers)

These are lipids that contain many double bonds. When exposed to air there is a polymerization reaction started by oxygen that cross links these compounds forming a tough film. Catalysts (eg. cobolt) are often added to speed up this polymerization reaction. Linseed oil (from flax seed) is a common drying oil.

Soaps

Soaps are made by adding sodium hydroxide to a fat or oil. The resulting chemical reaction produces glycerol plus a soap. Soaps are so named because the reaction to produce them is known as saponification. Soap molecules contain a long oil soluble hydrocarbon chain with an ionic water soluble carboxylate group at one end. One end of the molecule will thus dissolve in oil and the other end will dissolve in water. Applied to dirty skin/cloth etc, the fatty acid will bind to oils and greases. This detaches them from the surface and they can be rinsed away with water.

Detergents

Detergents are made by reduction of fats or fatty acids to alcohols, followed by adding a sulphur atom by treatment with sulphuric acid, and finally treatment with sodium hydroxide to produce a sodium salt of the acid. Detergents work in the same basic way as soaps, and commercial mixtures often include a soap as well as other components such as enzymes.

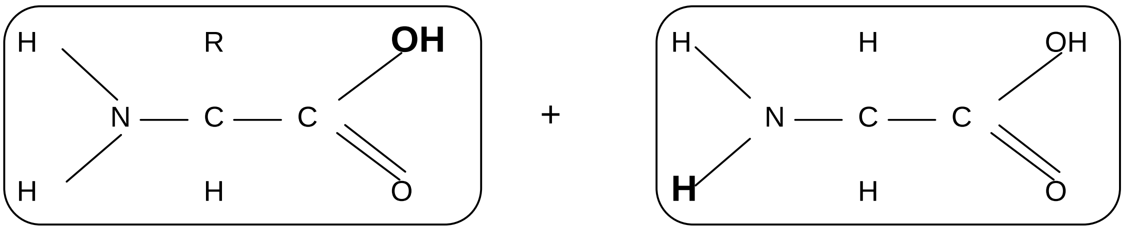
Waxes

Waxes are relatively simple compounds consisting of esters of long chain fatty acids (carboxyl functional group) and long chain fatty alcohols (OH functional group). Naturally occurring waxes (eg. beeswax); usually occur as a mixture of esters.

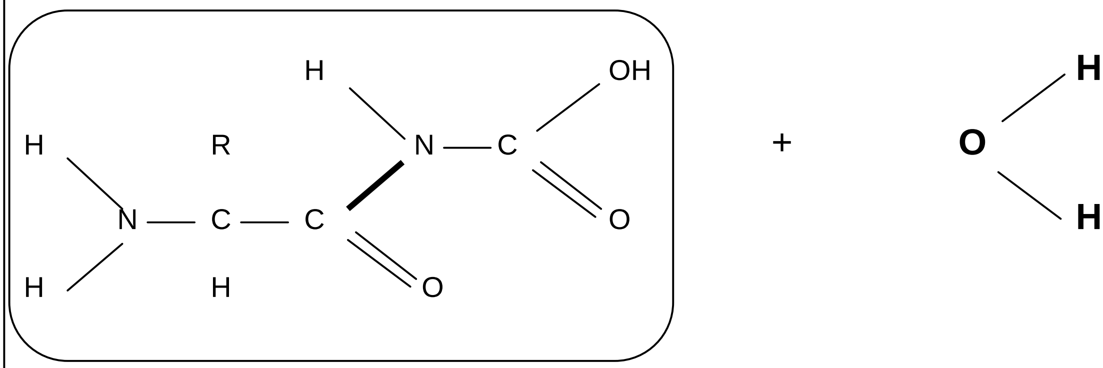
PROTEINS

Proteins are organic molecules comprised of hydrogen, carbon oxygen and nitrogen. They are made up of subunits called amino acids. Amino acids each have an amine group (one nitrogen atom bound to two hydrogen atoms, NH2) and a carboxyl group (a carbon atom bound to an oxygen atom by a double bond, and two a hydroxyl group with a single bond, COOH). The amino acids are bound to each other by a peptide bond, shown in the diagram below. The properties of different amino acids are related to the functional group that makes up their side chain. These can be polar, non-polar, or have other atoms, such as sulphur in them. The unique combination of different amino acids gives proteins their specific conformations, polarity, solubility and other characteristics.

Amino acid (side chains vary and are represented by an R)



Peptide bonding



The bonding of two amino acids results in a peptide bond and a molecule of free water
(Bold shows the atoms that make up the resulting water product, and the new peptide bond)

Amino acids may be grouped by their side chains (neutral, basic or acid; polar or non-polar). They may also be grouped by their structure. Review the following table:

	Abbreviations		Structure	Side Chain Properties	
Name				**Acid/Base**	**Polarity**
Alanine	Ala	A	Aliphatic	Neutral	Non-polar
Arginine	Arg	R	Aliphatic guanidinium	Basic	Polar
Asparagine	Asn	N	Aliphatic carboxamide	Neutral	Polar
Aspartic Acid	Asp	D	Aliphatic dicarboxylic	Acidic	Polar
Cysteine	Cys	C	Aliphatic thiol	Neutral	Non-polar
Glutamic Acid	Glu	E	Aliphatic dicarboxylic	Acidic	Polar
Glutamine	Gln	Q	Aliphatic carbamoyl	Neutral	Polar
Glycine	Gly	G	Aliphatic	Neutral	Non-polar
Histidine	His	H	Heterocyclic imidazole	Weakly basic	Polar
Isoleucine	Ile	I	Aliphatic chiral branched side chain	Neurtal	Non
Leucine	Leu	L	Aliphatic branched side chain	Neutral	Non
Lysine	Lys	K	Aliphatic	Basic	Polar
Methionine	Met	M	Aliphatic sulfanyl	Neutral	Non
Phenylalanine	Phe	F	Aromatic	Neutral	Non
Proline	Pro	P	Heterocyclic	Neutral	Non
Serine	Ser	s	Aliphatic monohydroxyl	Neutral	Polar
Threonine	Thr	T	Chiral aliphatic monohydroxyl	Neutral	Polar
Tryptophan	Trp	W	Heterocyclic indole	Neutral	Non-polar
Tyrosine	Tyr	Y	Aromatic phenol	Neutral	Polar
Valine	Val	v	Aliphatic branched side chain	Neutral	Non-polar

Amino acids can combine to form two structurally distinguishable types of protein: fibrous or globular.

Fibrous Proteins

Fibrous proteins are ones where there are long, thin chains of amino acids. These chains are joined to each other by different types of bonds to make them stable. These fibrous proteins are relatively insoluble and quite tough, forming sheets that often have a structural or protective function in the body. Examples of fibrous proteins are keratin, collagen and myosin.

Globular Proteins

These are different in shape to the fibrous proteins. The amino acids are arranged in elliptical patterns, with a lot of folding along the peptide chain. Instead of forming a sheet they form complex three dimensional shapes, and there shape (conformation) is crucial to their function. Examples of globular proteins include haemoglobin and enzymes.

Functional Categorisation of Proteins

Another way to categorise proteins is by their function. There are at least seven broad functional categories:

1. *Structural*
These proteins have a structural function, providing shape, support and protection. Structural proteins may be found inside cells, as well as in the extracellular environment supporting tissues.

2. *Contractile*
Found in a wide range of organisms, and different tissue types. They have the ability to contract (shorten). Examples include actin (found in all cells) and myosin (found in muscle cells)

3. *Antibodies*
An antibody is a protein specific for a particular antigen (a micro-organism of part of a microorganism that is recognized as a hazard by the immune system) that binds to the antigen and begins events to destroy the perceived threat. Antibodies are globular and known as immunoglobins.

4. *Blood Proteins*
These proteins control osmotic pressure in the blood, and help buffer the pH of blood. Examples include albumin and haemoglobin as well as fibrinogen, which functions in blood clotting.

5. *Hormones*
Function as chemical messengers allowing communication and direct effects on function by cells that are often a long distance from each other.

6. *Enzymes*
These are biological catalysts -they help speed up chemical reactions that happen within the metabolism of various organisms.

7. *Precursors*
Proteins can function as precursors for other biomolecules. Some amino acids can be converted into glucose by gluconeogenesis; tryptophan is used to make serotonin, a neurotransmitter

Proteins in the human diet
During digestion proteins are broken down, liberating the constituent amino acids. The value of protein food is assessed by considering the amounts and nature of various amino acids produced.

The body has limited powers of converting one amino acid into another as the need arises. While there are 20 amino acids, 8 of them cannot be manufactured by the body in sufficient quantities, and these 8 are known as "essential amino acids". They MUST be provided in the diet of every adult human

Proteins in the Human Diet
During digestion proteins are broken down, liberating the constituent amino acids. The value of protein food is assessed by considering the amounts and nature of various amino acids produced.

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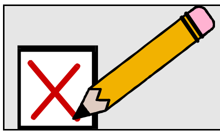
The essential amino acids for adults are:

- Isolencine
- Leucine
- Lysine
- Methionine
- Phenylalanine
- Threonine
- Tryptophan
- Valine

In addition one other amino acid, **histidine**, is essential for growth in children.

Proteins can also be an energy source; however, they are more important for other purposes and are metabolized for energy only as a very last resort when carbohydrates and fats are not available.



SELF ASSESSMENT
Perform the self assessment test titled ‘Self Assessment Test 2.1’
If you answer incorrectly, review the notes and try the test again.

ASSIGNMENT
Download and do the assignment called ‘Lesson 2 Assignment’.