

# AS Biology - Module 1



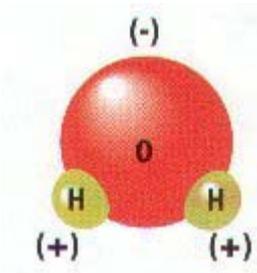
## CHAPTER 3 - BIOCHEMISTRY "THE CHEMISTRY OF LIFE"

### WATER

Compare the body of the jellyfish with our own bodies. The jellyfish will die if it is removed from its water environment, yet we can live in the driest parts of Earth. Jellyfish and humans seem utterly unlike each other, yet the bodies of both are made of cells filled with water. The chemical reactions of all living things take place in an **aqueous environment**. Water has several properties that make it one of the most important compounds found in living things.

#### POLARITY

1. Many of water's biological functions **stem from its chemical structure**.
2. In the **water molecule**,  $H_2O$ , the hydrogen and oxygen atoms share electrons to form a **covalent bond**, but these atoms **do not** share the electrons equally.
3. The oxygen atom, because of its 8 protons *cf* hydrogen's single proton, **pulls the shared electrons towards its nucleus and away from the hydrogen atom**. As a result, the electrical charge is **unevenly distributed** in the water molecule.

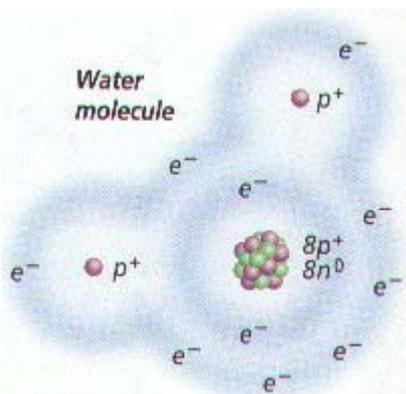


4. Although the total electrical charge on a water molecule is zero, the region of the molecule where the oxygen atom is located has a **slight negative charge** while the regions of the molecule where each of the two hydrogen atoms are located each have a **slight positive charge** ( $\delta^+$ ).
5. Because of this uneven pattern of charge, water is a **polar molecule**. All molecules with an uneven charge like this are polar molecules.
6. It is this that makes water such a good solvent of other polar molecules - such as **salts, sugars** and **proteins**.

7. An ionic compound dissolved in water tends to **dissociate** into ions. This breaking up of an ionic compound means the ions can participate in many biological reactions.

#### HYDROGEN BONDING

1. The polar nature of water also causes water molecules to be attracted to one another or stick together.



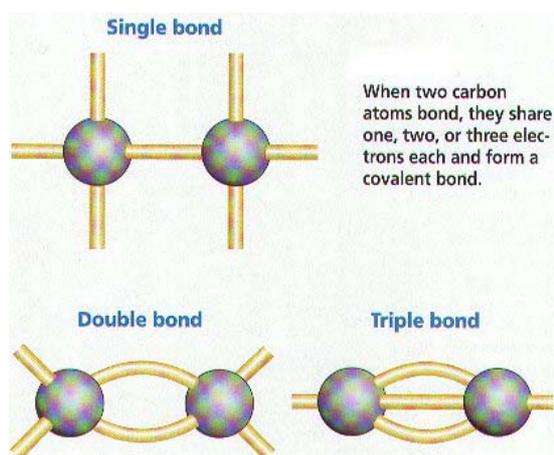
2. This attraction between water molecules is caused by **hydrogen bonding**.
3. A positive region of one water molecule is attracted to the negative region of another water molecule.
4. Hydrogen bonds are **weak bonds** that can be easily broken - particularly if bent (e.g. DNA replication).
5. Hydrogen bonds can also be formed between hydrogen and nitrogen atoms (only).

- The hydrogen bonds in water exert a significant attractive force, causing water to cling to itself (**Cohesion**) and to other surfaces (**Adhesion**).
- Together, adhesion and cohesion enable water molecules to move upwards through narrow tubes against the force of gravity - a property of water known as **capillarity**.
- Water moves up a plant stem through **cohesion-tension** in the **xylem** – only possible because of the hydrogen bonds.
- Water must gain or lose a large amount of energy for its temperature to change – which makes it a **stable environment** to live in (**homeostasis**).
- Water's ability to absorb large amounts of energy (= **high specific heat capacity**) helps to keep cells at an even temperature despite changes to the external temperature.

## CARBON COMPOUNDS

All of the many compounds discovered can be classified into two broad categories: **organic** (= **contain carbon atoms** covalently bonded to other carbon atoms) and **inorganic compounds**. Other elements found in most organic molecules are hydrogen, oxygen, and nitrogen.

### CARBON BONDING



1. A carbon atom has 4 electrons in its outermost shell, and to be stable a carbon atom needs 8 electrons in its outer shell, so carbon atoms therefore readily form 4 covalent bonds with other elements.

2. Carbon also readily bonds with other carbon atoms, forming chains or rings.

3. This tendency of carbon to bond with itself results in the enormous variety of **organic compounds**.

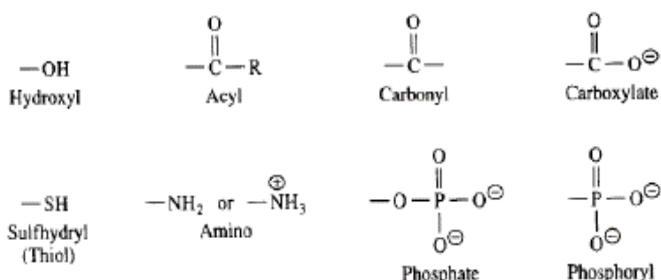
4. Carbon can also share two pairs of electrons with another carbon atom:

A. **Single Bond** - A bond formed when two atoms share **one** pair of electrons.

B. **Double Bond** - atoms share **two** pairs of electrons.

### FUNCTIONAL GROUPS

1. In most organic compounds, clusters of atoms, called **functional groups**, influence the properties of the molecule they compose.



2. The **functional group** is the structural building block that determines the characteristics of that compound.

3. One functional group important to living things is the **hydroxyl group** (represented by OH).

4. An **alcohol** is an organic compound with a hydroxyl group attached to one of its carbon atoms.

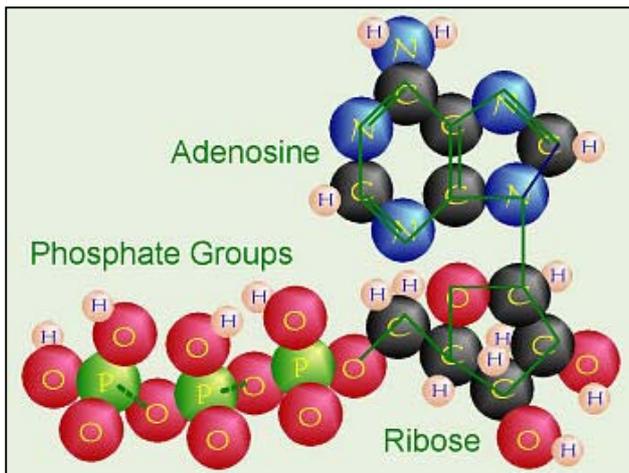
5. The hydroxyl group makes alcohols (e.g. sugars) polar molecules that have some properties similar to water, including the ability to form hydrogen bonds.

## LARGE CARBON MOLECULES

1. Large carbon compounds are built up from smaller simpler molecules called **monomers**.
2. Monomers can bind to one another to form complex molecules known as **polymers**.
3. A polymer consists of repeated, linked units, forming (very) large polymers called **macromolecules**.
4. Monomers link to form polymers through a chemical reaction called a **condensation reaction**. During the formation of polymers, water is released – it is a by-product of the reaction.
5. Example - during the formation of the sugar **maltose**, two molecules of **glucose** combine.
6. In this condensation reaction, one glucose molecule releases a hydroxide ion, OH<sup>-</sup>, and the other molecule releases a hydrogen ion, H<sup>+</sup>. The OH<sup>-</sup> and H<sup>+</sup> ions that are released then combine to form water. This bond (between the 1- carbon of the first glucose and the 4- carbon of the second), is known as a **1:4 Glycosidic bond** and it is also found in starch, glycogen and cellulose.
7. The breakdown (= digestion) of these complex molecules, occurs through the reverse process known as **hydrolysis**.
8. Hydrolysis requires the **addition of one water molecule**, to break each bond within the polymer and so break the bonds that hold them together.

## ENERGY CURRENCY - ATP

1. Life processes require a constant supply of energy. This energy is available to cells in the form of compounds that contain a large amount of energy in their overall structure.



2. The most common energy compound used by all cells is **Adenosine TriPhosphate** or **ATP**.
3. An ATP molecule comprises **a sugar (ribose)**, a pentose (= 5-C) sugar), an **Adenosine** molecule (a **base**) and **a chain of 3 Phosphate** groups. When the bonds between the outermost two phosphate groups are broken, ATP becomes ADP (**Adenosine DiPhosphate, ADP**).
4. The reaction that forms ADP from ATP releases a sizeable amount of energy (and yes, it is a hydrolysis reaction!)



5. The transfer of this energy fuels most biochemical reactions. This conversion of energy is used by the cell to drive the chemical reactions that enable an organism to function (i.e life).

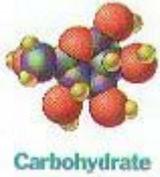
## MOLECULES OF LIFE

The four main classes of organic compounds that are essential to the life processes of all living things are: **carbohydrates**, **triglycerides** (lipids), **proteins**, and **nucleic acids**.

These compounds are built from carbon, hydrogen, and oxygen: the atoms occur in different ratios in each class of compound.

# CARBOHYDRATES

1. The cells of the human body obtain most of their energy from carbohydrates.



2. **Carbohydrates** are compounds containing **Carbon, Hydrogen** and **Oxygen**, with the number of H and O atoms in the ratio of 2:1. The number of carbon atoms varies, from 3-100,000+.

3. Sugars, starch, glycogen and cellulose are all carbohydrates.

4. There are **three** types of carbohydrates, grouped according to complexity: **monosaccharides** (e.g. *glucose, fructose, galactose*), **disaccharides**, (e.g. *maltose, sucrose, lactose*) and **polysaccharides** (e.g. *starch, glycogen, cellulose*)

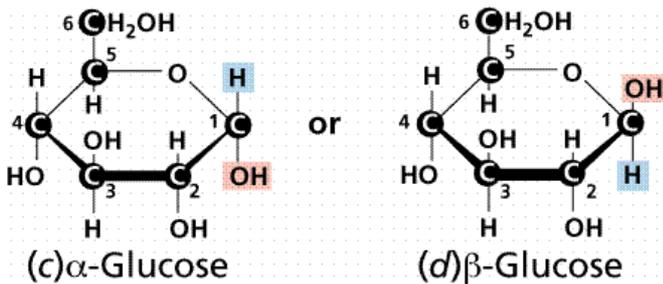
5. **Monosaccharides** are single sugars and are named after the number of carbon atoms they contain:

**Triose** (an intermediate in respiration and photosynthesis)  $C_3H_6O_3$

**Pentose** (found in DNA, RNA and ATP).  $C_5H_{10}O_5$ .

**Hexose** (by far the most common – found everywhere else!)  $C_6H_{12}O_6$ .

Glucose, Fructose, and Galactose are all hexoses, with the same molecular formula, but their differing structures determine the different properties. Compounds like these sugars, with a single chemical formula but different forms, are called **isomers**. AQA requires you to know the **structural formula** (i.e. you can draw it!) of the 2 isomers of glucose, known as  **$\alpha$ -glucose** and  **$\beta$ -glucose**.

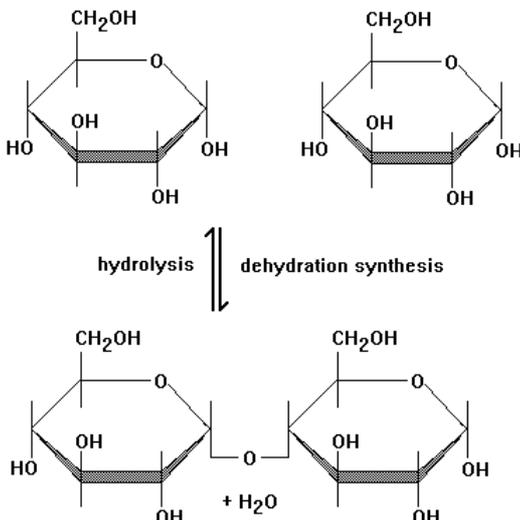


Note:

a) The **numbering of the carbon atoms** (1-6, with 1 and 4 being at opposite ends and 6 being out of the ring).

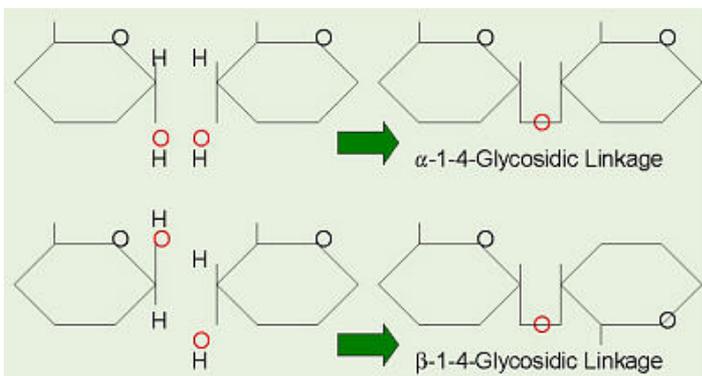
b) The two forms are identical **apart from** the position of the OH group on the 1-C atom.

7. **Disaccharides**, or double sugars, are formed when two single sugars (or monosaccharides) condense together to form a disaccharide and a molecule of water. The bond between the two parts of the disaccharide is known as a **glycosidic bond**. Common disaccharides include **maltose** ( $\alpha$ -glucose +  $\alpha$ -glucose) **sucrose** ( $\alpha$ -glucose + fructose), and **lactose** ( $\alpha$ -glucose + galactose). AQA require you to be able to draw maltose (only) – see below – and they also require you to be able to draw its synthesis and breakdown:



A good animation of this reaction is available at: <http://www.biotopics.co.uk/as/disaccharideformation.html>

8. **Polysaccharides** are carbohydrates made of long chains of sugars. **Starch**, which is found in plants **only**, is a polysaccharide. Starch actually consists of **two** different molecules: **amylose** (a long chain of ‘poly maltoses’, thus **only** having  $\alpha$ -1:4 glycosidic bonds) and **amylopectin** (which has a branched structure, containing **both**  $\alpha$ -1:4 glycosidic bonds **and**  $\alpha$ -1:6 glycosidic bonds). *[Therefore the ‘enzyme’ amylase must be at least two different enzymes to break both sorts of bond.]*
9. Animals store  $\alpha$ -glucose in the form of the polysaccharide **glycogen** in their liver and muscles, (where it is regulated by the hormones **insulin** and **glucagon**). Glycogen keeps the blood glucose concentration roughly constant throughout the day. It consists of tens of thousands of glucose molecules in a highly branched structure similar to amylopectin (i.e it has both  $\alpha$ -1:4 glycosidic bonds **and**  $\alpha$ -1:6 glycosidic bonds and can thus be digested by **amylase**).
10. Plants make **cellulose** - also a polysaccharide – to form the main component of their rigid cell walls. Cellulose makes up about 50 percent of wood and consists of **very** long, unbranched chains of  $\beta$ -glucose.



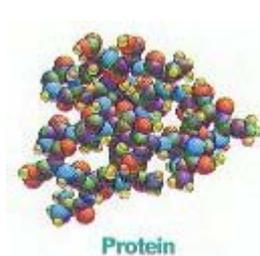
Top = amylose;  $\alpha$ -1:4 glycosidic bonds.

*Note: all 6-carbons on the top*

Lower = cellulose;  $\beta$ -1:4 glycosidic bonds

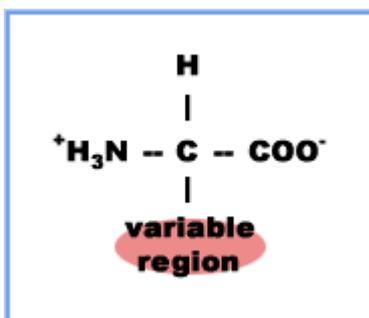
*Note: alternate 6-carbons on top and bottom*

## PROTEINS



1. Proteins are organic compounds containing the elements Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur (= ‘**CHONS**’).
2. Proteins are the materials used to build much of our bodies – such as skin, muscles and blood, but their most important use is to form **enzymes**.
3. Proteins are made up of smaller units called **amino-acids** – the monomer from which the polymer proteins are made.

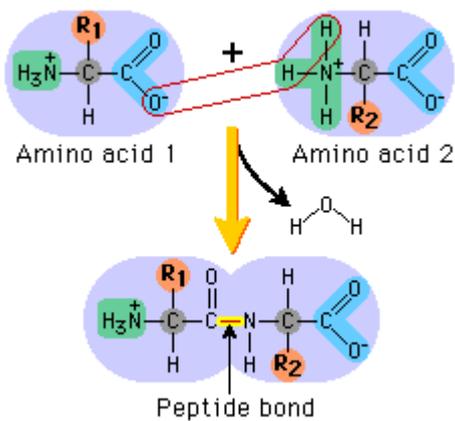
5. Our cells each contain thousands of different proteins. All these proteins are made from about **20** different amino acids. Note that each amino-acid has the same basic structure- they differ **only** in the R-group they carry. *You do **not** need to know the names or structures of any **individual** amino-acids, but you do need to be able to draw their **general** structure:*



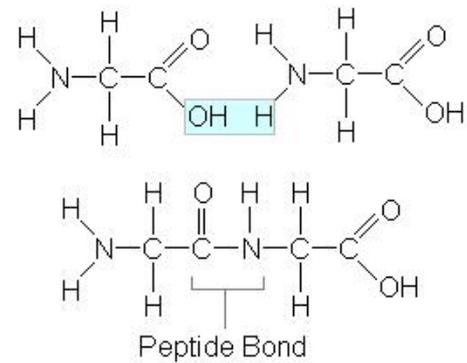
6. **Amino-acids differ only** in the type of R-group they have. The simplest is **glycine**, with an R-group of a single H-atom; the next simplest is **alanine**, with  $\text{CH}_3$ . Others are much more complex, **and just two** (i.e. 10%) contain an atom of sulphur.

7. These different shapes allow proteins to fold into many different shapes and so perform many different roles in the chemistry of living things.

8. Two amino-acids bond to form a **dipeptide** and water, during a condensation reaction. The covalent bond between them is called a **peptide bond**. *AQA require you to be able to draw this!*



Or



A molecule of water is removed from two glycine amino acids to form a peptide bond.

Note that when the two amino-acids bond, **it is the C and N atoms join up in a peptide bond!!**

9. Amino-acids can bond to each other one at a time, forming a long chain called a **polypeptide**. These are made on the **ribosomes** in the cell (**80s in eukaryotes, 70s in prokaryotes and mitochondria and chloroplasts**).

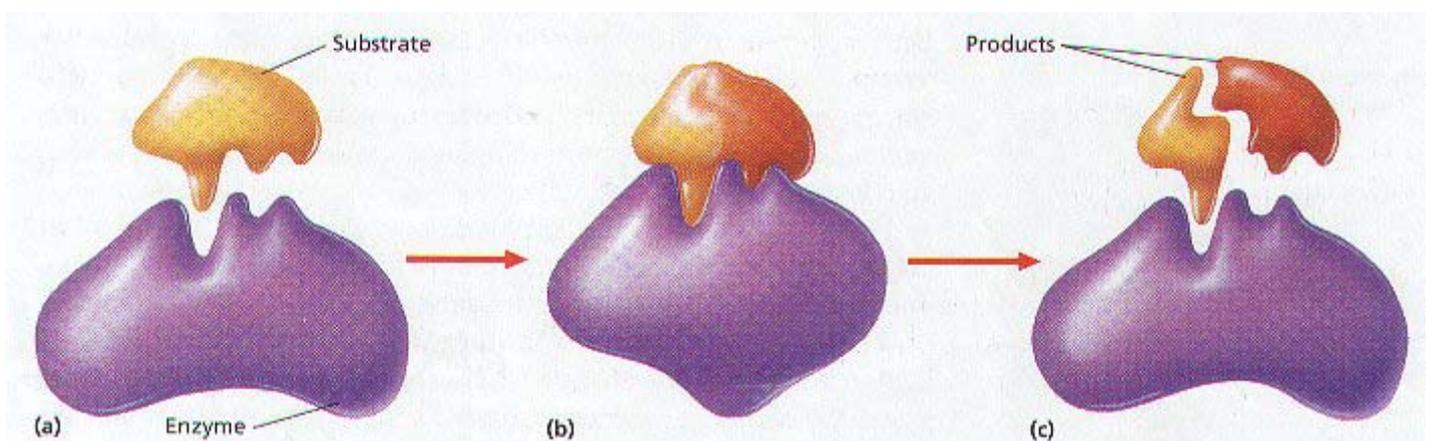
10. Proteins normally comprise one (*rarely 2 or 4*) polypeptides. Most proteins are large molecules, and contain a hundred or so amino-acids.

11. One group of proteins - **enzymes** - help control chemical reactions by acting as **catalysts**; they are essential for the functioning of cells. Catalysts can speed up some reactions by more than a billion fold.

12. Enzymes work by a physical fit (the **'Induced Fit Theory'**) between the enzyme molecule and **its substrate**, i.e. the reactant being catalyzed.

13. The fitting together of the enzyme's **'active site'** and the substrate bends (and so weakens) some chemical bonds, which therefore reduces the **Activation Energy** for the chemical reaction to occur.

14. After the reaction, the enzyme's active site 'springs back' to its normal shape, the product(s) is released, and the unchanged enzyme can then be reused many times each second (known as its **'turnover number'** *higher number = faster enzyme*).



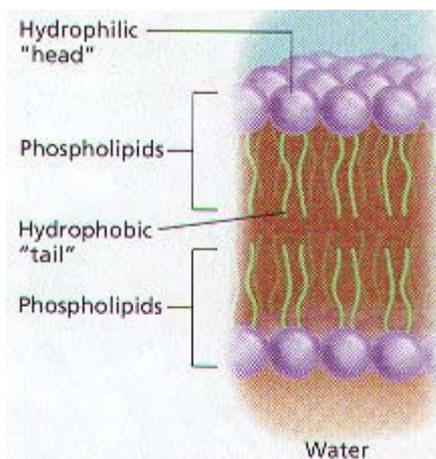
# TRIGLYCERIDES or LIPIDS



1. Lipids are moderately sized, **non-polar organic molecules that do not dissolve in water.**
2. Lipids have fewer oxygen atoms (*typically*  $< 6$ ) than carbohydrates do.
3. Lipids store energy efficiently, since they have large numbers of C – H bonds, which store more energy than C – O bonds; they can also be stored **without water, and without affecting** the **water potential** ( $\Psi$ ) of the cell.
4. Lipids which are liquid at room temperature = **oils**; if they melt below  $100^{\circ}\text{C}$  they are **fats**; if they melt above  $100^{\circ}\text{C}$  they are **waxes**.
5. The **longer the fatty-acid chain** (see below), the **higher the melting-point.**
6. They also have a function in many living things as a waterproofing chemical (*e.g skin, waxy cuticle on leaves*).

## FATTY ACIDS

1. **Fatty acids** are the hydrocarbon chains that make up most of a lipid molecule.



2. The two ends (**the head and the tail**) of a fatty acid molecule have different properties – they are therefore **polar molecules**:

a). The **carboxyl** end (= **head**) of the molecule is **charged**, and thus attracted to water molecules. It is said to be **hydrophilic**, which means “water-loving”.

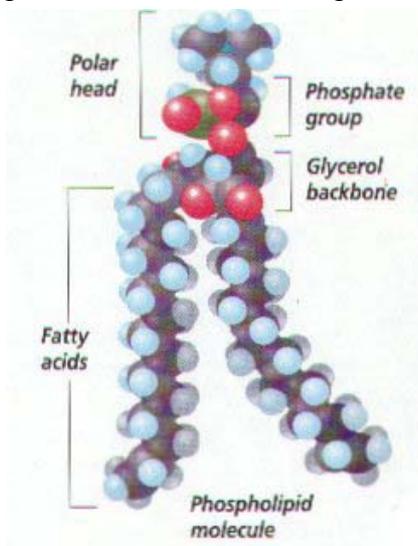
b). The **hydrocarbon** end (= **tail**) of the molecule is non-polar, and tends **not** to interact with water. It is said to be **hydrophobic** or “water fearing”.

4. Fatty acids are classified as either **saturated** (= *contains only C-C (single) bonds*) or as **unsaturated** (= *contains at least one C=C (double) bond*).

5. If the lipid contains **only one C=C bond**, it is said to be a **mono-unsaturated lipid** (*e.g. olive oil*). These are thought to be good for us.

6. If the lipid contains **two or more C=C double bonds**, it is said to be a **polyunsaturated lipid**. The value of these to our health is less clear; **cholesterol** is a polyunsaturated fat!

7. Unsaturated lipids tend to have lower melting points (they are generally oils); and are found in plants and fish. The exception is Palm Oil – which is a saturated lipid.



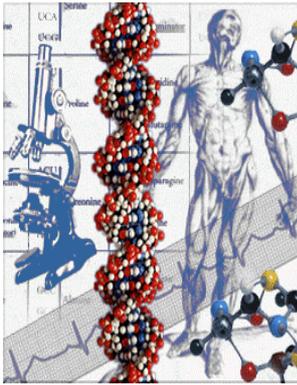
**Triglycerides** contain three molecules of fatty acid joined to one molecule of glycerol.

**Phospholipids** have **one of the three fatty acids** substituted by a **phosphate group**. All cellular membranes are composed of two layers of phospholipids (called a **phospholipid bilayer**), together with embedded protein molecules. Cell membranes form a barrier between the inside and outside of the cell.

**Steroids** are related to lipids. They are molecules with four fused carbon rings with various functional groups attached to them. Their main role is as hormones (both male and female sex hormones are steroids); **anabolic** (= *building*) **steroids**, such as **testosterone** are abused by some athletes.

8. Another steroid is **cholesterol**, which is needed by the body for nerve cells (and others) to function normally.

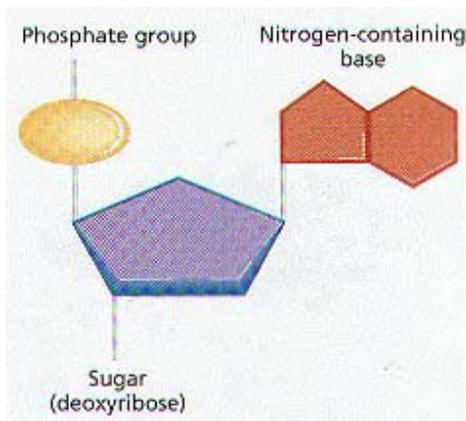
# NUCLEIC ACIDS – DNA & RNA (and ATP too!)



1. Nucleic acids are **very large and organic molecules that store genetic information in cells.**
2. Nucleic acids (DNA, RNA) use the **sequence of four organic bases to store genetic information.** The sequence in which the bases are arranged forms a (*universal*) code of genetic instructions of the cell.
3. There are **five different organic bases – Adenine (A), Guanine (G), and Cytosine (C),** are found in **both DNA and RNA.** **Thymine (T)** is found **only** in DNA, whilst **Uracil (U)** is exclusive to RNA (all sorts).
4. DNA (**Deoxyribose Nucleic Acid**) contains the genetic information used to make and operate all cells; every cell also contains the genetic information to make the **whole** organism. Since DNA is passed on from one cell to the next at cell division, and from one generation to the next in reproduction, **DNA is immortal!**
5. **DNA is extremely long** and consists of **two strands,** running in opposite directions (= '*antiparallel*') held together by the billions of hydrogen bonds which join the bases together. The number of such bonds is different between the two possible base pairs:

**A = T** (i.e. 2 H-bonds); **but G ≡ C** (i.e. 3 H-bonds).

6. RNA (**Ribose Nucleic Acid**), exists in three forms – **messenger RNA, transfer RNA and ribosomal RNA.** These are known as **mRNA, tRNA and rRNA,** respectively. They are all essential for the complex process of the manufacture of proteins.



7. RNA is much shorter and is **single-stranded,** though it may coil back on itself, using hydrogen bonds to do so. (especially tRNA) .
8. Both DNA and RNA are polymers, composed of thousands of linked monomers called **nucleotides.**
9. Each nucleotide is made of **three** main components:
  - a) A **phosphate group**
  - b) A **5-carbon (pentose) sugar**
  - c) An **organic base** (normally **A, T, G, C, or U**).
10. Note that **ATP is also a nucleotide,** and contains the 5-carbon sugar **ribose.**

## Food tests

**Reducing Sugar:** Benedict's reagent → Boil → **Blue** → **Brick-red**

**Non-Reducing Sugar:** First show **Benedict's test is negative!** Then (on fresh sample):

Add few drops **dil. HCl** → **Boil** (*sugar hydrolysed*) → **Neutralise** with **dil NaOH**

Then **repeat Benedict's test** → **Blue** → **Brick red**

**Starch:** Add few drops **Iodine solution (I<sub>2</sub>KI soln).** **Yellow/orange** → **blue/black** (*NB No heat!*)

**Triglyceride (lipid):** Add **5cm<sup>3</sup> ethanol.** Warm gently &/or shake 30 sec. (*lipid dissolves*)

**Pour slowly into ½ test-tube cold water** → **CLOUDY WHITE** emulsion forms.

**Protein:** Add few drops **Biuret reagent** to **liquid sample.** (*Pale*) **Blue** → **Lilac** (*NB No heat!*)