Introduction to Biochemistry

Lesson Aim

Identify characteristics of common chemical compounds important in animal and human biochemistry.

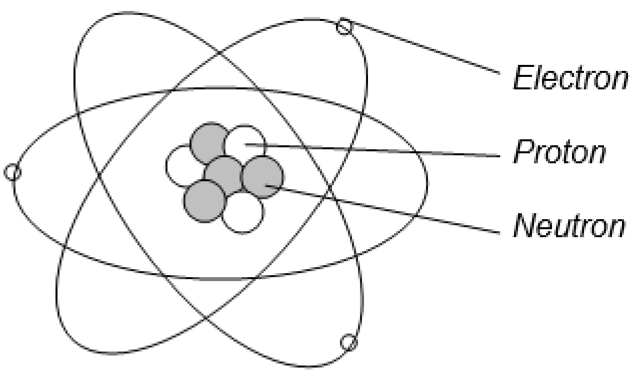
This is not a course designed to train you to be a chemist. If you have never studied chemistry before, or if you remember very little of your past studies, it is worthwhile advising your tutor of this when submitting your first assignment. Naturally, with a topic like this, you may have to put in some extra effort to get full benefit from the course and additional reading or supporting study may be necessary. We highly recommend the use of media clips and online presentations which illustrate or display animations of complex concepts.

The purpose of this course is to allow you to appreciate the application of biochemistry to your area of applied science and to use biochemical applications and services in a very practical way in your study area.

THE BASICS OF CHEMISTRY

Atoms
All matter is made up of atoms. An atom is composed of a **core of protons and neutrons**, surrounded by **orbiting electrons** which move extremely fast. Protons and neutrons are referred to as subatomic particles.

> *<u>Look at this example of an atom:</u>*
>
> The lithium atom, which is has an Atomic Number 3 (a number seen on the periodic table) has a core of 3 protons, with 4 neutrons and 3 electrons. So we can see that the atomic number in this example is 3, relates simply to the number of protons found in the atom's nucleus (or core).
>
> The diagram below shows a Lithium atom, with protons in white, neutrons in grey and the small white electrons orbiting about the centre core.



Atomic mass is the weight of the neutrons, protons and electrons. Electrons are much smaller and weight much less than protons or neutrons.

The parts of an atom can have electrical charges.

- o Electrons have a negative charge

- Protons have a positive charge
- Neutrons are electrically neutral.

When the positive and negative charge is balanced, the atom is electrically neutral (i.e. the positive and negative charges cancel out each other).

Ions

When an atom carries a charge, either positive or negative, **we refer to it as an ion**. Remember ions can be charged positively if they have more protons or negatively if they have more electrons.

- A positively charged atom (ion) is called at cation.
- A negatively charged atom (ion) is called an anion.

Knowing these terms allows you distinguish between ions based on their type of charge.

Stability is important to understand as ions are less stable than neutral atoms. Chemical stability in this respect refers to the ion's tendency to resist change when exposed to changes in the environment such as heat, light, pressure etc.

As a result of their instability, ions will generally seek a partner to bind to, to form an overall neutral molecule and become stable. The bond between two charged atoms is called an ionic bond.

Ionic bonding

In this bond, one atom assumes a negative charge, one a net positive charge and they are held together by the attractive forces of the charges (much as two magnets will attract each other if you put the + end of one and the – end of the other close to each other).

Refer back to the lithium diagram – if one of the electrons was lost, the lithium atom would be positively charged. If an electron was added, the lithium would become negatively charged.

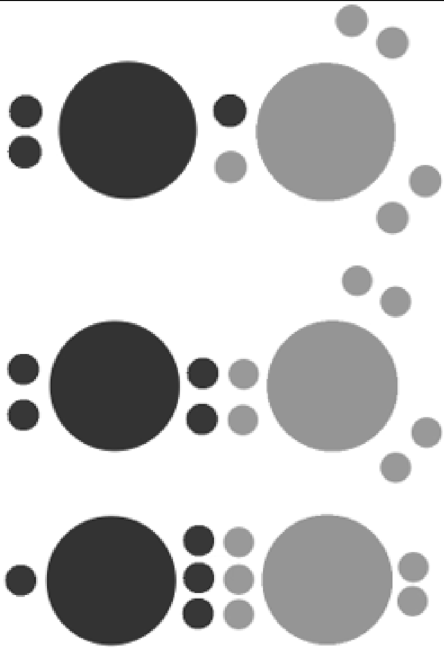
Electrons can shift from one atom to another (ie. changing the nucleus which they orbit around). If this happens, the atoms involved can become negatively or positively charged.

Bonds between two ions may be stronger or weaker depending on how much charge (or how many electrons) are involved.

Covalent bonds and Compounds (Molecules)

If two **neutral atoms** bond to each other by **sharing electrons the bond is called a covalent bond**.

- In an example where two atoms are joined, a covalent bond may have 2, 4 or 6 electrons in total with each atom contributing 1, 2 or 3 electrons. *This is shown in the following diagram.*



Two atoms share two electrons (contributing one each).

The atoms share one single bond, often represented as a – between the atoms.

Two atoms share four electrons (contributing two each).

The atoms share a double bond, often represented as a = between the atoms

When two atoms share six electrons (contributing three each).

The atoms share a triple bond, often represented as a $\equiv$ between the atoms

These are covalent bonds. The single bond is the most common and weakest.

- A group of two or more atoms, bonded together is called a compound. Compounds may also be referred to as molecules.

Chemical Elements & the Periodic Table

An element is any chemical that is comprised of only **one type of atom**. This may be single atoms or compounds. For example, the oxygen we breathe is an element and exists as two covalently bound oxygen atoms.

The periodic table lists all the currently known elements. It also lists them in a precise order, which allows us to get additional information at a glance. Elements are listed from the top left to the bottom right in order of increasing atomic number.

The atomic number tells us the number of protons in the atoms making up the element. While atoms can lose electrons, they do not lose protons, so an atom of oxygen always has the same number of protons, whether it is in a compound, as a diatomic element (O_2) or carrying a charge. The atomic numbers noted relate to the individual atoms, not the overall element.

The columns of the periodic table are called groups. The group of an element gives us information about the electrons and how readily an element will donate or accept electrons. The table also includes the atomic mass of the elements.

PARTS OF A MOLECULE

Atoms group together in small OR very large numbers to make chemical compounds. There are however subgroups within compounds.

Take water as an example. **Water** is known by the chemical symbol **H_2O** and by its chemical name **dihydrogen oxide**.

In biochemistry the numbers of occurrences are known by specific prefixes.

1 – mono

2 – di

3 – tri

4 – tetra

5 – penta

6 – hexa

7 – hepta

8 – octa

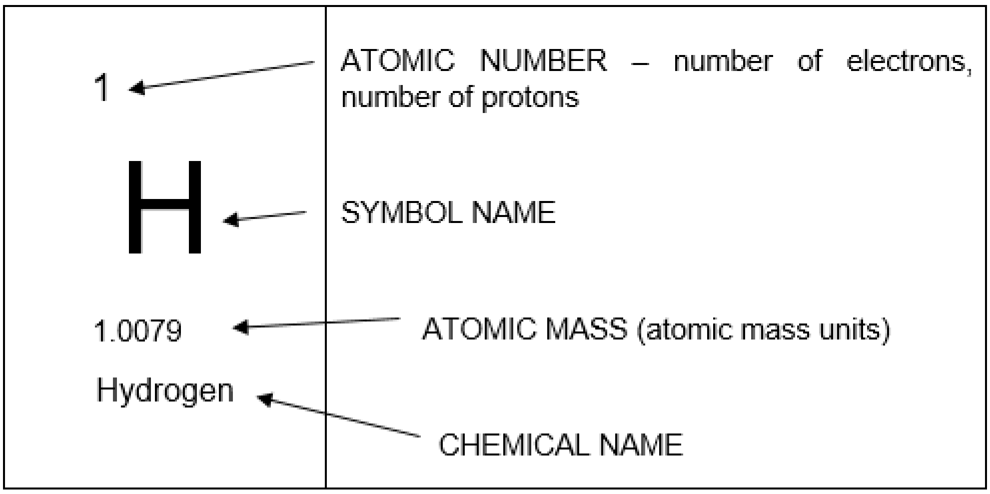
9 – nona

10 – deca

So there are two atoms of hydrogen and one atom of oxygen for one molecule of water (so water is NOT an element).

Looking at the periodic table we find that hydrogen has only one electron (we can tell this from the atomic number – hydrogen's atomic number is 1, that means it has one proton, to be neutral it has to have one electron). AT THIS STAGE IS IT ADVISABLE TO SOURCE A PERIODIC TABLE FOR YOUR NOTES. You may choose to find one online, save or print, or you may have one in a reputable chemistry textbook available for use.

__Look at this example for Hydrogen:__

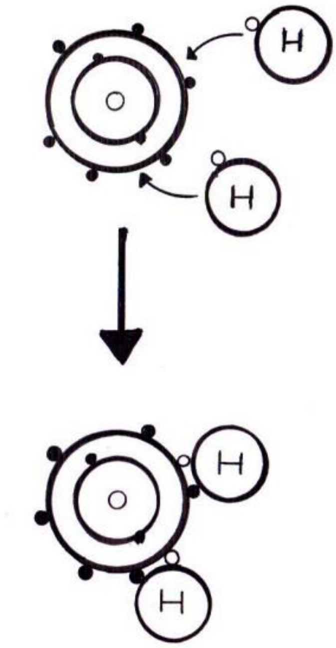


Although we already know electrons orbit the nucleus, they can be thought of as existing in shells around the nucleus.

To position the electrons around atom, the shells closest to the nucleus are filled to their maximum capacity first. Each shell surrounding an atom has its own maximum capacity.

So the first shell from the nucleus can only hold 2 electrons, the second shell can hold 8 electrons, the third shell can hold up to 18, the fourth shell can hold up to 32.

<u>*Let's consider oxygen. Oxygen has 8 electrons.*</u>



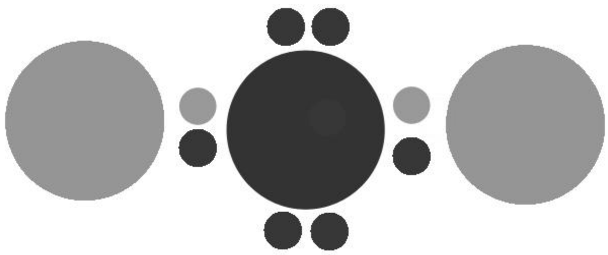
So the first shell can only hold 2 electrons, therefore we have 6 leftover which can fit on the second shell. Remember, the second shell has space for 8 electrons though, which means there is space available for two more electrons to complete the shell.

In order to complete the shell, oxygen will share (bond with) hydrogen's electrons.

Each hydrogen atom will contribute one electron and oxygen will contribute one electron to two hydrogen atoms thus fulfilling each of the atoms requirements for a full shell.

This means that the chemical configuration of water is:

H – O – H (with oxygen bound to both the hydrogen atoms)



And not, for example:

H – H – O

Using Lewis dot drawings we can better visualise the bonds:

H : O : H (Each atom contributes 1 electron to a bond, making both bonds single)

In actual fact, one of these two bonds tends to be stronger than the other and the molecule breaks up producing a hydrogen ion with a positive charge (H^+, also referred to as a proton as it is one proton with no orbiting electrons), and a hydroxide ion (ie. OH^-).

When a molecule breaks up like this, but there is still some attraction between the atoms or molecules that made it up, it is called dissociation.

Why does water dissociate? The electrons aren't shared exactly 50/50, as the oxygen atom takes more than its share. This means each hydrogen atom has a partial positive charge and the oxygen atom has a partial negative charge. This makes the individual water molecules attract each other like little magnets. In this situation the bonds are neither covalent nor ionic, but are called hydrogen bonds and they are much less stable, and therefore weaker than the other bond types.

This is the basis of acidity and alkalinity. In pure water, there are as many OH- ions as H+ and the resulting solution is neutral. If there are more H+ ions in a solution the solution will be acidic (pH will be less than 7) and if there are more OH- ions the solution will be alkaline (or basic) and the pH will be more than 7.

In summary:

Water is made up of a hydroxide ion where the bond between the hydrogen and oxygen is very strong, AND a hydrogen ion joined to the hydroxide by a weaker and more easily disrupted bond.

Similarly, other chemicals, even very complex chemicals are made up of various groups (within which the chemical bonds are very strong), joined together by bonds which are weaker.

COMMON CHEMICAL GROUPS

Chemical groups control the overall structure, properties and reactions. Groups themselves are defined by specific atoms and bonds which exist in larger hydrocarbon chains. You will find it beneficial to recognise some common groups.

Below is an example of a functional group names.

PROPANOL = dropped "e" added "ol"

propane

alcohol

$$CH_3CH_2CH_2\text{-}OH$$

The root name – in this example is propane – tells is the about the longest continuous chain of carbons.

The suffix here denotes the functional group (or type of compound) – here is a hydroxyl group.

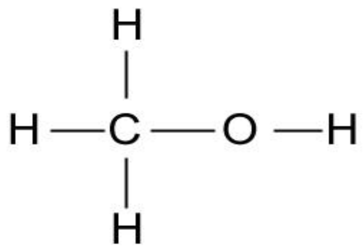
When we drop the “e” from the three carbon root name and add the “ol” for the ending in alcohol = propanol.

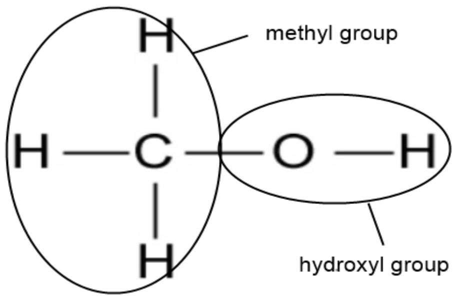
NAME	STRUCTURE
Methyl	***CH_3-***
Ethyl	CH_3CH_2-
Propyl	$CH_3CH_2CH_2$-
Butyl	$CH_3CH_2CH_2CH_2$-
Isopropyl	CH_3CH_2CH-
Isobutyl	$CH_3CH_2CH_2CH$-
Amino	-NH_2
Hydroxyl	-OH
Carbonyl	CO-

Aldehyde	-COH
Carboxyl	-COOH
Ether	-COC-

Using these groups

Methanol is a methyl group with the carbon atom binding to oxygen atom of a hydroxyl group (hydroxide):



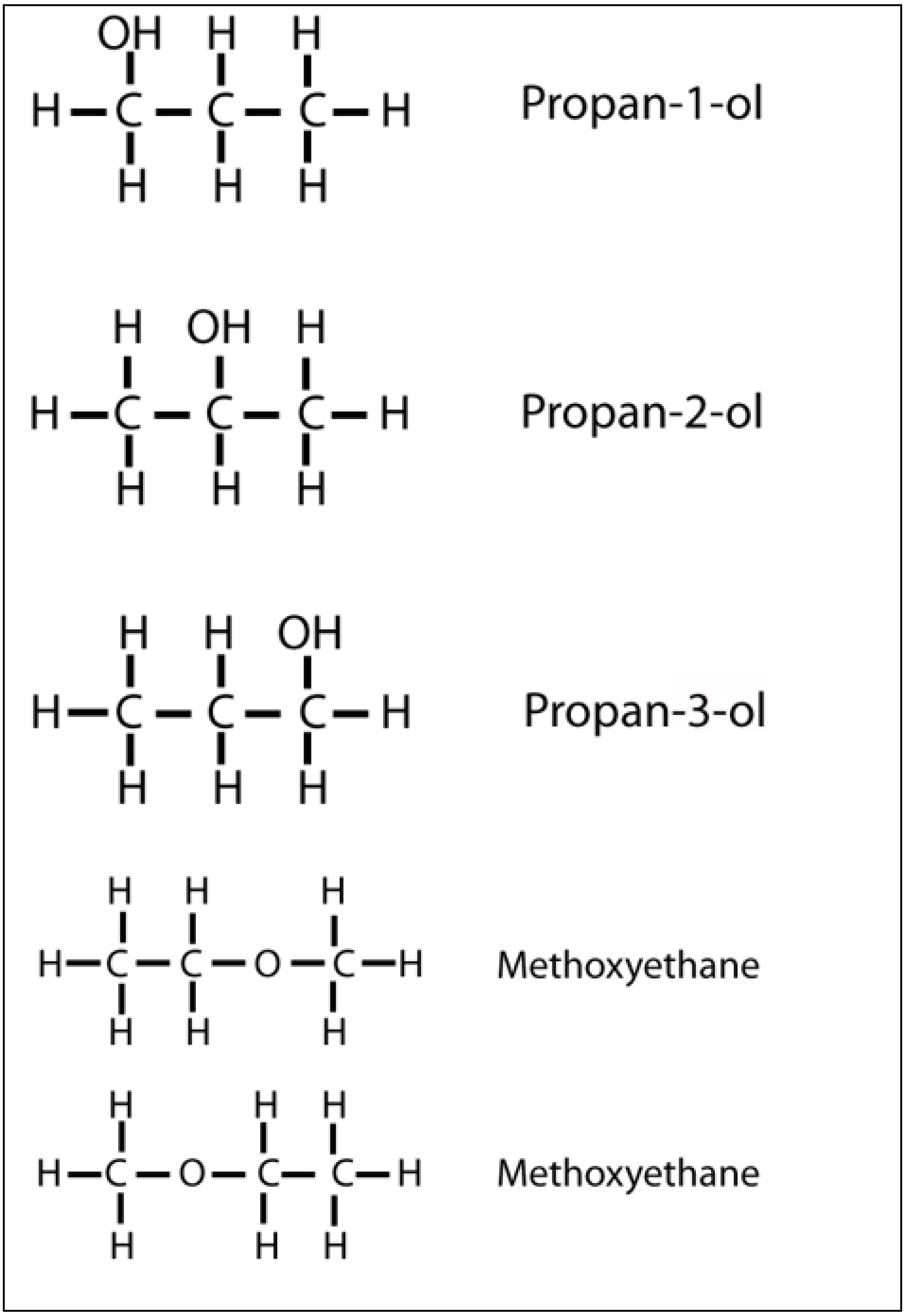


Arrangement of Atoms in a Molecule

Two different compounds can have exactly the same number of atoms of each of their constituents, but be different compounds with different characteristics. They are different because the arrangement of the atoms in space is different.

A Hypothetical Example:

So, for example if you have a three carbon atoms, eight hydrogen atoms and one oxygen atom, they could be bound to each other in the following ways:



All of these compounds have the same chemical formula, C8H5O, but they are all distinctly different from each other, based on the arrangement of those 14 molecules. Compounds which have the same chemical formula, but where atoms are arranged differently are called isomers.

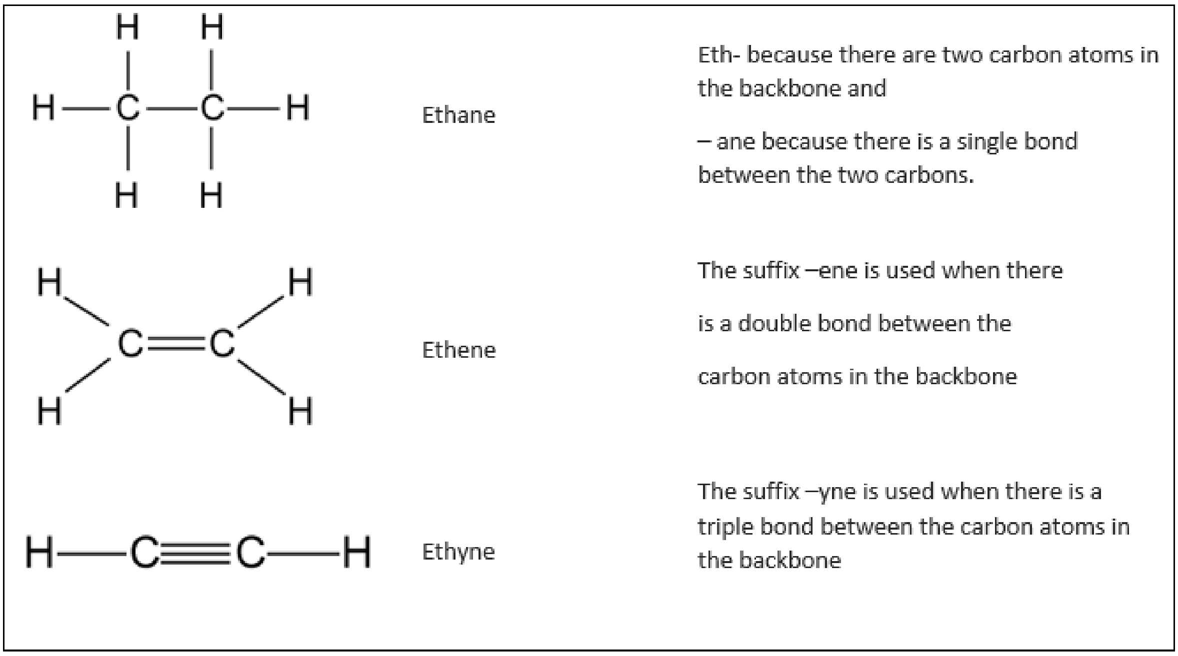
NOMENCLATURE

Nomenclature is a specific routine way of naming compounds. Where a chemical formula can be ambiguous (as shown on the previous page) naming of compounds according to the IUPAC nomenclature rules is specific enough to allow a person to distinguish between molecules with the same chemical formula. Returning to the previous page, IUPAC nomenclature has been used to distinguish between the different propanol molecules, by naming the carbon that the –

OH group is attached to. The rules of naming chemicals are complex, beyond the scope of this course, however we will touch on some important nomenclature for biological compounds.

Hydrocarbons

Hydrocarbons, that is, molecules with a backbone of carbon atoms bonded to hydrogen atoms are found both in living organisms and in industry. They are named based on the functional groups attached to the backbone as well as the types of bonds between the atoms in the backbone. For example (bonds):



The general term for a hydrocarbon with single bonds is alkane, for hydrocarbons with a double bond, the term is alkene and for a triple bond alkyne. The basic formulae for each are:

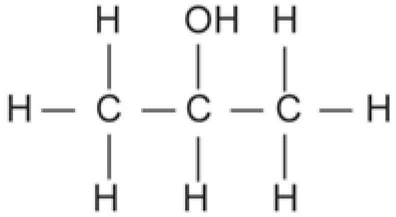
(n can be any number)

Alkane – C_nH_{2n+2} Examples: C_2H_6 (ethane) C_8H_{20} (octane)

Alkene – C_nH_{2n} Examples: C_4H_8 (butene) $C_{10}H_{20}$ (decene)

Alkyne – C_nH_{2n-2} Examples: C_3H_4 (propyne) C_9H_{16} (nonyne)

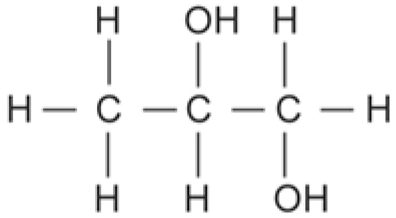
For example: (side chains or functional groups)



Propan-2-ol

Prop because there are 3 carbons in the backbone

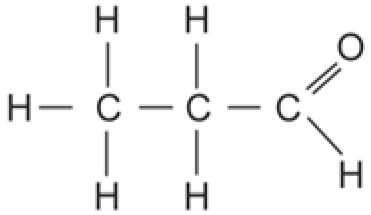
-**2**- tells us there is a functional group bound to the second carbon and –**ol** tells us the group is an (-OH) alcohol. (ALCOHOL)



1, 2 Propanediol

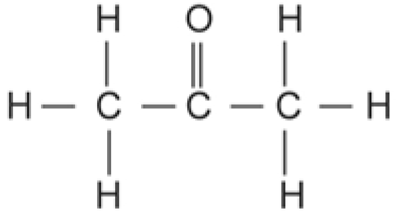
1, 2 tells us that bound to carbons 1 and 2 are functional groups.

–**di**- tells the two groups are the same and –**ol** tells us they are OH.



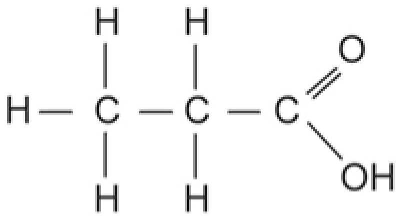
Propanal

-**al** tells us one of the end carbons has bound to an oxygen atom with a double bond. (ALDEHYDE)



Propan-2-one

-**2**- tells us there is a functional group on the second carbon, and –**one** tells us the group is a single oxygen with double bond. (KETONE)

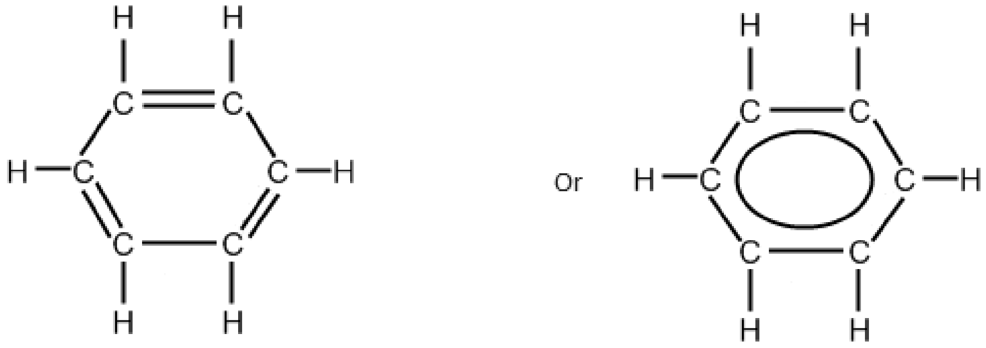


Propanoic Acid

-**oic** acid tells us that this molecule has a double bonded oxygen and a –OH group attached to the terminal carbon

AROMATICITY

Aromatic compounds are molecules that have a cyclic carbon based structure with a combination of double and single bonds. In actual fact the bonds are each somewhere between double and single, but this concept is beyond the scope of this introductory course. Aromatic hydrocarbons are known as arenes. You will see aromatics depicted in either of the following ways:



General aromatic structure (benzene)

Purines and pyridines are aromatics found in living organisms, they are a component of DNA.

ORGANISMS AND ORGANIC COMPOUNDS

Organic compounds are compounds that contain carbon. The four main types of organic compounds are carbohydrates, proteins, lipids and nucleic acids which we will look at in depth in subsequent lessons.

Biochemistry is the chemistry of organisms and organic compounds. An organism is anything that is alive, or if not, was once alive (a "dead" organism"). What, then, is the condition we call life? We cannot offer a rigid, precise definition, but we do know that living things are characterised by metabolism, growth, and reproduction. Metabolism is the process by which a body introduces into itself various energy-rich materials from its environment (food or nutrients), and transforms these materials, with the release of energy, into other substances, some of which are retained by the body and some eliminated. Reproduction is the process by which one body produces another that is like itself in properties, structure, composition, and function, including metabolism and reproduction.

The distinction between an organism and a material is not always clear. A virus consists of particles that can reproduce themselves in a suitable environment but they do not ingest food, or grow, or carry on any other metabolic processes. Are viruses, then, living organisms, or are they chemical materials that consist of large molecules capable of replicating themselves under suitable conditions? To include viruses among the living, the definition of life must be modified. Most broadly, we may consider anything living if it can bring order out of disorder at the expense of energy and has the capability to preserve accidental variations (called mutations) that may occur in the process.

In an organism, the structure called the cell may be considered to be a biochemical reactor. An organism consists of one or more cells, and the various groups of cells in a multi cellular organism may be sharply differentiated in their biochemical function.

The reactions in the cell are said to occur *in vivo* (Latin, "in the living organism"); the corresponding reactions outside of the cell are said to occur *in vitro* (Latin, "in glass). The living cell is not merely a tiny membranous beaker with homogeneous contents. It is, rather, entity of great complexity, not yet completely understood as to structure and function.

There are specific sites within the cell at which specific reacting systems, metabolic or reproductive, operate. The biochemist seeks to identify these sites, and to illuminate the course and mechanism of the reactions that occur there. Sometimes he tries to remove a chemically reacting system from its cellular environment and duplicate it *in vitro*. He does this because reactions are usually easier to study under the more controllable conditions of laboratory reactors than they are *in vivo*.

Biochemical Process in the Cell

Several anatomical features are so small that they can be revealed only with the aid of an electron microscope. Some of these fine structures of the cell are non-essential inclusions, like blobs of fat, or particles of starch. Others called organelles, perform essential functions and are reproduced when the cell divides. Some of these functions are well known; others still elude us.

The mitochondria are oval shaped organelles. The highly differentiated structure of a mitochondrion contains some 40 enzymes, which control a complex series of reactions, including the conversion of diverse organic substances into ATP, which is the cellular energy source. The energy reservoir that is thus stored up is available for biomechanical work such as muscle contraction, for electrical work like the action of nerve impulses, and for the activation of other biochemical reactions. Mitochondria are essentially, the powerhouses of cells.

Chloroplasts are organelles that occur in plant cells and that contain the green pigment chlorophyll. Chlorophyll is the catalyst for the endothermic process of photosynthesis, in which glucose is synthesized from carbon dioxide.

The nucleus is a well defined structure which contains the genetic material of the cell; the nucleus thus is the site of the reproductive function. Each time a cell divides, it reconstitutes itself. The ability of self duplication is retained by the new cells and is transmitted repeatedly through successive generations of cells. The reliability of this transmittal accounts for the continuity of species.

Assignment 1

Question 1

List ten molecules commonly found in animals and humans. Explain the chemical formulae of these ten compounds.

Question 2

Calculate the percentages of elements contained in two specified chemical compounds:

- a carboxyl group (-COOH)
- NH_3

Question 3

Name the biomolecules shown in the graphic below, being as specific as you can. Don't worry if you are uncertain, submit your answers anyway and your tutor can provide guidance.

The first one is done for you:

1 = Butane-2-one

“But”: there are four carbons

“ane”: they are single bonds

“-2”: because there is a functional group on the second carbon

“-one” tells us the group is a single oxygen with a double bond.