PRE-UNIVERSITY REMEDIAL PROGRAM FOR THE 2014 E.C. ESSLCE EXAMINEES

BIOLOGY MODULE

Biology Module Remedial Courses

Unit one: The Science of Biology

Introduction

Biology is a special branch of science that deals with living things. Biology uses the scientific methods to study the nature and functions of living things as well as the interactions with each other and with the environment of which they are parts. The sphere of Biology is unique in that it covers a highly organized form of matter. Biology is one of the most interesting subjects. It is especially important subject for everyone, since it will affect every one's future. Many Biologists are working on problems that critically affect our lives, such as the world's rapidly expanding population and diseases like cancer, COVID 19, and AIDS.

What opportunities exist in Biology now and in the immediate future?

There is much opportunity for researchers, particularly in developmental biology (What genes cause birth defects and can anything be done to correct the damage?). Immunology (will there be a cure for cancer, AIDS, or the common cold?

Why is Biology important to you? and your community (discuss in group)

Use the following information and helps us to

- Use and manage natural resources
- Prevent and cure diseases
- Improve the quality of our lives and the future generations

The Scientific Method

Science in general is a body of knowledge, which is systematically organized on nature, society and thought. Studies in science involve three interrelated concepts,

- ✓ Method of investigation
- ✓ Field of investigation and
- ✓ Results of investigation

The **scientific method** involves a series of logical steps that help to study natural processes. It is a powerful method, which can help to solve new scientific problems. Knowledge is not absolute and unchanging as it always faces the test of time. Thus, it is the knowledge that has accumulated by scientific method. We humans often ask whom we are, where we come from, how we could live in harmony with the environment. The measures that we take to provide scientific explanations to these and other similar questions constitute the scientific method. Existing scientific truth is relative and must be continually tested, evaluated and reconstructed. The scientific method is not limited to the laboratory but is a way of everyday life. It helps to investigate a crime, diagnosis of a disease, etc. These could be justified and validated following certain scientific steps:

The steps of the scientific method

Scientists use different scientific methods to solve problems and they all share the following common steps.

1. Observation:

Our entire view of the natural world depends on the accurate recording of data and the organization of these data into general concepts. Observations can be made directly through the sensory systems, mainly vision, hearing, taste, smell and touch. They can also be made indirectly, through the use of special equipment such as the microscope that extends the range of perception. Preliminary observation with curiosity leads to identification of a specific problem among the many that exist in the environment. Most biological investigation starts with an observation of structure process or a behavioral pattern, that raises inquiry like why, how when etc.

2. Defining or identifying the problem or asking question:

Scientific experiments are carried out based on a specific problem or question. First such a problem has to be identified before proceeding to the next steps. Observations are made and facts gathered leading to the definition and elaboration of the problem or question more precisely. A scientist's natural reaction is to ask question about it. What will happen? Why is it so? How does it take place? etc.

3. Gathering information and forming a hypothesis:

The information gathered could be qualitative describing color, taste, etc. or quantitative involving the measurement of an amount of quantity. Observations provide the raw material, which leads to the formulation of a hypothesis. Hypothesis could be defined as a suggested explanation of certain observed phenomena/problem. Scientific hypothesis need to be tested since they are assumptions of tentative explanations. On the other hand, a hypothesis is a tentative theory characterized as:

- → An intelligent guess
- → Gradual accumulation of indirect evidence

- → It may have number of predictions
- → It consists of interconnected statements that give a possible solution to a problem

New observations that support the hypothesis will strengthen it, whereas new observations that contradict with the hypothesis may result in its being modified or even rejected.

Inductive and deductive reasoning

Induction and deduction are patterns of thought often recognized in the creation of a hypothesis. **Inductive** logic proceeds from the specific to the general whereas **deductive** logic proceeds from the general to the specific. Consider the following examples for better understanding of the difference b/n inductive and deductive reasoning.

Deductive reasoning: Example

- ✦ All animals are mortal (major premises)
- ✦ Dogs are animals (minor premises). Therefore, Dogs are mortal

Inductive reasoning: Example

- ✓ Apple x – tastes sweet
- ✓ Apple y – tastes sweet
- ✓ Apple z – tastes sweet etc.

Conclusion: All apples are sweet.

4. **Testing hypothesis / Experimentation**
   - → Hypothesis testing often involves experimentation
   - → A hypothesis that has with stood many such tests and has been shown to allow prediction to be made is known as **theory**. A theory may generate such confidence through its predictive ability to be known as a **law**.

4.1. Scientific experiment

In most hypotheses there are a number of factors which may influence the observation. These are called **experimental variables**. The 3 general categories of variables are:

i. **The <u>independent variables</u>** - are the conditions or events under experimentation or testing. It can be changed systematically in an experiment. Example: In an experiment in which seedlings are grown at different temperatures. Temperature is the independent variable.

ii. **The <u>dependent variables</u>** - are variables that can possibly change because of the presence of or changes in the independent variables. e.g. the rate of growth (fast or slow) of seedlings at different temperatures.

iii. **The <u>controlled variables</u>** – are conditions that could affect the outcome of an experiment but that do not do so because they are held constant. e.g. in an investigation of the effect of light on plants the control will be a plant kept in the dark.

The usual way of testing hypothesis is by performing a carefully planned experiment. Such a carefully planned experiment consists of two components

a) Experimental group (treated group)
b) Control group (un treated group)

A controlled experiment tests only one factor at a time keeping the rest of the factors constant. Example: "Germinating seeds produce $C0_2$ during respiration" There will be two set ups

i) A set up with a test tube containing germinating seeds connected to another test tube containing water
ii) Similar set up but with the test tube with non-germinating seeds (control)

The experiment will turn limewater into milky color due to release of $C0_2$ during respiration by germinating seeds, but in (ii) the limewater will not turn milky. Now a comparison of (i) with (ii) leads to a conclusion that $C0_2$ evolve during respiration.

5. Recording Analysis and interpretation of Data

Results are recorded carefully and systematically and usually organized in the form of data tables, charts or graphs in addition to verbal explanations. Analysis of data means studying the organized material in order to discover the essential facts.

Here are four helpful modes that help you to analyze the data gathered:

a) Choose clear tables or figures for presenting the data
b) Examine carefully the statement of the problem
c) Further discuss with others about the problem
d) Treat the data using various statistical calculations to check similarities and differences.

The stage **of interpretation** after analysis is essential to state what the results show. Hence, interpretation needs a careful logical and critical examination of the results obtained after analysis.

6. Drawing conclusions

Conclusions or generalizations require careful and objective analysis of the data gathered.

7. Theory, principles, fact and law

When a given hypothesis has been tried (tested) many times by independent investigations and found to be acceptable it is no longer a hypothesis, but it becomes a **theory**.

- → a theory is a hypothesis tested to be true
- → a theory is open to tests, revision and tentative acceptance or rejection. e.g. A theory of evolution has changed over a period of time
- → At times discoveries are made much earlier but take the form of a theory after subsequent findings only. E.g. Robert Hooke discovered cell in 1665 but cell theory was formulated by schleiden and schwann in 1838 - 1839.

When a theory has proved invariable under all circumstances, or such variations are systematic and predictable, then it may be accepted as a **fact, principle or law**. This happens by further experimentation or observation as the case may be another highest level of scientific concept is modeling. A model is a mental map formed by deliberate analogy with a more familiar concept. Models are used in science to simplify ideas or certain aspects of a phenomenon.

e.g. – The key and lock model of enzyme action

- The crick and Watson model of DNA structure

8. Evaluation

For valid conclusions many rounds of the same experiment need to be undertaken. i.e. each experiment should be done again and again until consistent results are obtained. This phase of a scientific experimentation is known as **evaluation**.

9.**Reporting and publishing results**

Communication is an important component of the scientific method. The knowledge generated in a field of science has to reach the scientific community. The proper channels of communication for scientists and researchers are scientific journals, conference proceedings, bulletins and other publication series. Communication through reporting also avoids repetition of the same work.

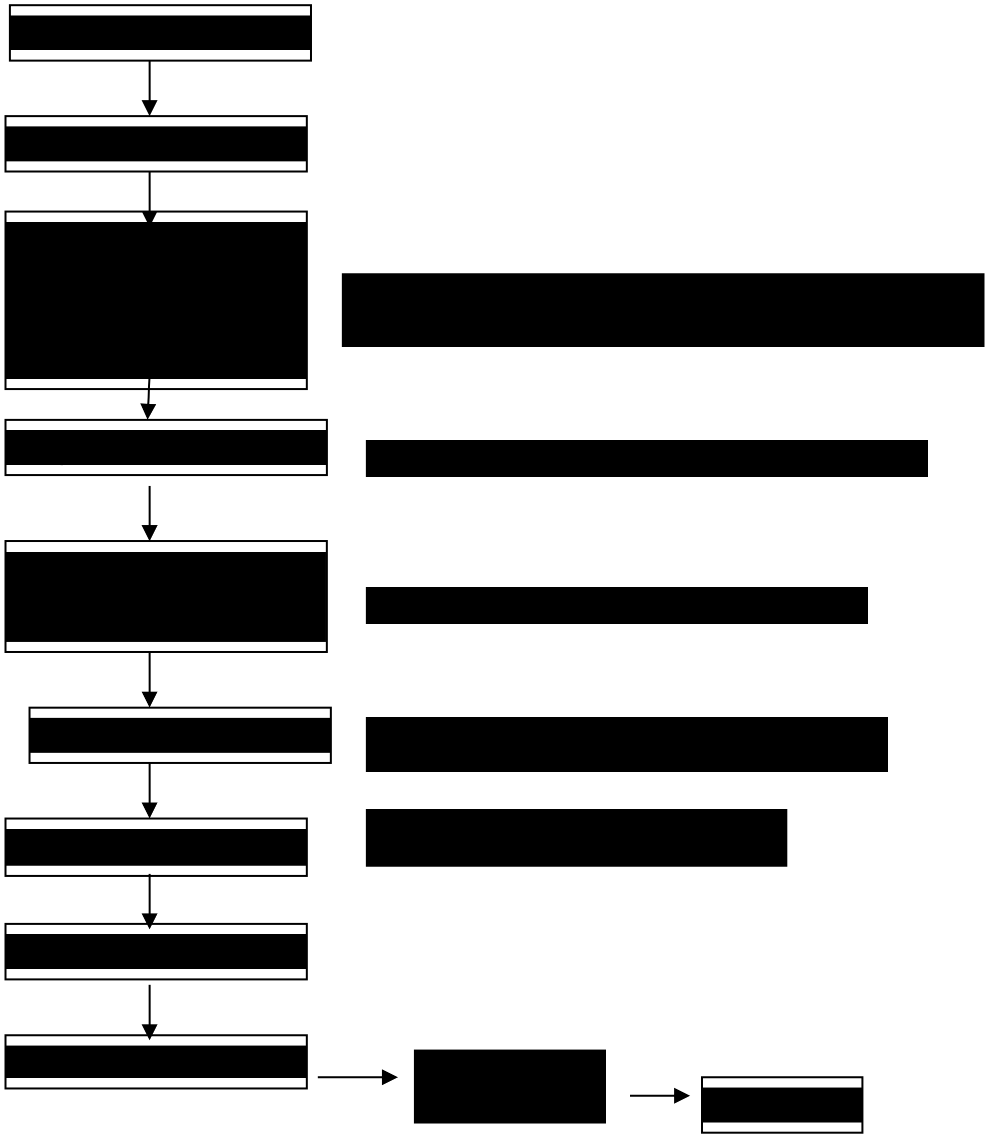


Figure 1. Summary of scientific method (The way How it proceeds).

1.2. The Basic tools of a Biologist

Biological information is gathered through observations and experiments, conducted in the laboratory and in the field. Practical interactions with biological objects and processes are important in making the theoretical knowledge more concrete and meaningful. Many techniques and tools or instrument are used in Biology. For convenience, they can be divided into tools used in the **laboratory** and tools used in the **open fields**. Hence, in this unit you study and use many of the tools of the biologist as described below and then the microscope is studied in detail.

Activity 12: Study on the basic tools of a biologist

Materials:

Laboratory tools/instrument	**Field tools/instrument**
1.Dissecting kit (forceps, scalped mounting needle, scissors, dropper, brush)	1. Plant press, plastic bags, envelops
2. Mortar and pestle	2. Insect net
3. Pipette	3. Secateurs
4. Microscope (Slides, cover slips)	4. Auger
5. Hand lens	5. Meter
6. Petri-dish	6. Altimeter
7. Rulers	7. GIS*/GPS**
8. Centrifuge, water-bath over	8. Traps, Cages
9. Glassware, aquarium	9. Digger
10. Balance, test tubes	
11. Calculators	
12. Computer	

* GIS (Geographical information system) is a software package for visual display of spatial data and computations based on the data and

** GPS (Geographical positioning system) is an equipment used to find a location.

The Microscope

A microscope is a precision device used to show objects that are too small to be seen at all with the naked human eye. Most cells are microscopic in size. Without microscopes, very little would have been known about cells. The microscope is the most important tool used in biological sciences. A microscopy is an old technique used in biology and it is still very important instrument. Advancements in biology are partly due to the invention and improvement modernization of the microscope.

After the invention of the first simple and crude type of microscope by Anthony van Leeuwenhoek advancements were made in the field of microscopy. By the end of the 19th century a light microscope was made, which used light as a source of energy to enlarge the image of an object and improve its vision. The best light microscope can magnify structures (increase in size of the image) up to 1500 times (x 1500) their original or normal size. At this high magnification, the image becomes less clear because the lenses cannot distinguish b/n small structures lying close together. The power of the microscope to scatter the image and show more details is known as the **resolving power** of the microscope.

Microscopes could be categorized into the following major groups depending on **their complexity**.

A. Simple microscope

The hand lens is an example of a simple microscope. It consists of a biconvex lens in a supporting frame. It is used to observe the external form of objects, and not the details of their internal structures. The magnification power of the common hand lens is usually between x 10 and x 20. The first microscopes were made of a single lens and hence were **simple microscopes**.

B. Compound microscope

This is a microscope with magnifying powers of two convex lenses, the eye piece (ocular lens) and the objective lens are used to produce a magnified image of small objects. The compound microscope uses light rays coming from a certain source (open light or an electric bulb), it is known as a light microscope. It uses to investigate internal structure of objects. Compound light microscopes are important to biologists because they allow them to observe many kinds of cells & single celled organisms while they are still alive. That is, an organism does not have to be filled to be observed under a compound microscope. There are limits to what we can see with the compound light microscope. As we increase the magnifying power of a light microscope, we see more and more detail - up to a certain point. Beyond that point, called the **limit of resolution**, objects get blurry & details are lost. For standard light microscopes, the limit of resolution is about 0.2 micrometers (A typical cell is about 10 micrometers across).

C. Electron microscope

Although light microscopes are very useful, their limits of resolution restrict their useful ness for studying very small objects such as viruses & individual molecule.

In the 1920s, physicists in Germany realized that electromagnets could bend streams of $\overrightarrow{es}$ in much the same way that glass lenses bend beams of light. This is a more powerful type of microscope. It uses a beam of electrons instead of light with a greater resolving power unlike the light microscope. The two types of electron microscopes are known as:

1. **Transmission electron microscope (TEM):** shine a beam of electrons at a specimen and then magnify the specimen onto a fluorescent scram. It reveals the inner most details of the cell interior.

2. **Scanning electron microscope (SEM):** beam of electrons that scans back & forth across the surface of specimen are picked up by detectors that provide the information to from an image on a TV screen. SEM allow us to study the surface of objects in their dimensional detail. The limitation of electron microscope is that living cells must be killed before they can be observed.

D. Other Types of microscopes

i. Dissecting microscope

This is designed to enable small objects to be dissected or manipulated while viewed under a moderate degree of magnification. In its simplest form, it consists of a stage above which is mounted a single lens magnifying about x 10. A dissecting microscope is binocular, which has two oculars. It is made easier to make manipulation under the microscope easier. This type of microscope is intended for use in manipulative biological work, and for the examination of relatively large objects such as insects.

ii. Phase contrast microscope

In recent years the use of this type of microscope became popular with research workers. This microscope is especially important in studying fine structures in living cells.

iii. Interference microscope

It Works with the same principle as phase contrast microscope. But, increases in contrast as a result of interference between light waves. The interference microscope however, enables smaller differences in contrast to be detected and also gives color effects.

Parts of the compound microscope

Study the diagram (Figure 2) below of the standard compound microscope and identify each of the parts with their functions described in Table (3.2)

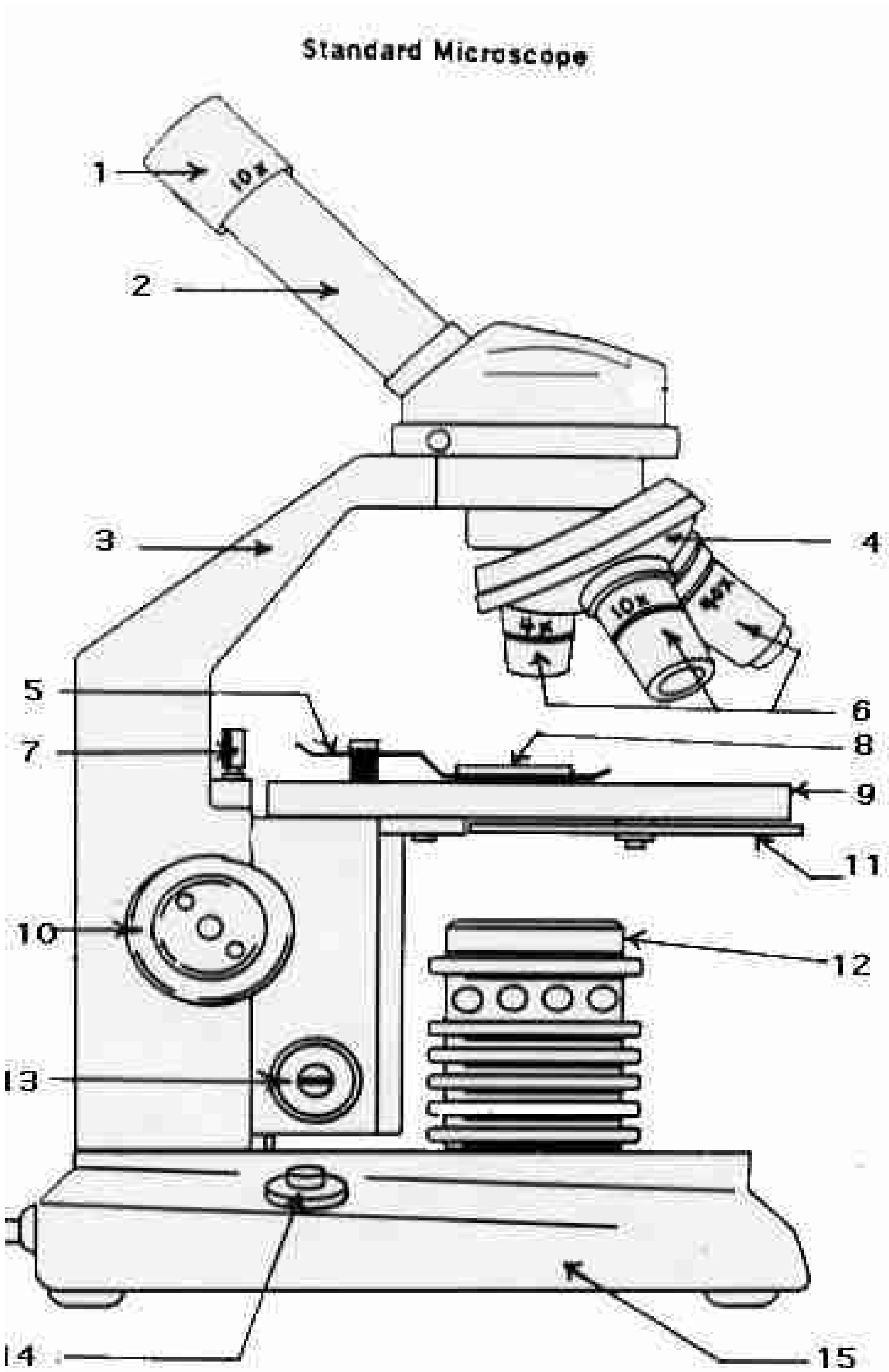


Figure 2. Parts of the compound microscope

Table 3. Parts and Functions of a compound microscope:

Part	Position and Function
Arm (limb)(2)	Supports the body tube and is the part with which you can grip to carry the microscope.
Base (foot)(15)	Gives a firm and steady support to the microscope
Ocular (eye piece lens) (1)	A lenses system of the microscope with a magnification power 7 x6, x or x 10. This lens is often un attached to the other parts, hence can fall down if not properly kept.
Objective Lens(6)	The lens, closed to the object placed on the stage, have several alternative lenses that are switched one at a time. The objective lens x10, gives the smallest image the middle power (40x), gives intermediate size and the high power (x100) gives the largest magnification. The oil immersion lens (x400), operates with the addition of oil, giving even larger magnification.
Nose piece(4)	The revolving part to which the objective lenses are attached.
Body tube	This may be monocular or binocular, where the eyepiece and objective lenses are supported, at a known distance and angle. The lower and of the tube possess a revolving nosepiece on which the objective lenses are screwed.
Stage(9)	This is a broad flat surface with a circular opening at its center that serve as a passage for light from the condenser to the objectives. The stage is also used to support the glass slide that holds the object.
Knobs(10)	These are used to move the stage up and down in order to bring the specimen into focus. The focusing knobs may be located near the base or the upper arm depending on the type of the microscope
Coarse adjustment	Moves the body tube or stage up and down, depending on the design of the microscope, to approximate the right position so that the specimen is in focus.
Fine adjustment	This is used to move the stage or body tube up and down to exactly the right position, so that the specimen is in focus. It uses to get fine focus with the low power objective and for all the high power and oil immersion objectives
Iris diaphragm(11)	This is controlled by a lever than can be moved back and forth. It is used to regulate how much light and lamp heat goes through the specimen.
Condenser(12)	This is a lens located above the diaphragm, which concentrates the light before it passes thought the specimen.
Mirror	Collects light and directs it to the condenser
Stage clip(5)	This is located on the stage and hold the glass slide in position(place)

Resolution and magnification principle of a microscope

The ability to distinguish between two separate objects is known as **resolution**. If two separated objects cannot be resolved, they will be seen as one object. Resolution is not the same as magnification which is simple enlargement of the specimen for a better observation.

Illustrative example:

If you take a photograph and keep on magnifying or enlarging it, magnification can be increased, but the resolution of the photograph stays the same when the limit of resolution is reached. We enlarge photographs in order to see them move clearly, but if we go too far, the picture breaks up into separate blurred dots. The resolution of an electron microscope is about 0.5nm (nanometer) in practice and that of the light microscope is 200nm. The shorter wavelengths of electrons have greater resolving power than those of light because there is an inverse relation between wavelength and resolving power. Light microscopes are important for getting an overall view of cells or tissues, and the preparation procedure of the objective much quicker and easier. They can also be used to view living material, which is not possible with an electron microscope. A compound microscope may have two or three objective lenses and one or more eyepiece lenses. The total magnification using any combination of these lenses is simply obtained by multiplying the magnification power of the eyepiece lens by that of the objective lens.

Total magnification = magnifying power x image. Power of objective used

of specimen of eye piece of

Unit 2: Biochemical molecules

2.1. organic Molecules

Introduction

All living organisms require several compounds to continue to live. We call these compounds **biomolecules.** The **smallest unit that make up a cell are called element**s. Scientists have identified 109 different elements & of the 103 different known elements only about, 13 kinds are involved in producing & maintaining life on our planet. Of these 13, 6 make up the common building block, which chemically join together to give a cell its unique structure & internal activity (chemical function). These 6 are the elements of carbon (C), hydrogen (H), nitrogen (N), phosphorus (P) & sulfur (S). All living things are composed these 6 elements. The 4 most common elements in living organism are, in order, H, C, O & N. The biological importance of H, O, N & C is largely due to their having **valences** of 1,2,3 & 4 respectively & their ability to form more **stable covalent bonds** than any other elements with these valences. C, H, and O & N chemically join or bond together to form 4 large units of organization called **organic compounds**, i.e. carbohydrates, lipids, proteins & nucleic acids. Biomolecules are formed by joining many small units together to form a long chain. This process is called **synthesis.** Often, a water molecule is removed in the process. **When this happens, we call it dehydration synthesis.**

A. Carbohydrates

Carbohydrates are substances that contain the elements C, H & O, & have a general formula $C_x(H_2O)_y$, Where x & y are variable numbers. Carbohydrate means **hydrated carbon** & this name derived from the fact that H & O are present in the same ratio as in water, i.e. 2H atoms; 1O atom. Carbohydrates are good energy source for living organisms. Therefore, cells need large amount of carbohydrates. All carbohydrates are **aldehydes or ketons**, & all contain several hydroxyl groups. These groups determine their chemistry. Carbohydrates are divided into three main classes, monosaccharides, disaccharides & polysaccharides depending on their **sugar units**.

i) Monosaccharides

Monosaccharides are **single sugar** units. The smallest functioning unit of a biomolecule is a **monomer** and the monomer for carbohydrates are **monosaccharides**. Their general formula is $(CH_2O)_n$. Monosaccharides are classified according to the **number of carbon** atoms as trioses (3C), tetroses (4C) pentoses (5C), hexoses (6C) & heptoses (7C). Of these, pentoses & hexoses are the most common monosaccharides. One of the most common monosaccharides is **glucose**, a six carbon sugar. A glucose molecule consists of six atoms in a ring (look for functions of monosaccharides in table 2.1).

Why is glucose important?

Cells use glucose for many purposes. Here are mentioned some of its functions.

- → It is important for brain cells
- → Synthesized by green plants and used as a food by others
- → A constant level of it should be maintained in the blood for normal functioning of the body
- → It acts as a fuel & releases energy for cellular activity
- → Stored in liver or muscles as a storage molecule in animals
- → Stored as starch in plants
- → Forms cellulose, building block of plant cells. Besides some other function of other monosaccharides are mentions in the table below.

Table 2.1. Chief functions of monosaccharides

Monosaccharide class	**Examples**	**Function**
Trioses ($C_3H_6O_3$)	Glyceraldehyde, dihydroxyacetone	Intermediate in cellular respiration (see glycolysis), Photosynthesis (see dark reaction) & other carbohydrate metabolism,
Pentoses ($C_5 H_{10}O_5$)	Ribose, deoxyribose, ribulose	- Synthesis of nucleic acids; ribose is a constituent of RNA & deoxyribose of DNA - Synthesis of some coenzymes; ribose is used in NAD & NADP synthesis - Synthesis of ATP requires ribose - Ribulose bisphosphate is the CO_2 acceptor in photosynthesis
Hexoses ($C_6H_{12}O_6$)	Glucose, fructose galactose	- Source of energy when oxidized, e.g. glucose - Synthesis of disaccharides & polysaccharides

In monosaccharides, all the carbon atoms except one have a hydroxyl group attached. The remaining carbon atom is either part of an aldehyde group, in which case the monosaccharide is called **aldose** or **aldo sugar**, or is part of keto group, when it is called a **ketose** or **keto sugar**. Thus all monosaccharides are aldose or ketose. All monosaccharides are **reducing sugar**, i.e. they carry out a type of chemical reaction known as **reduction reaction**. The two common tests for the presence of reducing sugar are **Benedict's test & Fehling's test**, which make use of the ability of these sugars to reduce copper from a valence of 2 ($CuSO_4$) to a valence of 1 (Cu_2O).

ii) Disaccharides

Disaccharides are formed when two monosaccharides, usually hexoses, combine by means of a chemical reaction known as a **condensation**, i.e. removal of water. The bond formed between two monosaccharides as a result of condensation is called a **glyosidic bond**. The process can repeat many times to build up the giant molecule of **polysaccharide.** The most common disaccharides are **maltose** (glucose + glucose), **lactose** (glucose + galactose) & **sucrose** (glucose + fructose). Maltose & lactose are reducing sugars while sucrose is the only common **non-reducing sugar**.

iii) Polysaccharides: As already mentioned, polysaccharides are polymers of monosaccharides. They function chiefly as food & energy stores (e.g. starch in plants & glycogen in animals) & as structural material (e.g. cellulose). They are convenient storage molecules because their large size makes them more or less insoluble in water, so they exert no osmotic or chemical influence in the cell; they fold into compact shape & they are easily converted to sugars by hydrolysis when required. **Chitin & murein** are compounds closely related to polysaccharides. **Chitin** is closely related to cellulose in structure & function as being a structural polysaccharide. It occurs in cell wall of fungi & exoskeleton of arthropods. **Murein** acts as the strengthening material of bacterial cell wall. **Pectin** are polysaccharides of galactose & galacturonic acid residues, & is an important component of the first layer of a cell wall. **Hemicelluloses** are made up of pentose sugar & sugar acid residues. **Inulin**, a polymer of fructose, is a reserve carbohydrate found in some groups of plants as an alternative to starch.

B. Lipids

What are Lipids?

Lipids are organic molecules consists of C, H & O, as do carbohydrates, but in lipids the proportion of O is much less & H is more. Lipids usually contain Sulfur (S) & sometimes Phosphorous (P). Lipids are also insoluble in water & are said to be hydrophobic (water-hating). But they are soluble in organic solvents such as **ethanol & ether**. They are of two types: **fats & oils**. There is no basic difference between them but fats are simply solid at room temperature (10-20^{o} C) whereas oils are liquids. They are made up of **fatty acids & glycerol** (an alcohol).

Fatty acids contain the acid group -COOH (the carboxyl group). Fatty acids sometimes contain one or more double bonds (C=C) & called **unsaturated fatty acids**. Fatty acids & lipids that lacking double bond are said to be **saturated**. Unsaturated fatty acids melt at much lower temperature than saturated fatty acids. The higher the proportion of unsaturated fatty acid the more likely the lipid to be liquid at a given temperature. Most lipids are triglycerides. Glycerol has three hydroxyl group (-OH) groups. Usually all three -OH groups undergo condensation reaction with fatty acid, & the lipid formed is therefore **triglycerol (triacylglycerol)**. Therefore, a triglyceride molecule consists of four molecules joined together: three fatty acid molecules attached to a glycerol molecule.

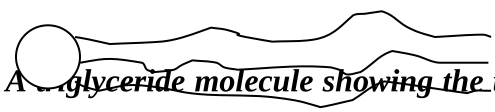


Figure .2 A triglyceride molecule showing the three fatty acid molecules *joined to the glycerol molecule*[redacted] [redacted]

The three fatty acid molecules combine with the glycerol molecule in a condensation reaction as shown below.

Figure3. A condensation reaction occurs when a triglyceride molecule is formed.

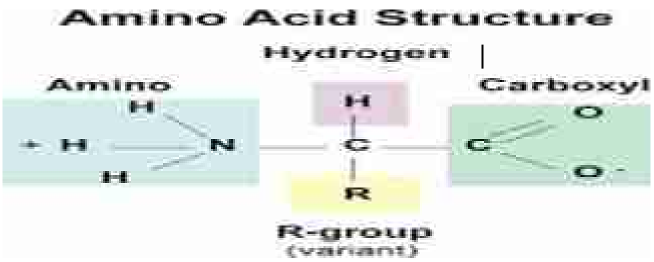
In living the organisms' lipids (triglycerols) have the following major function:

- ✓ Source of energy & heat. A given mass of lipid will yield more energy on oxidation than an equal mass of carbohydrate. This is because lipids have a higher proportion of hydrogen compared to carbohydrates.
- ✓ Structural constituent of cell membrane, e.g. phospholipids & glycolipids.
- ✓ Synthesis of hormones such as testosterone & estrogen, e.g. steroids (cholesterol in the tissue of mammals)
- ✓ Both bile acids that involve in digestion & vitamin D (involve in calcium ion absorption) are manufactured from steroid such as cholesterol.

✓ Plant scents are derivatives of fatty acids. They are attractive to insects & thus aid pollination.

C. Proteins

Proteins are made up of a number of units called **amino acids**. More than 170 amino acids are currently known to occur in cells & tissues, but only 20 are commonly found in proteins. In the structure of amino acids there is a **central carbon (known as α-carbon)** to which are attached an acidic **carboxylic group** (-COOH), a basic **amino group** (-NH) & a **hydrogen atom**. The fourth position in the molecule is the only variable part & is known as the **R group**. One amino acid is different from the other by this R group.



Plants can synthesize all the amino acids they require from simpler substances, but animals unable to synthesize some of them. An **essential amino acid** is one, which must be included in the diet because either it cannot be made in the body at all, or it is made too slowly to meet needs. **Non-essential amino acid** is the one that can be synthesized in the cell or in the body.

Amino acids can react with each other by condensation, i.e. the amino group of one amino acid reacts with the carboxylic group of the other with the removal of water. The bond formed between them is called **peptide bond**, & the resulting compound is a **dipeptide**. Three amino acid molecules will combine in this way to form **tripeptide**, & so on. If many amino acids are joined in this way a **polypeptide** is formed. Polypeptide chain is assembled to form proteins.

Proteins differ from each other in the kind, number and sequence of amino acids along its chain. In the living cell the sequence of amino acids in polypeptide chain is determined by DNA. Each protein possesses a characteristic three-dimensional shape, its **conformation**. There are 4 separate level of structure & organization of proteins, i.e. primary, secondary, tertiary & quaternary.

A. Primary structure: It is the linear sequence of amino acids in a polypeptide chain.

B. Secondary structure: Polypeptide chains may be folded & twisted in various ways. The most common ways are the **coil to form a helix** (**α-helix**), e.g. keratin or to **fold into sheets** (**β-sheets**). These forms are referred to as secondary structure of proteins.

C. Tertiary structure: Usually the polypeptide chain bends & folds extensively, forming a precise, compact 'globular' shape. This is the protein's tertiary structure & the shape is maintained by ionic, hydrogen & disulphide bonds as well as hydrophobic interactions.

D. Quaternary structure: Many highly complex proteins consists of more than one polypeptide chain. The separate chains are held together by hydrophobic interactions & hydrogen & ionic bonds. Their precise arrangement is known as the quaternary structure.

Because of the complexity of protein molecules & their diversity of function they classified in various ways & three of them are:

- → their structure
- → their composition and
- → according to functions

D. Nucleic acids

Nucleic acids are made of **polymers of nucleotides**. Individual nucleotides comprise three parts:

a) **Phosphoric acid** (phosphate H_3PO_4): This has the same structure in all nucleotides.

b) **Pentose sugar:** Two types occur, ribose ($C_5H_{10}O_5$) and deoxyribose($C_5H_{10}O_4$)

c) **Organic (N-base):** There are five different bases which are divided into two groups as:

   I. **<u>Pyrimidines</u>**: these are single rings each with six sides. Examples found in nucleic acids are Cytocine (C), Thymine(T) and Uracil(U)

   II. **<u>Purines</u>**: these are double rings comprising a six-sided and a five-sided ring. Two examples are found in nucleic acids: Adenine (A) and Guanine(G).

The three components of a nucleotide are combined by **condensation reactions** to give a nucleotide and linked with a **phosphodiester bonds**. By a similar condensation reaction between the sugar and phosphate groups of two nucleotides, a **dinucleotide** is formed. Continued condensation reaction lead to the formation of a **polynucleotide.** The function of nucleotides is the formation of the nucleic acids **RNA** and **DNA**, which play vital roles in protein synthesis and heredity. In addition, they form part of other metabolically important molecules.

Table 2.2. Biologically important molecules containing nucleotides, and their functions

Molecules	**Abbreviation**	**Functions**
Deoxyribonucleic acid	DNA	Contains genetic information of cells

Ribonucleic acid	RNA	All three types play a vital role in protein synthesis
Adenosine monophosphate Adenosine diphosphate Adenosine triphosphate	AMP ADP ATP	Coenzymes important in making energy available to cells for metabolic activities, osmotic work, muscular contraction, etc.
- Nicotine adenine dinucleotide - Flavine adenine dinucleotide	NAD FAD	Electron (hydrogen) carries important in respiration in transferring hydrogen atoms from the Krebs cycle along the respiratory chain.
Nicotine adenine dinucleotide phosphate	NADP	Electron (hydrogen) carrier important in photosynthesis for accepting electrons from the chlorophyll molecule and making them available for the photolysis of water.
Coenzyme A	CoA	Coenzyme important in respiration in combining with pyruvate to form acetyl coenzyme A and transferring the acetyl group into the Krebs cycle.

A. Deoxyribonucleic acid (DNA)

DNA is a double-stranded (chained) polymer of nucleotide where the pentose sugar is always deoxyribose and the organic bases are adenine, guanine, cytosine and thymine, but never uracil. Each of these polynucleotide chains is extremely long and may contain many million nucleotide units. By the early 1950s, information on DNA from a variety of sources had been collected, but no molecular structure had been agreed. The available facts about DNA included:

- → It is a very long, thin molecule made up of nucleotides.
- → It contains four organic bases: adenine, guanine, cytosine and thymine.
- → The amount of guanine is usually equal to that of cytosine
- → The amount of adenine is usually equal to that of thymine
- → It is probably in the form of a helix whose shape is maintained by hydrogen bonding.

Using the accumulated evidence, James Watson and Francis Crick in 1953 suggested a molecular structure, which proved to be one of the greatest milestones in biology. They postulated a **double helix** of two nucleotide strands, each strand being linked to the other pair of organic bases, which are themselves joined by hydrogen bonds. The pairing is always cytosine (C) with guanine (G) and adenine (A) with thymine (T).

B. Ribonucleic acid (RNA)

RNA is a single-stranded polymer of nucleotides where the pentose sugar is always ribose and the organic bases are adenine, guanine, cytosine and uracil. There are three types of RNA found in cells, all of which are involved in protein synthesis.

a) Ribosomal RNA (rRNA) or" work bench" is a large, complex molecule made up of both double and single helices. Although it is manufactured by the DNA in the nucleus, it is found in the cytoplasm where it makes up more than half the mass of the total RNA of a cell and its base sequence is similar in all organisms.

b) Transfer RNA (tRNA) or "***Adapter***" is a small molecule (about eight nucleotides) comprising a single strand. Again nuclear DNA manufactures it. It makes up 10-15% of the cell's RNA and all types are fundamentally similar. It forms a clover shape, with one end of the chain ending in a cytosine-cytosine-adenine sequence. It is at this point that an amino acid attaches itself. There are at least twenty types of tRNA, each one carrying a different amino acid. At an intermediate point along the chain is an important sequence of three bases, called the **anticodon**. This lines up alongside the appropriate **codon** on the mRNA during protein synthesis.

c) Messenger **RNA (mRNA)**" or ***blue print***" is a long single-stranded molecule, of up to thousands of nucleotides, which is formed into a helix. Manufactured in the nucleus, it is a mirror copy of part of one strand of the DNA helix. There is hence an immense variety or types. It enters the cytoplasm where it associates with the ribosome and acts as a **template** for protein synthesis. It makes up less than 5% of the total cellular RNA. It is easily and quickly broken down, sometimes existing for only a matter of minutes.

Difference between RNA and DNA

Despite the obvious similarity between RNA and DNA, a number of differences exist and these are listed in Table below.

Table2.4. Differences between RNA and DNA

RNA	**DNA**
Pentose sugar is ribose	Pentose sugar is deoxyribose
Single polynucleotide chain	Double poynucleotide chain
Smaller molecular mass	Large molecular mass

In most case single helix chin	Always a double chain
Organic bases present are adenine(A), guanine(G), cytosine(C) and uracil(U)	Organic base present are Adenine(A), guanine(G), cytocine(C) and thymine(T)
Ratio of A and U to C and G varies	Ratio of A and T to C and G is one
Manufactured in the nucleus but found throughout the cell	Found almost entirely in the nucleus
Amount varies from cell to cell (and within a cell according to metabolic activity)	Amount is constant for all cells of a species (except gametes and spores)
Chemically less stable	Chemically very stable
May be temporary-existing for short periods only	Permanent
Three basic forms: Messenger, transfer and ribosomal RNA	Only one basic form, but with an almost infinite variety within that form

2.2. Inorganic Bases of Life (Water and Minerals)

Overview

All cells, tissues and organs are composed of chemicals. Some of the chemical substances are found in non-living matter as well, while others are found in living organisms only. Out of all the elements found on the earth, about 24 are essential for life. They occur in different proportions in a cell. Some exist in large amount the other is trace (small) amount.

Water

Of the smaller molecules, water is the most abundant, typically making up between 60-95% of the fresh mass of living organism. Without water, life could not exist on this planet. It is important for two reasons.

- ✓ First it is a vital chemical constituent of living cells, &
- ✓ Secondly it provides an environment for those organisms that live in water.

The interesting chemical & physical properties of water are due to its **small size**, its **polarity** & to **hydrogen bonding** between its molecules. Table 2.5 below shows the significance of water physical property in living organisms.

Table 2.5. *The significance of the physical property of water*

Properties of water	**Significance in living things**
Liquid at room temperature	Liquid medium for living things & for the chemistry of life
Very high latent heat (much heat energy is needed to raise the temperature of water)	Aquatic environments are slow to change temperature Large organisms have a stable temperature in the face of fluctuating temperatures.
Very high latent heat of vaporization (evaporation of water needs great deal of heat)	Evaporation of water in sweat or in transpiration causes marked cooling Much heat is lost by evaporation of small quantity of water
Very high latent heat of fusion (much heat must be removed before freezing occurs)	Contents of cells & aquatic environments are slow to freeze in cold weather.
Maximum density at 4°C (ice is less dense than water, even very cold water)	Ice forms at the surface of water, insulating the water below When surface water does freeze aquatic life can survive below the ice
Very high surface tension (water molecules at surface with air orientate so that hydrogen bonds face inward)	Water forms droplets on surfaces & run off Certain small animals exploit surface tension to land on & move over the surface of water
Very low viscosity (water molecules slide over each other very easily	Water flows readily through narrow capillaries
High surface cohesion (water molecules adhere to surfaces)	With low viscosity, capillarity becomes possible; water moves extremely narrow spaces, e.g. between soil particles & in cell walls
High surface tension (water column does not break or pull apart under tension	Water can be lifted by forces applied at the top, e.g. movement of water up the xylem of tall trees

Universal **solvent** (water dissolves more substances than any other common liquid)	Medium for chemical reactions of life Acts as transport medium, as in blood, lymphatic & excretory systems, the alimentary canal & xylem & phloem.
High **transmission of visible light** (water is colorless)	Plants can photosynthesize at depth in water Light may penetrate deeply into living tissue
Water as **reagent**	Water acts are as essential metabolite, i.e. participate in the chemical reactions of metabolism, e.g. it is source of hydrogen in photosynthesis & used in hydrolysis reactions

Table 2.6. Some biologically important functions of water

Plants:	**Animals:**
➢ In osmosis & turgidity ➢ Reagent in photosynthesis ➢ Transpiration ➢ Translocation of inorganic ions & organic molecules ➢ Germination of seeds	➢ Transport in blood vascular, lymphatic, excretory systems ➢ Osmo-regulation ➢ Cooling by evaporation ➢ Lubrication, as in joints ➢ Support: hydrostatic skeleton of e.g. annelid worms ➢ Protection, e.g. lachrymal fluid (tear), mucus

All organisms:

- Structure (high water content of the cell)
- Solvent & medium for diffusion
- Reagent in hydrolysis
- Support for aquatic organisms
- Fertilization by swimming gametes
- Dispersal of seeds, gametes & larval stage of aquatic organisms, & seeds of some terrestrial species, e.g. coconut

Mineral and Salts

Minerals form important components of organic and inorganic molecules. The minerals, which are essential for growth and development, form **essential elements** required in large quantity. Some are called **major essential elements** like calcium, phosphorus, nitrogen, sodium, chlorine, magnesium and sulfur; some are required in traces and form **trace elements**. These are iron, manganese, molybdenum, copper, cobalt, zinc, fluorine, iodine and selenium. The functions of these are listed in table 2.7.

Table 2.7. Functions of essential elements

Element	**Symbol**	**Function**
1. Major Elements		
Calcium	Ca	- strength and rigidity to bones and teeth - used as fertilizer in bone dust - exoskeleton of invertebrates ($CaCO_3$) - shells of mollusks (CaO) - formation of middle lamella in plant cell walls
Sulphur	S	- synthesis of proteins e.g. Keratin - synthesis of organic compounds e.g. Co-enzyme A.
Nitrogen	N	- synthesis of proteins, nucleic acids and organic compounds - synthesis of chlorophyll
Phosphorus Magnesium	P	- synthesis of nucleic acids, ATP and proteins - constituent of bones and teeth enamel - as phospholipids in membranes - rigidity to bones and teeth - structure of chlorophyll - Co-factor of enzymes like ATPase
Sodium	Na	- maintenance of electric potential across the membrane - conduction of nerve impulses - balance of anion/cation and osmotic balance of cellular fluids - C0-factor in photosynthesis and respiration
Potassium	K	- Similar function as sodium; generally, there is a Na+/K+ pump i.e. exchange of Na+ for K+
2. Trace elements		

Iron	Fe	- oxygen carrier as a haem group in hemoglobin and myoglobin (respiratory pigments) - electron carriers in cytochromes (respiration, photosynthesis) - synthesis of chlorophyll, its deficiency leads to **anemia.**
Manganese	Mn	- for oxidation of fatty acids - for enzymes in respiration and photosynthesis. (mitochondria are rich in manganese) - for bone development
Molybdenum	Mo	- fixation of nitrogen catalyzed by nitrogenase
Copper	Cu	- electron carrier in cytochrome oxidase (respiratory system and photosynthesis) - production of melanin
Iodine	I	Important constituent of hormone Thyroxine. Deficiency leads to goiter. Cretinism in children

Unit 3: Cell Biology

3.1. Cell Theory

Introduction

The **cell** is a basic unit of structure and function in living organisms. Cell is the simplest structure capable of existing as an individual living unit in unicellular organisms. There are certain chemical reactions within a cell, required to maintain life. With time cellular organization has led to cell-differentiation and that has given rise to organs and organ systems. This is possible only by division of labor, an individual comprised of many organ systems working in a co-coordinated manner.

Cells → Tissues → Organs → Organs systems → Individuals

Cell, though very small, is extremely complex. It acts as an autonomous unit i.e. able to carry out its activities independently:

- ✓ it can carry out all biological processes
- ✓ it can oxidize the food molecules to produce energy & store this energy rich molecule
- ✓ by using nutrient molecules, it can build new structures & can replace worn out cells
- ✓ it can respire and exchange gases with its surroundings
- ✓ it can replace its own self
- ✓ it can maintain homeostasis
- ✓ each cell has its own life span

Discovery of the cell and the cell Theory

It is because cells are so small that they were not observed until microscopes were invented in the mid-seventeenth century. **Robert Hooke** first described cells in 1665, when he used a microscope he had built to examine a thin slice of cork, a non-living tissue found in the bark of certain trees. Hooke observed a honeycomb of tiny, empty (since the cells were dead) compartments in the cork cellulose (Latin, "**small rooms**"), and the term has come down to us as **cells**. The first living cells were observed a few years later by the Dutch naturalist **Anton Van Leeuwenhoek**, who called the tiny organisms that he observed "**animalcules**," meaning **little animals**. For another century and a half, however, biologists did not appreciate the general importance of cells. In 1838 a botanist, **Mathias Schleiden**, after a careful study of **plant tissues**, made the first statement of the cell theory. He stated that all plants "are aggregates of fully industrialized, independent, separate beings, namely the cells themselves." In 1839, a zoologist **Theodor Schwann** reported that all **animal tissues** are also composed of individual cells.

The formulation of **cell theory** and the present day knowledge of cell structure & function is the chronological order of scientific works

- in the mid-16th Antony Van Leeuwenhoek (using his own compound microscope) was the first person to see micro-organisms.
- in 1665 Robert Hook was the first to observe the tiny box-like structure in the tree cork & called it 'cells'.
- in 1838 a formal hypothesis that cells make up the part of living thing was advanced by Mathias Schleiden & Theador Schwann.
- in 1855 Virchow showed that all cells arise from pre-existing cells by cell division.

The cell theory, in its modern form, includes the following three principles:

1. All organisms are composed of one or more cells within which the life processes of metabolism and heredity occur.
2. Cells are the smallest living things, the basic units of organizations of all organisms.
3. Cells arise only by division of a previously existing cell. Although life evolved spontaneously in the hydrogen rich environment of the early earth, biologists have concluded that additional cells are not originating spontaneously at present. Rather, life on earth represents a continuous line of descent from those early cells.

In nature we have two categories of cells: ***Prokaryotic and Eukaryotic.***

In broad terms cells can be divided into two major classes, i.e. Prokaryotic & eukarotic cells.

Prokaryotic cell

The word **prokaryote** comes from two Greece words, <u>**pro**</u> meaning before (primitive) & <u>**karyo**</u> means nucleus. Therefore, prokaryotic cells are cells lacking a membrane-bound nucleus or membrane-bound organelles, e.g. bacteria, blue-green algae, spirochetes, etc. Prokaryotic cells were probably the first form of life on earth. Prokaryotic cells refer to a bacterial cell where the hereditary material called DNA is not enclosed in a membrane and there is no internal structure like nucleus. Also it lacks other intracellular cell organelles. Absence of intracellular organelles indicates primitive nature of prokaryotic cell. Prokaryotes is the term given to organisms without true nucleus.

Eukaryotic cell

Eukaryotic cells (Eu = good, true or well, karyo = nucleus) are cells characterized by membrane -bound nucleus and other organelles, e.g. in plants from algae (some of them) to angiosperms and in animals from protozoa to mammals. The cells of other multicultural organisms (like plants, animals and fungi) have a membrane bound nucleus. The hereditary material (DNA) is present within this nucleus. The cytoplasm contains a number of membrane bound organelles like mitochondria, chloroplast etc. There are a number of non-membranous organelles also like centriole and ribosomes. Each organelle performs a specific function.

For the sake of discussion organelles in a typical **(generalized) eukaryotic cell** may be grouped into 4 main parts, i.e.

- → cell wall
- → cell membrane
- → cytoplasm &
- → Nucleus

1. Cell Wall

Cell wall is the outer thick cellulose wall around the cell membrane of plant cell. It contains pores called **plasmodesmata** that facilitate free passage of materials in and out of the cell. It gives strength & rigidity to the cell & also acts as protective structure.

2. Cell Membrane (plasma membrane or plasma lemma)

Cell membrane made up of a double layer of lipo-protein (phospho-lipid with protein molecule embedded in it). It is elastic, porous & selectively permeable (semi-permeable) membranous cover of the cell. Cell membrane controls the flow of materials into & out of the cell, & acts as protective structure in animal cells.

3. Cytoplasm

The cytoplasm refers to clear watery liquid or jelly-like substance & organelles contained between the cell membrane & the nuclear membrane. May be divided into two parts, i.e. cytoplasmic matrix & the various cytoplasmic organelles.

A. Cytoplasmic matrix: Is a translucent, homogenous liquid that fills the space b/n cell membrane & the nucleus. It consists of various inorganic molecules such as water; salts of sodium, potassium

& others. Organic compounds such as carbohydrates, lipids, amino acids (proteins), nucleotides (RNA, DNA), ATP, a variety of enzymes, etc. are also found in it.

B. Cytoplasmic organelles

Cytoplasm contains various organelles with specific functions. These include:

a) Plastids

Plastids are small bodies found in plant cells & certain single-celled animals. Three kinds of plastids are found in plant cells. These are:

i) Chloroplast: contains the green pigment chlorophyll that involve in photosynthesis. Within the chloroplast envelope are two distinct regions called stroma & grana (thylakoids) where photosynthetic processes take place.

ii) Chromoplast: stores orange, yellow & red pigments that give flowers & fruits their colors.

iii) Leucoplasts: are colorless plastids that store nutrients such as starch.

b) Vacuoles

Vacuoles are fluid-filled membranous sacs only found in plant cells & unicellular animals. Plant cells have large central vacuoles (filled with fluid called **cell sap**) & animal cells have small temporary vacuoles. Common types in animal cells include food vacuoles, phagocytic vacuoles and contractile vacuole. Vacuoles store nutrients like **protein, oils & water.** Occasionally contain **hydrolytic enzymes** & so perform functions similar to those of **lysosomes**. Some of them temporarily **store & remove wastes** from the cell

c) Mitochondria

Mitochondria are granular structures bounded by two or double membrane. The inner membrane is folded forming convolutions called cristae that increase surface area for activity of enzymes found there. The remainder of the mitochondrion is called matrix. Its function is converting energy in the food into biologically useful energy or ATP. Because of this it is called **'power house of cells'**. Found in large number in cells that expend more energy (metabolically very active), e.g. muscle cells, liver cells, etc.

d) Endoplasmic reticulum (ER)

Endoplasmic reticule is a system of membranous tubes, channels & flattened sacs that form compartment within the cytoplasm. There are two kinds of ER, i.e.

i) Rough ER: contains ribosomes attached to their membrane

ii) Smooth ER: contains no ribosomes.

Functions of ER are:

- → Its coils & folds increase surface or location for chemical reactions.
- → Some portions of ER are continuation of the cell membrane to the inside of the cell, forming channels that can transport newly synthesized products & substrates through the cell.
- → Collecting & storing synthesized materials.
- → Producing proteins, especially enzymes by rough ER
- → Producing lipids & steroids by smooth ER

e) Ribosomes

Ribosomes are the smallest (tiny), spherical structures that found attached to the membrane of rough ER & also freely in the cytoplasm. They are not surrounded by membrane. They are produced in the nucleolus (a structure in the nucleus) & consist of proteins & ribosomal RNA (rRNA). Facilitate the synthesis of proteins & called cell's **'protein factories'.**

f) Golgi bodies (Golgi complex or Golgi apparatus)

They are large cavities surrounded by a series of parallel membranes & are specialized area of the ER. There is normally only one Golgi apparatus in each animal cell but in plant cells there may be a large number of stacks known as dictyosomes. They store large concentrations of cell products (such as proteins & carbohydrates) produced by ribosomes & then release these products to the outside of the cell. Therefore, it is a temporary storage site of cell products (such glyco-proteins, carbohydrates, secretory enzymes like digestive enzymes). They also produce & release tiny membranous sacs called lysosomes.

g) Lysosomes *(lysis='splitting', soma='body')*

Are membrane-bound vesicles (sacs) found only in animal cells. Contains various powerful hydrolytic enzymes that break down macromolecules (e.g. proteins). They contain pockets, which serve to segregate the enzymes in the intact cell & prevent digesting the content of the cell. Therefore, they are directly or indirectly related to intracellular digestions. They also play a role in fertilization i.e. acrosome on the head of sperm cell contains lysosomes (with enzymes) that can digest the wall of egg cells & facilitate fertilization.

h) Peroxisomes *(Micro-bodies)*

Micro-bodies are membrane-bound bodies that found near mitochondria or chloroplast. Contains enzymes & considered as special class of lysosomes, e.g. the major kidney & liver peroxisomes are catalase (an enzyme that break down hydrogen peroxide (H_2O_2) in to water (H_2O) & oxygen (O_2).

i) Centrioles

Centrioles are tiny round, hollow cylindrical bodies found in the cytoplasm of animal cells. They arise in a distinct region of the cytoplasm known as the **centrosomes** (contains 2 centrioles). They play an active part in cell division, i.e. during cell division they migrate to opposite poles of the cell where they synthesize the microtubules of the spindle. Spindles help to draw (drag) chromosomes to opposite pole. Even though centrioles are absent in plant cells, they do form spindles.

j) Microfilaments

Microfilaments are long & thin protein fibers in the cytoplasm. They involve in several kinds of cell movements by pseudopodia in cells like amoeba & white blood cells. They consist of very thin strands of proteins, actin & myosin that involve in muscle contractions & movement.

k) Miro-tubules

Are small hollow tubes composed of tiny cylindrical proteins called tubulin. They form the structural units of centrioles & spindles (that involve in cell division), & also cilia & flagella (involve in movement of cells). Provides an internal skeleton (cytoskeleton) for cells & so help determine their shapes.

l) ***Microvilli***

Are tiny finger-like projections on the membrane of certain cells, e.g. intestinal epithelium & the kidney tubules. Microvilli provides large surface area & facilitates absorption of materials.

4. Nucleus

Is a round & dense body, usually spherical, & found near the center of the cell. The cytoplasm-like material within the nucleus is called **nucleoplasm.** Its functions are regulation of the life activities of the cell & controlling cell division. Composed of 3 structures, i.e.

A. Nuclear membrane

- It is the double-outer covering of the nucleus
- Regulates the flow of materials into & out of the nucleus.

B. Chromatins (Chromosomes)

- Are extended thread-like structures in the nucleus.
- Made up of DNA, RNA & proteins (histone)

- During cell division the chromatins condense to form the chromosomes
- Contains <u>genes</u> that control the activities of the cell & determine heredity.

C. <u>Nucleolus</u>

- It is a spherical body found within the nucleus & are not bounded by a membrane.
- Plays important role in the synthesis of RNA & Ribosomes.

3.4. The cell and its Environment

Overview

We begin by looking how molecules move around from place to place. How do substances such as water, nutrients and waste products move through the cell surface membrane to get in and out of the cell?

The center of the atom is called the nucleus and it makes up 99.9% of the mass of the atom. The nucleus continuous two different kinds of subatomic particles, the proton (a positively charged particle) and neutron (an electrically neutral particle). In addition, atoms contain a negatively charged particle, the electron. Some substances, known as elements, consists entirely of one type of atoms.

A. Atoms, ions, molecules, and Solutions

Atoms and Ions

Everything in the world is made up of tiny particles called **atoms**. It is the basic unit of matter. You, the paper and print on this page are, the air around you and the water that you drink are all made from atoms. Atoms are very, very small. No one can really imagine the size of an atom. They are just too small for the human brain to understand. The atom is consisting of many smaller particles, known as subatomic particles. The three principal subatomic particles are the **proton, neutron & electron**.

An atom is the particle from which all substances are made. It is the simplest form in which an element exists. An **element** is a substance, which is absolutely pure, composed of atoms of the same types. There are about 100 different kinds of atoms representing the 100 or so different elements, which exist in the world. **Hydrogen** is the simplest element and one atom of hydrogen is the simplest form in which an atom can exist. Atoms consist of a central nucleus surrounded by tiny particles called **electrons**. When an atom loses or gains an electron it is described as an **ion**.

Molecules

Atoms can join to form bigger particles called molecules. Molecules contain either the same kind of atom or different atoms joined together. Oxygen gas, for example, is made of molecules in which two oxygen atoms are joined together.

Solids, liquids and gases

Atoms and molecules are always moving around. In a solid substance such as ice, the molecules do not move very much. They just jiggle on the spot. They are held quite closely together. If you heat some ice, you give extra energy to the molecules. They start to move faster and travel further apart. When ice melts, it becomes **liquid** water. Each molecule is spaced further apart than when frozen. If you heat some water, you give even more energy to the molecules. They start to move so fast that they break right away from one another. Some of them fly off into the air. The steam that you see escaping into the air is made of very energetic water molecules. They have now become **a gas** and we call this gas **water vapor.**

B. Diffusion

1. Simple diffusion

Simple diffusion is the random (net) movement of molecules (ions) from place of high concentration to a place of low concentration. It tends to distribute molecules uniformly.

The rate of diffusion depends upon:

1. The **concentration gradient**. i.e. the greater the difference in concentration between two regions of a substance the greater the rate of diffusion.
2. The **distance** over which diffusion takes place, i.e. the shorter the distance between two regions of different concentrations the greater the rate of diffusion.
3. The **area** over which diffusion takes place, i.e. the larger the surface area the greater the rate of diffusion.

4. The **nature of any substance** across which diffusion occurs. Variation in the structure of cell membrane may affect diffusion, e.g. the greater the number & size of pores in cell membrane the greater the rate of diffusion.
5. The **size &nature** of the diffusing molecules, i.e. small molecules diffuse faster than larger ones; fat-soluble molecules diffuse more rapidly through the cell membrane than water soluble.

2. Facilitated diffusion

Facilitated diffusion is the transport of molecules across membrane by a carrier or channel protein from high concentrated area to low concentration.

C. Osmosis

Osmosis is the diffusion of water across a semi-permeable membrane from high concentrated area of **water** to low concentration (from low concentrated area of **solution** to high concentration). Osmosis in living cell takes place whenever the cell is surrounded by a solution with a concentration different from that of inside of the cell. If the concentration of dissolved substance (solution) in the cell is greater than its surrounding solution, the cell is said to be **hypertonic**, if lower than the surrounding called **hypotonic** & if equal known as **isotonic**. **Turgor pressure** is the pressure exerted by the content of the cell against the cell wall (due to the entrance of water into the cell when the cell is hypertonic). Turgor means the rigidity of the cell, i.e. turgid cell is stiff & firm, but un-turgid cell is **flaccid** (not able to support itself).

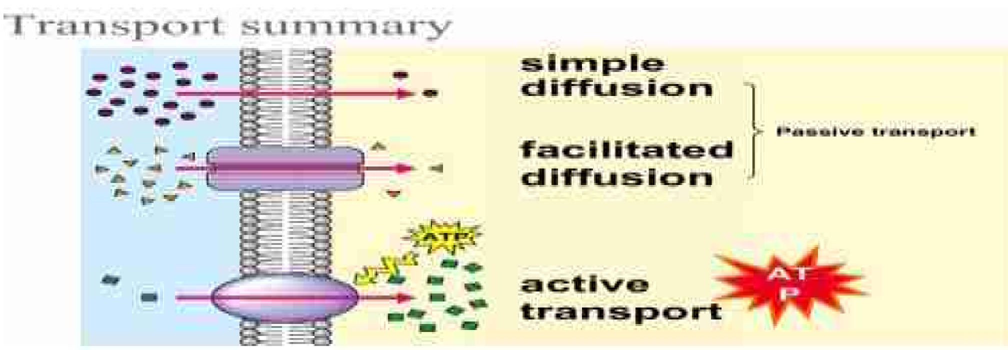
- The importance of turgor pressure is:
    - in non-woody plants it is important in supporting the plant body (maintaining the form of the plant).
    - in young cells it provides the force to stretch cell wall & makes possible cell growth.
- **Plasmolysis** is the shrinking of the cell content away from the cell wall (due to removal of water from the cell when the cell is hypotonic). The term used for animal cell is **crenation**.

D. Active Transport

- Active transport is the transport of molecules across a membrane usually to a region of high concentration by expenditure of chemical energy.
- The different kinds of molecules enter & leave cells by way of a wide variety of different kinds of selectively permeable **transport channels or carrier proteins**, e.g. the sodium-

potassium pump is an active transport process, transporting sodium & potassium ions from area of low concentration to area of high concentration.

- The many channels in the membrane that the cells use to concentrate metabolites & ions called **coupled channels**, e.g. molecules such as sugar, proteins, etc. are transported coupled with sodium & potassium ions.
- The processes in which the cell membrane actively participate in the ingestion (taking in) & expulsion (release out) of large sized (bulky) substances are endocytosis & exocytosis.
- **Endocytosis:** involves the incorporation of a portion of the exterior medium into the cytoplasm of the cell by capturing within the vesicle. Two kinds: **phagocytosis** (phagein = "to eat") is a process in which cells literally engulf solid food or foreign particles, enfolding them within vesicles. **Pinocytosis** (pinein = "to drink") is a process in which cells engulf liquid that contains dissolved molecules.
- **Exocytosis:** is the expulsion of materials from a cell by discharging it from vesicle at the cell surface.



3.5. Cellular respiration

One of the essential functions of cells is the processing of energy. **Energy** is the ability to do work. For students of Biology, work is often the maintenance of order. Cells and organisms are highly ordered systems and energy is required to maintain that order. The process by which cells produce energy through the breakdown of biomolecules (carbohydrates, proteins) or by which microorganisms obtain the energy is called **cellular respiration**. When carbohydrates are broken down inside the cells, the energy is retained in the form of energy rich molecules **Adenosine Triphosphate (ATP)**. This is harvested and stored for later use. The whole process of ATP synthesis inside the cells is called **cellular respiration**.

A chemical reaction is molecular transformation of reactants (Starting substances) into products (new substances). The set of chemical reaction occurring in a cell constitute **metabolism.** Generally speaking, there are two types of chemical reactions that take place in a cell.

1. **Anabolic (synthetic) reactions**

These refer to those reactions in which molecules are linked together by chemical bonds to form a more complex compound.

They can be represented as follows.

$$\underbrace{A + B}_{\substack{\text{Reactants}\\\text{(Substrates)}}} \longrightarrow \underbrace{C + D}_{\text{Products}}$$

There are often two reactants and two products. There is a case also where reactants can be transformed into one product or one reactant can become one or two products.

What are the common anabolic reactions that occur in living things?

Anabolic reactions are concerned with building up processes in cells. Storage compound and complex metabolites such as starch, glycogen, lipid and protein are all products of anabolic reactions. They are big molecules built up from smaller units.

2. **Catabolic (break down) reactions**

These include reactions in which a complex compound is spilt into simpler molecules. Catabolic reactions can be represented as follows.

$$\underset{\text{(Reactant)}}{\text{D}} \longrightarrow \underbrace{A + B}_{\text{(Products)}}$$

The hydrolysis of a disaccharide into monosaccharide units, lipid into fatty acids and glycerol, protein into amino acids are all examples of catabolic reactions. Cellular respiration also follows catabolic pathways.

During the process of cellular respiration, glucose (a sugar produced as a result of digestion) reacts with oxygen to release energy that can be used by the cell. Carbon dioxide and water are produced as waste products. The reaction can be summed up as follows:

glucose + oxygen → carbon dioxide + water + energy (ATP).

This is called **aerobic** respiration because it uses oxygen from the air. Aerobic respiration takes place in the mitochondria in cells.

All of your cells need energy to carry out the reactions of life, and respiration provides this energy. Respiration releases energy from the food we eat so that the cells of the body can use it. The energy that is used by the cells is stored in the form of a molecule known as **ATP**, which stands for **adenosine triphosphate**. This is an adenosine molecule with three phosphate groups attached to it. When energy is needed for any chemical reaction in the cell, the third phosphate bond is broken in a hydrolysis reaction. This results in a new compound, **ADP** or **adenosine diphosphate**, a free inorganic phosphate group – and the all-important energy needed in the cell. This is a reversible reaction, and so during cellular respiration the energy from the reactions of glucose with oxygen is used to produce large quantities of ATP ready for use in the cells. This is why cellular respiration is so very important – ATP is the single energy providing and energy storing molecule for all the processes in living cells.

Why do living things need energy?

All living organisms can be regarded as working machines, which require a continuous supply of energy in order to keep working. Living things need a permanent source of energy to maintain orderliness and stay alive the following is a list of essential processes in life that need energy. Cellular respiration releases the stored energy and makes it available to do work. Except for photosynthetic organisms that obtain their energy from the sun's radiations, other life forms must derive energy for all their activities by breaking down fuel molecules.

- Active transportation of substances into and out of cells against concentration gradient such as Na^+ - K^+ pump.
- Mechanical contraction of muscle and electrical transmission of nerve impulses.
- Endocytosis & exocytosis (Bulk transport of materials into and out of cells)
- Synthesis of substances for growth and repair such as protein synthesis.
- heat energy released from cellular respiration to maintain constant body temperature

Anaerobic respiration

The energy released by aerobic respiration in muscle cells allows them to move. However, during vigorous exercise the muscle cells may become short of oxygen – the blood simply cannot supply it fast enough. When this happens the muscle cells can still obtain energy from the glucose but they have to do it by a type of respiration that does not use oxygen (**anaerobic respiration**).

Anaerobic respiration produces far less ATP than aerobic respiration. It also produces a different waste product called **lactic acid**. The body cannot get rid of lactic acid by breathing it out as it does carbon dioxide, so when the exercise is over, lactic acid has to be broken down. This needs oxygen, and the amount of oxygen needed to break down the lactic acid is known as the **oxygen debt**. Even though our leg muscles have stopped, our heart rate and

breathing rate stay high to supply extra oxygen until we have paid off the oxygen debt. After exercise, the lactic acid is oxidized by oxygen to produce carbon dioxide and water.

glucose → lactic acid + energy (ATP)

Oxygen debt repayment:

lactic acid + oxygen → carbon dioxide and water

When muscle cells have been used for vigorous exercise for a very long time they become fatigued, which means they stop contracting efficiently. They switch to anaerobic respiration, and as the levels of lactic acid build up, your muscles really start to ache. This is known as **muscle cramp**. Also, anaerobic respiration is not as efficient as aerobic respiration. It does not break down the glucose molecules completely so far less ATP energy is released than during aerobic respiration. So your muscles tire more rapidly and cannot work as well when they are respiring anaerobically, as there is not enough energy for them.

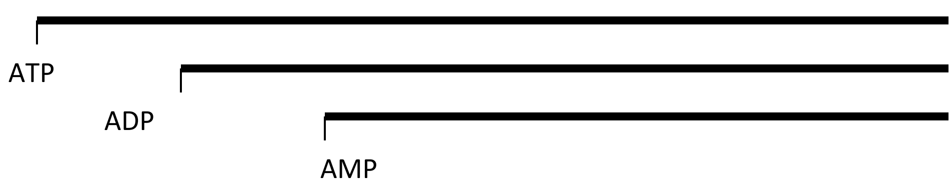
Anaerobic respiration isn't simply something that affects people. It takes place in all living organisms, and in a number of cases we have put anaerobic respiration to very good use, both in our industries and in our homes. For example, one of the micro-organisms that is most useful to people is yeast, a single-celled fungus. When yeasts have plenty of oxygen they respire aerobically, breaking down sugar to provide energy for the cells and producing water and carbon dioxide as waste products. However, yeast can also respire anaerobically. When yeast cells break down sugar in the absence of oxygen they produce ethanol (commonly referred to as alcohol) and carbon dioxide. The anaerobic respiration of yeast is sometimes referred to as fermentation. The yeast cells need aerobic respiration because it provides more energy than anaerobic, so it allows them to grow and reproduce. However, once there are large numbers of yeast cells, they can survive for a long time in low oxygen conditions and will break down all the available sugar to produce ethanol.

glucose → ethanol + CO2 + energy (ATP)

ATP: The Energy Currency of the Cell

All of the activities of a cell require energy. A single molecule, adenosine triphosphate, or ATP supplies a large proportion of this energy. Therefore, ATP is the cell's chief energy currency. Glucose, glycogen, and starch are like money that one has deposited in the bank. ATP is like the cash in one's pocket. ATP is made up of **adenine**, a five-carbon sugar known as **ribose**, and three **phosphate groups.** These three phosphate groups with strong negative charges are covalently bonded to one another; this is an important feature in ATP function. The last two phosphates are attached by high-energy bonds (wavy lines).

To understand the role of ATP, we have to return briefly to the concept of chemical bond and bond energies. A chemical bond is the total of the forces that hold the constituent atoms together in a molecule. Because a bond is a stable configuration, it takes energy to break an old bond and form a new one. This energy is the energy of activation. Because of enzymes, which greatly reduce the energy of activation required, the reactions essential to life are able to proceed at an adequate rate. However, there is an important additional limitation on chemical reactions in living systems: the bond energies of the products must always be less than the bond energies of the reactants.



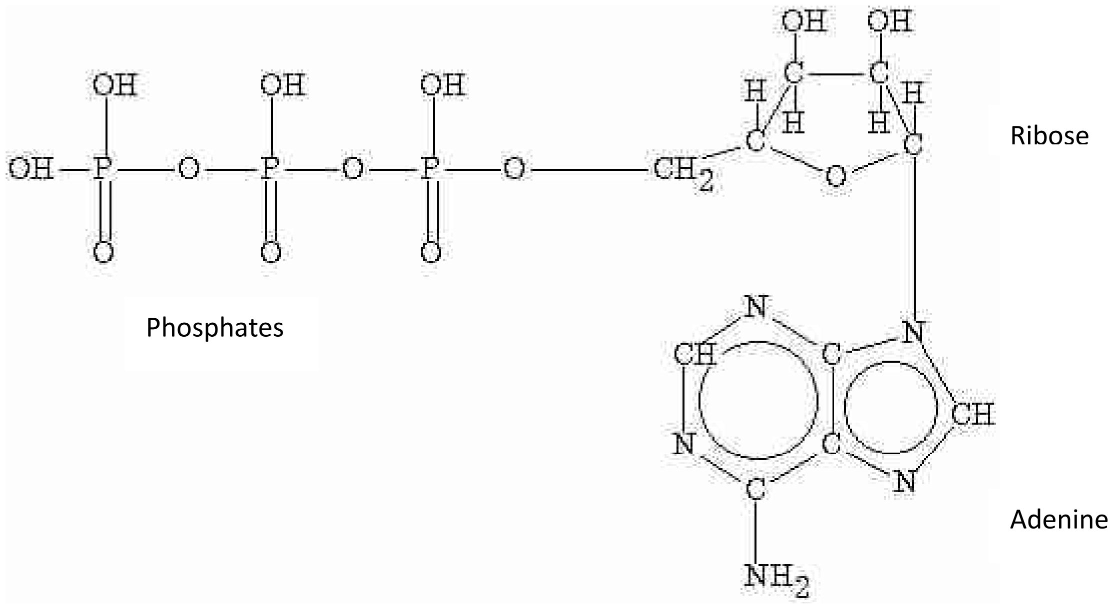


Fig. 3.2 The ATP molecule

Cells fulfill this requirement by **coupled reactions** in which energy-requiring chemical reactions are linked to energy-releasing reactions. The molecule that participates most frequently in such coupled reactions is ATP.

How is ATP adapted to its role as an energy transfer molecule in cells?
First, we must explain what we mean by an energy transfer molecule. Sunlight energy cannot be used directly by plants (and certainly not by other organisms) to ‘drive’ the synthesis of proteins or any other molecules. The same applies to the energy held in a glucose molecule. These two energy sources must be used to produce ATP, which is used to transfer the energy to the relevant cellular process. We say that it is coupled to these processes.

ATP is adapted to this role because it:

- releases energy in relatively small amounts that are closely matched to the amounts of energy required in many biological processes occurring inside cells
- releases energy in a single-step hydrolysis reaction, so the energy can be released quickly
- is able to move around the cell easily, but cannot escape from the cell

The following processes are examples of processes that require energy from ATP:

• the synthesis of macromolecules such as proteins

• active transport across a plasma membrane

• muscle contraction

• conduction of nerve impulses

• the initial reactions of respiration (the later reactions release energy from glucose to form more ATP)

The internal structure of the ATP molecule makes it usually suited to this role in living systems. In the laboratory, energy is released from the ATP molecule when the third phosphate is removed by hydrolysis, leaving **ADP** (Adenosine diphosphate) and a phosphate:

$$ATP + H_2O \longrightarrow ADP + Phosphate$$

In the course of this reaction, about 7 kilocalories per mole of ATP are released, a relatively large amount of chemical energy. Removal of the second phosphate by hydrolysis produces **AMP** (Adenosine monophosphate) and releases an equivalent amount of chemical energy.

$$ADP + H2O \longrightarrow AMP + Phosphate$$

To indicate that relatively large amounts of chemical energy are involved, the covalent bonds linking these two phosphates to the rest of the molecule are oftern called high-energy bonds, symbolized by a wavy line (as shown above). However, this term is somewhat misleading, because the energy released during the reaction does not arise entirely from the bond. The difference in energy between the reactants and products is due only in part to the energies in the bonds. It is also partly as a result of the rearrangement of the orbitals of the ATP or ADP molecules. Each of the phosphate groups carries negative charges and so tends to repel each other. Thus, when a phosphate group is removed, the molecule undergoes a change in electron configuration that results in a structure with less energy.

In living systems, ATP is also sometimes hydrolyzed to ADP. ATP hydrolysis provides, for example, a rapid means for producing heat, as in animals waking up from hibernation. Usually, however, the terminal phosphate group is not simply removed but is transferred to another molecule. this addition of a phosphate group is known as phosphorylation; enzymes that catalyze such transfer are known as kinases. This reaction transfers some of the energy in the "high-energy" bond to the phosphorylated compound, which, thus energized, participates in the reaction.

For example, in the reaction, $A + B \longrightarrow C + D$

If the bond energies of A plus the bond energies of B were less than those of C plus D, the reaction would not take place. Chemists could drive the reaction by supplying outside energy, probably in the form of heat. The cell might handle it this way:

$$A + ATP \longrightarrow A - P + ADP$$

The energy of the products is less than that of the reactants, so the reaction will take place. However, much of the ATP/ADP bond energy is conserved in the new compound A phosphate, or A - P. The next step in the reaction becomes:

$$A\text{-}P + B \longrightarrow C + D + P$$

With the release of the phosphate from A, this second reaction also becomes oen in which the energy of the products is less than the energy of the reactants and which, therefore, can take place. Take for instance, the formation of sucrose in sugarcane.

$$\text{Glucose} + \text{Fructose} \longrightarrow \text{Sucrose} + H_2O$$

In this reaction, the bond energy of the products is 5.5 kilocalories per mole greater than the bond energy of the reactants. However, the sugarcane plant couples this reaction to the breakdown of ATP:

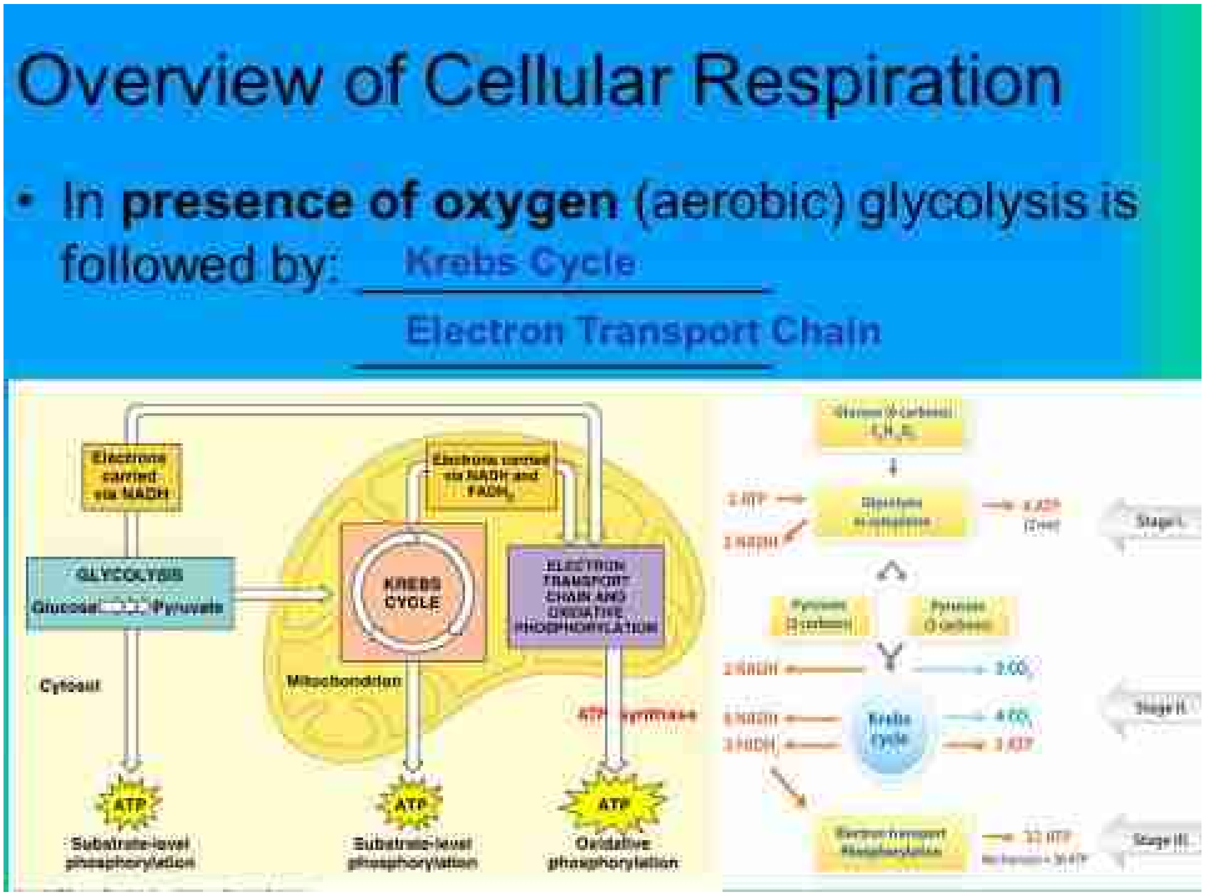
$$\text{Glucose} + \text{Fructose} + 2\ ATP \longrightarrow \text{Sucrose} + 2ADP + 2P$$

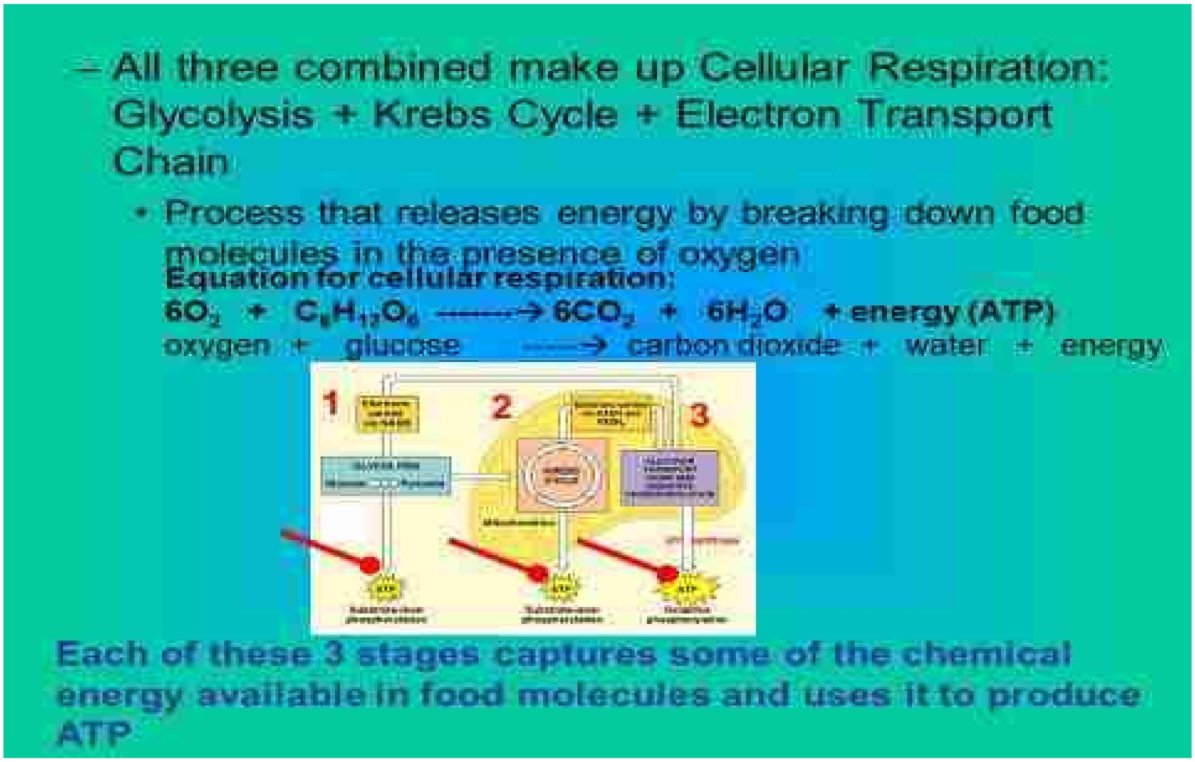
Since the bond energy of 2 ADPs is about 14 kilocalories per mole less than the bond energy of 2 ATPs, the overall difference in products and reactants becomes 8.5 kilocalories per mole. The coupling of the two reactions permits sugarcane to form sucrose.

Where the ATP comes from is an interesting question to examine. As we shall see in the following pages, energy released in the cell's catabolic reactions, such as the breakdown of glucose, is used to "recharge" the ADP molecule. Thus the ATP/ADP system serves as a universal energy-exchange system, shuttling between energy-releasing and energy-requiring reactions.

Cells do not burn glucose, they slowly release energy from it and other food compounds through several pathways (processes). The 1st pathway is **glycolysis**: releases only a small amount of energy (2 net ATP). If oxygen present, it will lead to two other pathways that release a lot of energy: **Krebs cycle** & **Electron Transport Chain.** In between glycolysis there is a **linked reaction** that bridge pyruvate produced during glycolysis with Krebs cycle.

If oxygen absent glycolysis is followed by a different pathway as in Alcoholic Fermentation or Lactic Acid Fermentation.





Glycolysis = splitting of sugar

Process takes place in the cytosol of the **cytoplasm** outside of mitochondria; coverts glucose with the help of 2 ATP molecules and eventually releases 4 ATP molecules; for a net gain of 2 ATP molecules.

ATP & NADH production in Glycolysis

Step 1: breaks 1 molecule of glucose in half, producing 2 molecules of pyruvic acid (a 3-carbon compound).

Step 2: 2 NAD+ electron carrier accepts 4 high-energy electrons transfers them to 2 NADH molecules and 2 H+ thus passing the energy stored in the glucose

Step 3: 4 ADP added producing 4 ATP

Step 4: 2 remaining pyruvic acids enter Krebs Cycle in presence of oxygen; IF no oxygen another pathway is followed.

- ✓ Glycolysis is a fast process
- ✓ Cells produce thousands of ATP molecules in a few milliseconds
- ✓ Glycolysis alone DOES NOT require oxygen
- ✓ It can supply chemical energy to cells when oxygen is NOT available

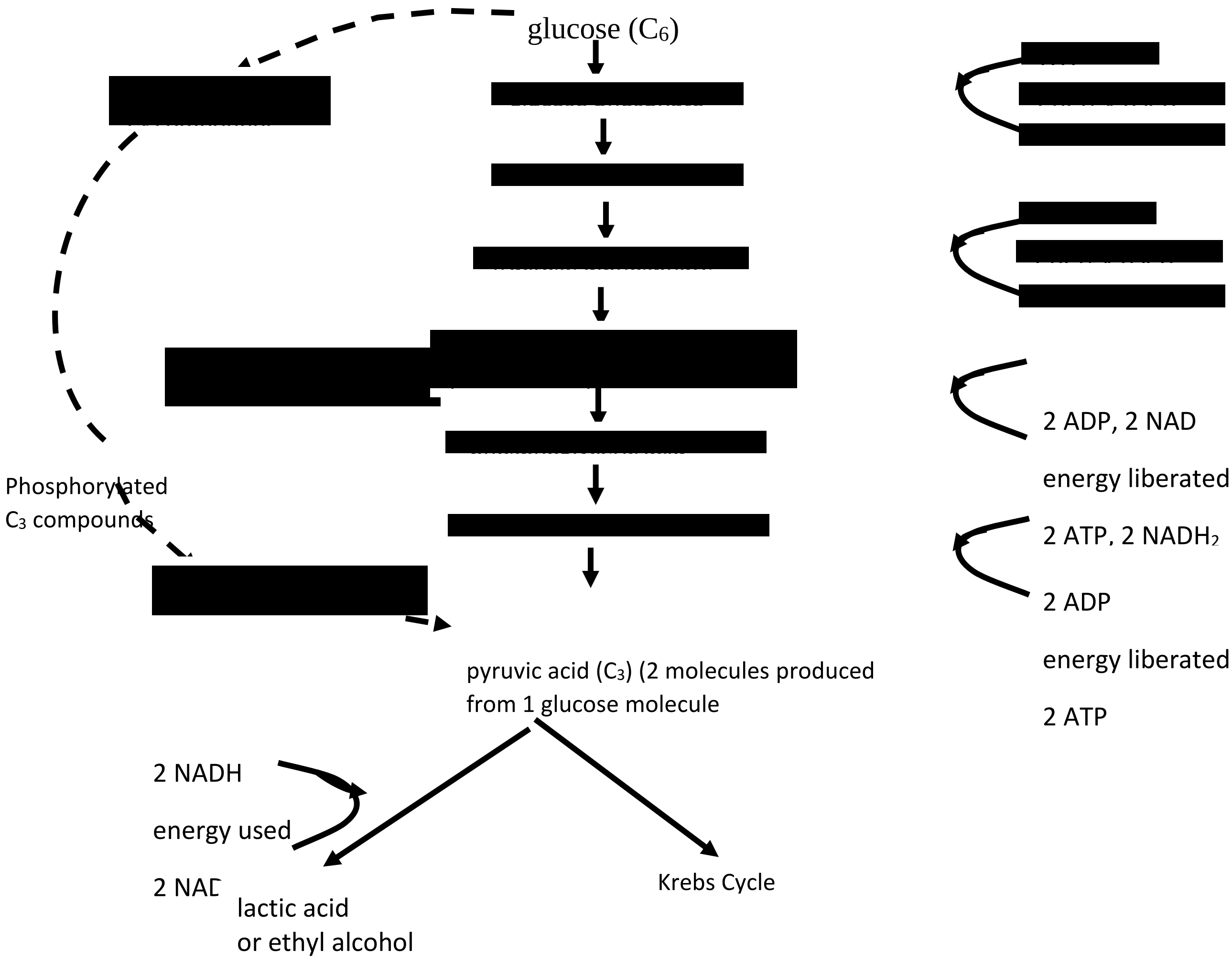
However, if a cell generates large amounts of ATP from glycolysis it can run into problems

a. the cell’s available NAD+ molecules become filled up with electrons

b. glycolysis shuts down, cannot proceed without available NAD+ molecules

c. ATP production stops

Summary of glycolysis



AEROBIC RESPIRATION: The Krebs Cycle and Electron Transport

At the end of glycolysis 90% of chemical energy from glucose still unused, locked in high energy electrons of pyruvic acid. Extracted by world’s most powerful electron receptor **oxygen**. Krebs and Electron Transport require oxygen thus they are **aerobic** processes.

The Krebs Cycle

It is the 2nd stage of cellular respiration and named after Hans Krebs, British biochemist in 1937. Here pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions.

Citric acid is the 1st compound formed in this series of reactions, so Krebs is sometimes called the Citric Acid Cycle/ Tricarboxylic Acid Cycle.

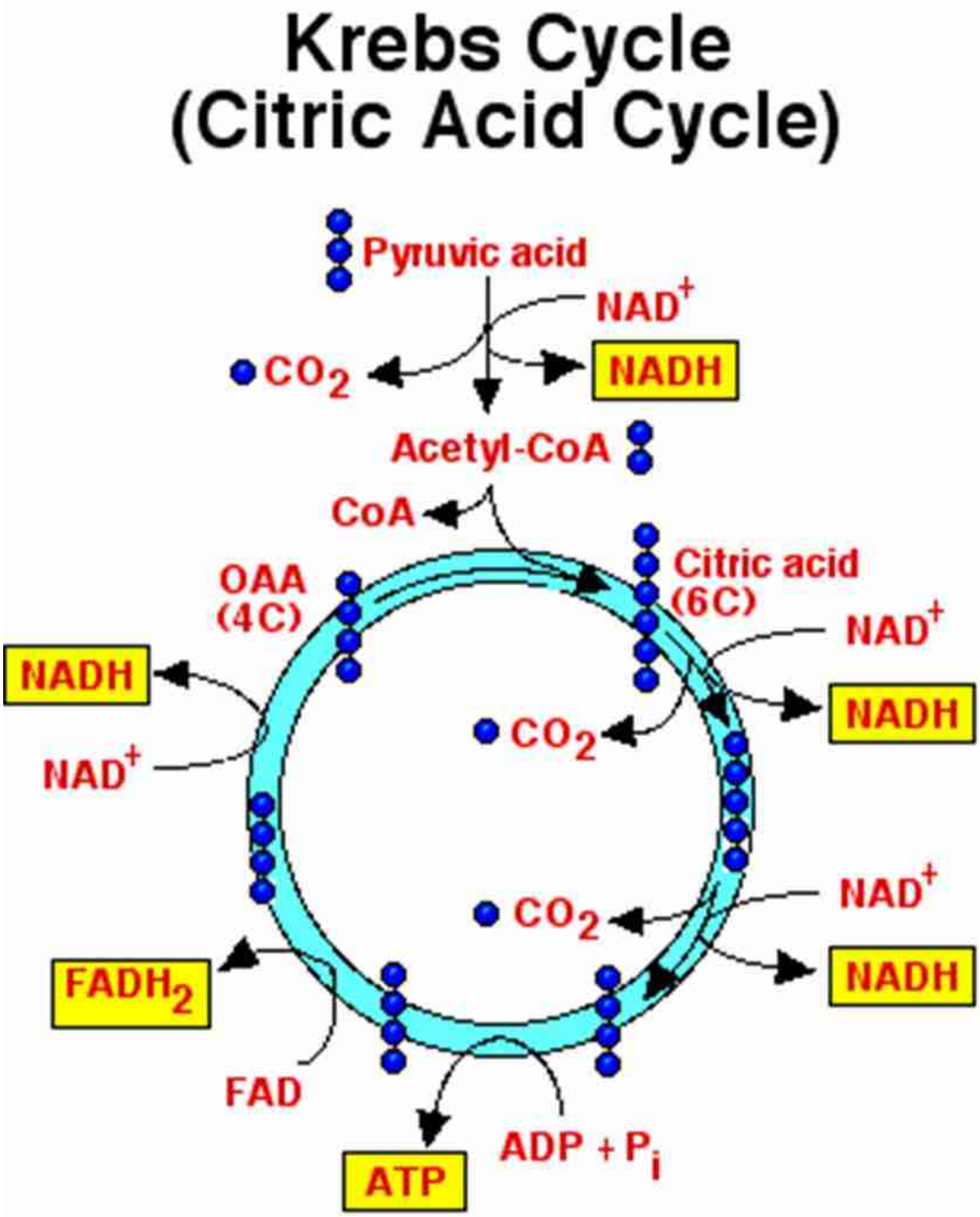
Pyruvic acid enters from glycolysis and one carbon removed = CO_2 formed (linked reaction). It is the junction between glycolysis and the Krebs cycle. NAD^+ again changed to NADH and CoA joins remaining 2 carbons = Acetyl-CoA.

Acetyl-CoA added to 4 carbon compound called oxaloacetate to form = Citric acid (6-C).

Citric acid broken down to 5-carbon then 4 carbons; more CO_2 released. Along the way more NADH and $FADH_2$ formed and one molecule of ATP also made. 2 turns & 2 pyruvic acid (from glycolysis) yield: 10 NADH (2 from glycolysis) 2 $FADH_2$ 4 ATP (2 from glycolysis).

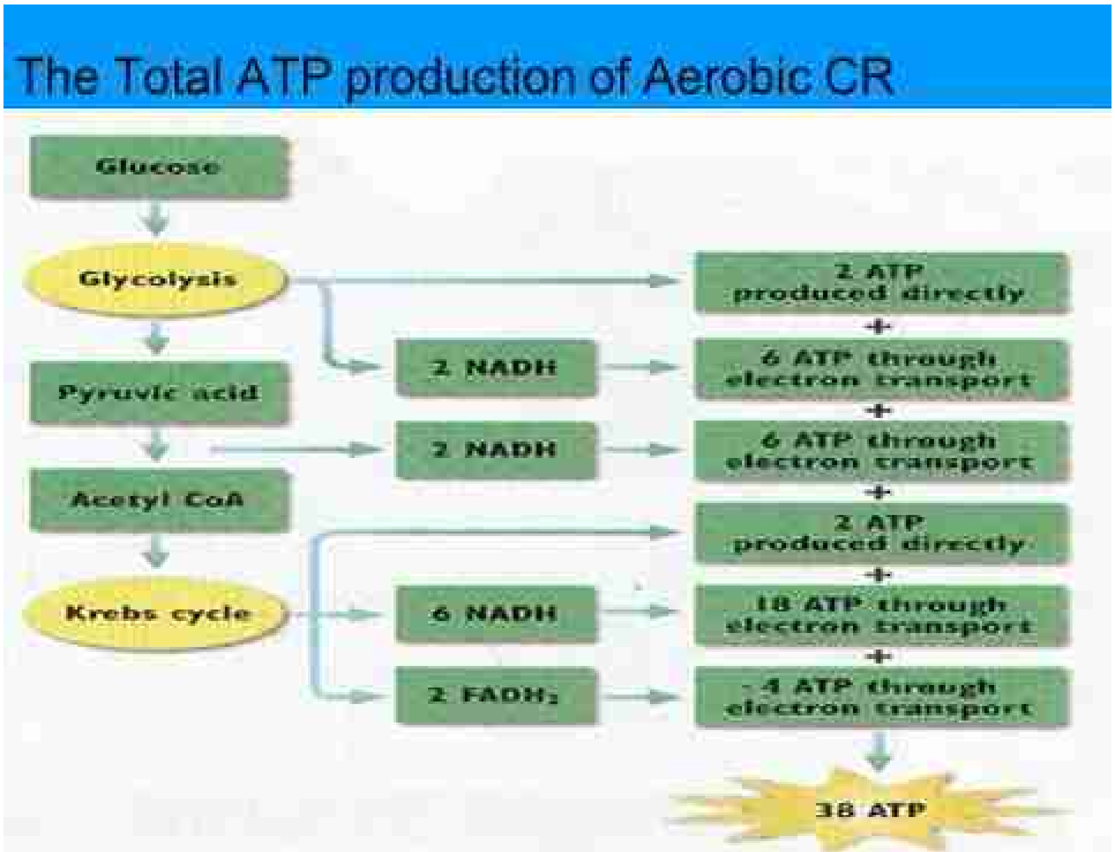
During formation of acetyl CoA, the following happens:

- → The carboxyl group of pyruvic acid is removed as a CO_2 molecule, which then diffuses out of the cell. Since pyruvic acid has three carbons, a two-carbon fragment remains.
- → This two-carbon fragment is oxidized while NAD^+ is reduced to NADH.
- → Finally, the oxidized fragment, called an acetyl group, is attached to coenzyme A (CoA). This coenzyme has a sulfur atom, which bonds to the acetyl fragment by a very unstable bond and will enter into the Krebs cycle.



Electron transport chain

Electrons from Krebs cycle are passed to electron transport chain by NADH & $FADH_2$. At end of the chain an enzyme combines electrons from the electron chain with H+ ions and oxygen to form water. Each time 2 high-energy electrons transport down the electron chain, their energy is used to transport H+ ions across the membrane. H+ ions build up in intermembrane space it is now positively charged, other side of membrane negatively charged. Electrochemical gradient (chemiosmosis gradient) created for ATP synthase to work. ATP synthase converts ADP into ATP.



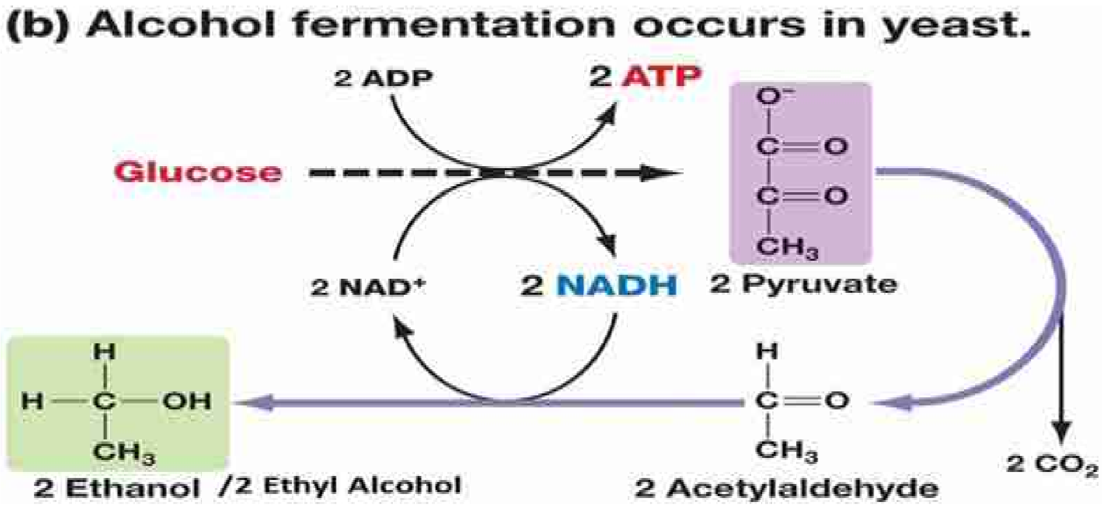
Anaerobic Respiration: Fermentation

This occurs after glycolysis when oxygen absents, thus anaerobic process. Fermentation releases energy from food molecules in absence of oxygen. In this process cells convert NADH to NAD+ by passing high-energy electrons back to pyruvic acid. Now glycolysis has NAD+ and can continue producing ATP. There are 2 types of fermentation:

→ Alcoholic fermentation

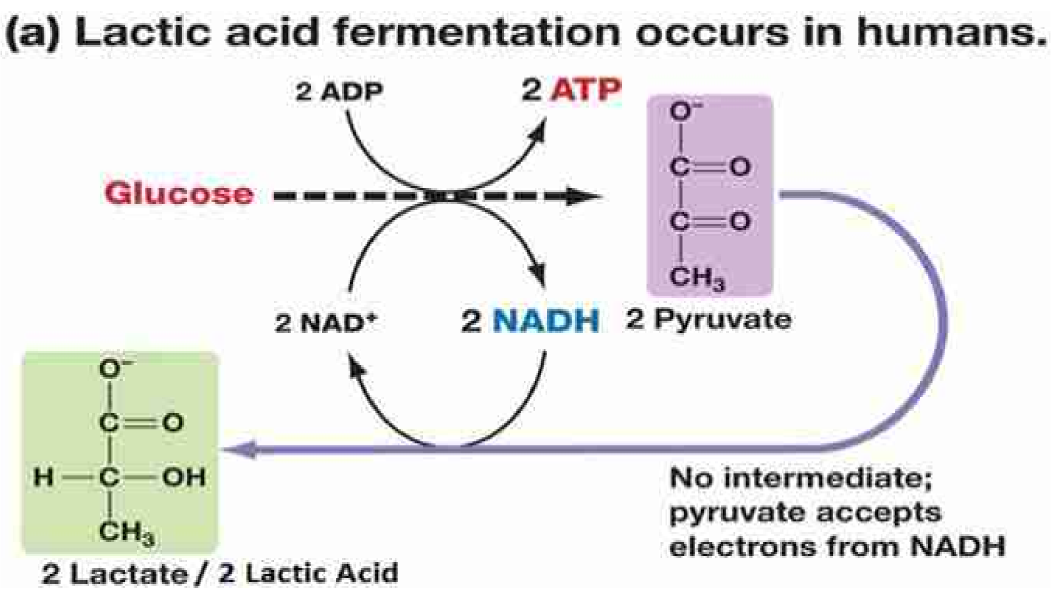
Yeast and a few other microorganisms use alcoholic fermentation, forming ethyl alcohol and carbon dioxide as wastes. Equation for alcoholic fermentation:

pyruvic acid + NADH = ethyl alcohol + CO_2 + NAD+



→ Lactic acid fermentation

Many cells convert accumulated pyruvic acid from glycolysis to lactic acid. Lactic acid fermentation regenerates NAD+ so glycolysis can continue. Equation for lactic acid fermentation: pyruvic acid + NADH = lactic acid + NAD+. When your body cannot supply enough oxygen to muscle tissues during exercise, this is produced. Without oxygen the body is unable to produce all the ATP it requires, so lactic acid fermentation takes over. Running, swimming, or riding a bike as fast as you can = large muscles in your legs and arms that quickly run out of oxygen. Muscles begin to rapidly produce ATP by lactic acid fermentation. The buildup of lactic acid fermentation causes a painful burning sensation making your muscles feel sore.



UNIT 4: Micro-organisms

Micro-organisms are tiny living organisms that are usually too small to be seen with the naked eye. To see them we need to use a microscope. Most micro-organisms are unicellular, although some do contain more than one cell. There are five main groups of micro-organisms. These groups are: protozoa, fungi, bacteria, algae and viruses.

1. Protozoa

Protozoa are eukaryotes and unicellular organisms that lack a cell wall. Most of them are motile (able to move), and include organisms such as *Amoeba*, *Plasmodium* and *Paramecium*.

2. Fungi

They are eukaryotes and have non-cellulose cell wall. They consist of **yeasts** and **moulds**. They obtain their food from other dead or living organisms. They are extremely important as decomposers, breaking down animal and plant material and returning nutrients to the environment.

- **Yeasts** are single-celled organisms. Each yeast cell has a nucleus, cytoplasm and a membrane surrounded by a cell wall. The main way in which yeasts reproduce is by asexual **budding** – splitting to form new yeast cells. These include brewer's yeast and baker's yeast (*Saccharomyces*) as well as the yeast that causes thrush in humans (*Candida*).
- **Moulds** are fungi that are made up of minute, thread-like structures, producing fruiting bodies containing spores. They produce a mycelium. **Mycelium** is the collection of very fine strands that makes up a fungus. Each strand is called a **hypha** (plural **hyphae**). They release enzymes from these strands that digest whatever the fungus is growing on. The hyphae are not 'compartmentalized' into cells; each is 'multinucleate' – the cytoplasm contains many nuclei. The products of digestion are then absorbed into the fungus to help with its growth and reproduction. Some fungi live on or in living organisms as **parasites**. Others live on dead material as **saprobionts**.

3. Algae

Algae are an important group of organisms. Many are large (the seaweeds are all algae), but some algae are unicellular. They obtain their nutrition using photosynthesis. The unicellular algae are part of the **plankton**, providing food for fish and other larger organisms. Some unicellular algae are motile – they can move. For example, an alga called *Chlamydomonas* has two flagella.

4. Viruses

Viruses are even smaller than bacteria. The basic virus is not even a cell – it has no nucleus and no cytoplasm – but it does have genetic material surrounded by a protein coat. They usually have regular geometric shapes. Viruses cannot independently carry out any of the processes common to all living organisms. They can only reproduce by taking over another living cell. So they are all **parasites**. As far as we know, all naturally occurring viruses cause disease.

5. Bacteria

Bacteria are single-celled organisms and prokaryotes. They have no true nucleus. They are much smaller than the smallest animal and plant cells. All bacteria do have a cell wall made from a substance called **peptidoglycan**, which makes it rigid, a cell membrane, cytoplasm, ribosomes and the genetic information (DNA) but this is not contained in a nucleus. Some bacteria have additional features like flagella to help them move, protective slime capsules, etc.

Bacteria also come in a variety of different **shapes**, **arrangements** and **sizes**. Bacterial cells are usually between 1 and 10 µm long, whereas eukaryotic cells are between 10 and 100 µm long.

Bacterial cells are sometimes found singly; sometimes two cells are stuck together; and sometimes the cells exist in chain. Bacterial cells come in three main shapes:

- ✓ **cocci** (singular, coccus) – spherical bacteria
- ✓ **bacilli** (singular, bacillus) – rod-shaped bacteria
- ✓ **spirochaetes** – spiral or corkscrew-shaped bacteria

The other way of classifying bacteria is based on their response to **Gram stain**. It is a test for classifying bacteria and named after Hans Christian Gram, who developed the technique in 1884. Because it produces different results with different types of bacteria, it is called a **differential stain**. There are four stages to make a Gram stain:

- ➢ Firstly, you stain all the bacteria on the slide with **crystal violet**, the primary stain.
- ➢ Then you use **Gram's iodine** as a mordant and leave it on the slide for 1 minute. This combines with the crystal violet in the cell to form a violet-iodine complex.
- ➢ Without washing off the Gram's iodine you now add 95% **ethanol**, which acts as a decolouriser. It washes the primary stain out of some types of bacteria but not others. You then rinse the slide in water until no more colour washes off.
- ➢ Finally, you use a secondary or counterstain called **safranin**. This is a basic dye that stains the decolourised bacteria red. Leave this on for one minute and then wash off with distilled water.
- ➢ Blot the slide gently dry and observe under the microscope.

This test gives two categories. The bacteria that are easily decolourised and so stain **red** are known as **Gram-negative bacteria**. The bacteria that keep the primary stain and so stain **purple** are called **Gram-positive bacteria**. The difference is due to the structure of the cell wall of the different bacteria. Gram positive bacteria have thick peptidoglycan in their cell walls. However, Gram-negative bacteria have much less peptidoglycan in their cell walls. **Peptidoglycan** is a complex molecule made from sugars and amino acids. It has a mesh-like structure and is found in bacterial cell walls. This is the part of the wall that absorbs the stain. Gram-negative bacteria also have an **outer membrane** outside the peptidoglycan cell wall, which Gram-positive bacteria do not have. This outer membrane secretes **endotoxins** (a type of toxin that is a structural component of these bacteria) and is also quite resistant to many antibiotics. This makes diseases caused by Gram-negative bacteria more difficult to treat. Gram-negative bacteria cause more serious diseases, although there are exceptions – the bacterium that causes tuberculosis is a Gram-positive bacterium.

The ecology and uses of bacteria

Whilst some bacteria cause disease, many are harmless and some are actively useful to people. Bacteria are found in every ecosystem. In fact, you contain millions of bacteria, which live both on your skin and inside your body. Most of these are found in the large intestine.

Bacteria are important because they:

- cause diseases
- are used in many industrial processes
- recycle mineral elements such as carbon, nitrogen and sulphur through ecosystems

The germ theory of disease

In the 17th century a Dutchman, Anton van Leeuwenhoek, designed the first microscope. Robert Hooke improved microscopes so much in the 19th century that people could see the tiny organisms. In the mid-19th century, Pasteur showed that micro-organisms in the air caused wine to go ‘sour’. In the 1860s, Lister showed that carbolic acid (phenol) acted as a disinfectant, and prevented disease in bones following surgery. In 1880, Robert Koch identified the micro-organisms that cause tuberculosis and cholera.

The theory that disease can be caused by micro-organisms is called the **germ theory**. Organisms that cause disease are called **pathogens**. **Infectious disease** is caused by a living organism entering or infecting another living organism. They are sometimes called **communicable diseases** because they can be transmitted or communicated from one person to another.

Koch’s postulates

It is a sequence of experimental steps that describes the germ theory of disease and involves:

1. The micro-organism must always be present when the disease is present, and should not be present if the disease is not present.
2. The micro-organism can be isolated from an infected person and then grown in culture.
3. Introducing such cultured micro-organisms into a healthy host should result in the disease developing.
4. It should then be possible to isolate the micro-organism from this newly diseased host and grow it in culture.

Different micro-organisms cause disease in different ways:

- **Bacteria** release toxins as they multiply. Some bacteria invade and grow in the tissues of organs, causing physical damage. Bacterial diseases can be treated with **antibiotics**.
- **Viruses** enter living cells and disrupt the metabolic systems of the cell. Viruses cannot be treated with antibiotics.
- **Fungi** secrete enzymes that digest substances in the tissues where they grow. Growth of hyphae also physically damages the tissue. Some fungi also secrete toxins. Others can cause an allergic reaction
- **Protozoa** cause disease in many different ways.

Reservoir of infection

Reservoir of infection is any person, animal, plant, soil or substance in which an infectious agent normally lives and multiplies. The reservoir typically harbours the infectious agent without showing symptoms of the disease and serves as a source from which other individuals can be infected. People acting as the reservoir of infection are sometimes called **carriers** of the disease.

The main methods of disease transmission

- ✓ **Droplet infection**: Many of these diseases are 'respiratory diseases' – diseases affecting the airways of the lungs. The organisms are carried in tiny droplets through the air when an infected person coughs or sneezes. They are inhaled by other people.
- ✓ **Drinking contaminated water**: They infect regions of the gut.
- ✓ **Eating contaminated food**: The organisms initially infect a region of the gut.
- ✓ **Direct contact**: Many skin infections, such as athlete's foot, are spread by direct contact with an infected person or contact with a surface carrying the organism.
- ✓ **Sexual intercourse**: Organisms infecting the sex organs can be passed from one sexual partner to another during intercourse.
- ✓ **Blood-to blood contact**: Many of the sexually transmitted diseases can also be transmitted by blood-to-blood contact. Drug users sharing an infected needle can transmit AIDS.
- ✓ **Animal vectors**: Many diseases are spread through the bites of insects. Mosquitoes spread malaria and tsetse flies spread sleeping sickness. Flies can carry micro-organisms from faeces onto food.

Other types of disease

The WHO's definition of **health** is a 'state of complete physical, mental and social well-being'. Definition of disease might be a condition with a specific cause in which part or all of a body is made to function in a non-normal and less efficient manner. Diseases can be categorised into:

- **Infectious diseases** caused by the entry of some organism into the body.
- **Human induced diseases** are diseases that arise as a result of a person's lifestyle (heart disease).
- **Degenerative diseases** often result from the ageing process. E.g. arthritis.
- **Genetic diseases** are diseases that result from the action of mutated genes. E.g. haemophilia
- **Deficiency diseases** are diseases that result from a lack of a nutrient in our diet. E.g. scurvy
- **Social diseases** are conditions that result from social activities. E.g. alcoholism
- **Multifactorial** describes a condition that is affected by the interaction of many factors. It does not fit neatly into any one category. E.g. atherosclerosis
- **Functional disease** is 'malfunction' of an organ or system, without there being any obvious damage or physical sign of disease in the organ. E.g. heart disease.

The role of bacteria in recycling minerals through ecosystems

Many bacteria are decomposers. When organisms die, these bacteria break down the complex molecules that are found in the bodies of the dead organisms into much simpler molecules. Many elements are recycled in this way, including: carbon, nitrogen, sulphur, and phosphorus.

The nitrogen cycle

The element nitrogen is found in many important organic molecules in all living organisms. These include: **proteins**, **DNA**, **RNA**, **ATP** and many others. Here are important microbes in nitrogen cycle.

- ➢ **Nitrogen-fixing bacteria** (*Rhizobium*): Nitrogen gas is fixed into forms other organisms can use (e.g. ammonium).

- **Ammonifying bacteria** (decomposers): The decomposers break down proteins in dead organisms and animal waste releasing ammonium ions, which can be converted to nitrates.
- **Nitrifying bacteria**: Nitrification is a two-step process. Ammonia or ammonium ions are oxidised first to nitrites (*Nitrosomonas*) and then to nitrates (*Nitrobacter*) which is the form most usable by plants.
- **Denitrifying bacteria** (*Pseudomonas*): Nitrates are reduced to nitrogen gas, returning nitrogen to the air and reducing the amount of nitrogen in the soil.

The sulphur cycle

Sulphur is found in fewer types of organic molecule than nitrogen, but it is found in many proteins. Important processes include:

- **Decomposition**: Sulphur is released from proteins of dead matter as hydrogen sulphide by anaerobic *Desulphovibrio*.
- **Oxidation of hydrogen sulphide**: Hydrogen sulphide is oxidised to release sulphur by anaerobic photosynthetic sulphur bacteria.
- **Oxidation of sulphur**: Sulphur is oxidised to sulphate ions by aerobic non-photosynthetic sulphur bacteria.

The use of bacteria in industrial processes

1. Food and beverage fermentation

Many micro-organisms are very useful to us and are used in making foods, such as bread, injera, ergoo (yoghurt) and ayib, and in producing alcoholic drinks, such as beer, wine and tej and as well as many other products.

2. Production of vinegar

Vinegar is a dilute solution of ethanoic acid (acetic acid) in water. It also contains other substances that give the vinegar its flavour. Vinegar is produced by fermenting beer, wine or cider for a second time. A culture of a special bacterium called *Acetobacter* is used. Vinegar is used in two main ways:

- to flavour foods and to preserve foods.

3. Producing antibiotics

Antibiotic is a drug that kills bacteria. The first antibiotics came from fungi. Today, they are increasingly being made using genetically modified bacteria in huge fermenters.

4. Sewage treatment

All types of sewage treatment rely on the action of a range of microorganisms to oxidise the organic matter present in sewage. There are two main methods:

- the **percolating filter** method and the **activated sludge** method

i. In the percolating filter method:

- sewage is screened and allowed to stand in settlement tanks

- it is then allowed to trickle through a bed of stones, each of which is covered in a layer of micro-organisms (bacteria, fungi and protozoa)
- as the sewage trickles through the filter bed, the microorganisms digest the organic matter and absorb the products
- by the time the liquid reaches the bottom of the filter bed, the polluting organic matter has all been removed

ii. In the activated sludge method:

- sewage is screened and allowed to stand in settlement tanks
- it is then pumped into treatment tanks, where:
    - **activated sludge**, rich in micro-organisms, is added
    - **oxygen** is blown through the mixture
- in the oxygenated mixture, the micro-organisms from the added activated sludge oxidise the polluting organic matter, reproducing as they do so
- some of the sludge formed is recycled to 'seed' new tanks.

Genetically modified bacteria (transgenic bacteria)

Genetic engineering is the practice of transferring genes from one organism to another organism (either belonging to the same species or belonging to a different species). This is done by taking DNA from the first organism and transferring it to the second organism. **Vector** is a means of transferring something. In genetic engineering, viruses and plasmids are used as vectors to transfer genetic information between different organisms

Bacteria can be genetically modified by transferring a gene from another organism; the newly formed transgenic bacterium is then able to carry out the process specified by its new gene. The development of three main techniques made genetic engineering possible.

i. The discovery that genes can be 'cut' out of a DNA molecule using enzymes called **restriction endonucleases**.
ii. The discovery that genes can be inserted ('tied') into another DNA molecule using a **ligase enzyme**.
iii. Genes can be transferred into other cells using **vectors**. These are usually either plasmids (small pieces of circular DNA found in bacteria), or viruses.

Genetically modified or transgenic bacteria can produce insulin, human growth hormone, antibiotics, enzymes for washing powders, human vaccines, such as the vaccine against hepatitis B, etc.

Genetic engineering of plants

Genetic engineering of plants posed problems for biologists, as plant cells will not accept plasmids in the same way as bacterial cells do. However, they discovered that one particular bacterium, called *Agrobacterium tumefaciens*, regularly infects plant cells. This bacterium can act as a vector to carry genes that have been inserted into a genetically modified *Agrobacterium* into plants.

However, *Agrobacterium* can't be used to genetically modify all types of plant. It will not infect cereals such as maize. To solve this problem, biologists developed the **gene gun**. is literally shoots the genes into cells of plants, using as 'bullets' tiny pellets of gold that are covered in DNA.

Viruses

Thee particle of a virus is called a **virion**. All virions contain at least two components: a **protein shell** or **capsid** and **DNA** or **RNA** as the genetic material. Some also have: a **membrane** made from lipids and proteins outside the capsid and other proteins and enzymes inside the capsid.

Viruses are much smaller than even the smallest bacterium. Most are between 0.01 and 0.1 μm in length or diameter. Nucleus and other cell organelles are absent. Because they do not have the major organelles that are present in living cells, virus particles can't carry out any of the normal metabolic processes of cells, such as:

- ✓ respiration, protein synthesis, DNA replication, photosynthesis, active transport, facilitated diffusion, and any other process requiring control by enzymes or the presence of proteins.

As a result, all viruses are **parasites**. The only way they can reproduce is to invade cells, 'hijack' the normal metabolic processes of those cells, and make the cells produce more virus.

Classification of viruses

They can be classified into three main groups, based on the nature of their **genetic material** and the way in which it is expressed. These groups are:

- o **DNA viruses** – contain genetic information stored in the form of DNA. For example, Herpes simplex (causes cold sores)
- o **RNA viruses** – contain genetic information stored in the form of RNA. For example, H1N1 virus (causes swine flu)
- o **Retroviruses** – contain RNA, but replicate in a different way. When they infect cells, they release into the cells their RNA and an enzyme that causes it to be 'reverse-transcribed' into DNA. For example, HIV (causes AIDS)

DNA is quite a stable molecule, is not very reactive with other molecules, and replicates very accurately. In contrast, RNA is quite unstable and makes frequent mistakes during copying. e unstable nature of RNA allows RNA viruses to evolve far more rapidly than DNA viruses, frequently changing their surface structure.

Viruses can also be classified by the type of **organism they infect**:

- o animal-infecting viruses
- o plant-infecting viruses
- o bacteria-infecting viruses – these are called **bacteriophages** (look rather like a lunar landing module)

Virus multiplication

There are three different life cycles in viruses:

- ✓ **Lytic life cycle** causes the rupture (lysis) of the host cell. It causes the cell to burst and release the viruses all at once.
- ✓ **Lysogenic life cycle** infection causes the virus to enter a latent state where its DNA is reproduced with the host DNA. Each time the cell divides, the DNA is replicated, and each daughter cell gets a copy of the cell's DNA, which now includes the virus DNA. No new viruses are formed.

- ✓ **Chronic release life cycle** infection causes viruses to be released without killing the host cell. A few at a time are released by exocytosis through the plasma membrane.

Modes of virus transmission

Different viruses enter cells in different ways.

- o The bacteriophage injects just its DNA; the rest of the virus remains outside the cell.
- o Many (but not all) animal viruses manage to get the whole virus inside the cell. This is done by using the process of endocytosis.

HIV and AIDS

Human immunodeficiency virus (HIV) is the causative agent of **AIDS (acquired immune deficiency syndrome)**. HIV is one of the retroviruses. It has RNA as its genetic material. This is transcribed to DNA by the enzyme **reverse transcriptase**, which HIV contains together with the RNA.

HIV targets cells that form part of the immune system. Its main target is a type of cell called a **CD4 T-lymphocyte**. These cells are also called T-helper cells, because they help other cells in the immune system to mount an immune response to pathogens in the body. Without this response, pathogenic micro-organisms can multiply in the body and cause disease.

- **Lymph** is fluid containing white blood cell (WBC) which flows through the lymphatic system. **Lymphocytes** are WBCs forming antibodies against microbes. There are two main types of **white blood cells** in the immune system. **T-cells** bind to the antigens on the invading micro-organism and destroy it. **B-cells** make **antibodies** which bind to the antigen and destroy it.

HIV has **spikes** on its surface, the heads of which are made from the glycoprotein known as **gp120**. This binds with CD4, a protein that protrudes from various types of human cell. Once the virus has attached to a cell, it can go on to the next stage and merge with the host cell.

Besides the T-helper cells, there are other types of cell that carry CD4 on their surface – such as **macrophages** and some **natural killer cells**.

How does HIV reproduce and cause AIDS?

After HIV has bound to the CD4 receptors on the surface of the T-helper cell, the following events occur:

- ➢ It fuses with the plasma membrane and then releases its RNA and reverse transcriptase enzyme into the cell.
- ➢ The reverse transcriptase converts the RNA into DNA.
- ➢ The viral DNA becomes incorporated into the cell's own DNA.
- ➢ The viral DNA is transcribed to viral RNA, which starts producing viral proteins, including the enzyme reverse transcriptase.
- ➢ The RNA, proteins and reverse transcriptase molecules are assembled by the cell into new HIV particles that escape by **budding** from the cell membrane – this is an example of **chronic release**.
- ➢ The viruses then infect other T-helper cells.

Because of the drastic reduction in the number of T-helper cells, the immune function is severely reduced and many opportunistic infections may occur. The period when the body keeps replacing the CD4 lymphocytes as fast as they are destroyed is called the **latency period**. This can last for many years.

AIDS is a disease that causes its victim's immune system to degenerate leaving them vulnerable to infectious diseases and some types of tumour.

Treatment of AIDS

There is no cure for AIDS and, as yet, no vaccine to give immunity against infection. AIDS is often best treated by **HAART (High Activity Anti-Retroviral Therapy)** in which several anti-retroviral drugs are combined to target different stages of the HIV infection process.

The social and economic impact of AIDS

Within families, the infection of family members is often not a subject for discussion. This is because of:

- shame associated with admitting to being infected
- fear of being isolated (or putting the family under pressure)
- fear of losing a job, etc.

Many affected families find themselves in a vicious circle:

- an increasing amount of money is needed for medical treatment and burials, but
- the number of breadwinners is decreasing.

Nationally, AIDS has a serious economic impact in two main areas:

- ✓ labour supply – the loss of young adults in their most productive years will affect overall economic output
- ✓ costs:
    - direct costs including expenditure for medical care, drugs and funeral expenses
    - indirect costs including lost time due to illness, recruitment and training costs to replace workers, and for care of orphans
    - if costs are financed out of savings, then the reduction in investment could lead to a significant reduction in economic growth

Stigma and discrimination: It is important to care for and support people who are living with HIV/AIDS. If the stigma of having the disease is removed, people will be more willing to have an HIV test. This means they can look after their health and reduce the risk of spreading the disease.

Care and support: If people living with HIV/AIDS can receive plenty of care and support within their own communities, this will help them to live longer and more healthily. It will also encourage others to be tested for the virus.

Voluntary counseling and testing services (VCTs) are very important in educating and informing people about HIV/AIDS and supporting them both before and after an HIV test.

Responsible sexual behaviour and life skills: It is important to develop personal skills such as assertiveness, decision making and problem solving to help you prevent HIV both personally and in society. Healthy lifestyle choices, e.g. abstinence, faithfulness to a partner and using a condom when having sex, all reduce the risk of becoming infected with HIV/AIDS. Male circumcision also reduces the risk of males acquiring the disease.

The immune system

Immune system is the system in the body which protects you against invading microorganisms and foreign proteins.

Antigens are proteins found on the outer surface of all cells or pathogens. When a pathogen gets into the body the antigens on the surface stimulate a response by the immune system, and the WBCs (lymphocytes) produce **antibodies** to disable the pathogen. Other WBCs (the phagocytes) then engulf and digest the disabled pathogens. **Immune** is protected from disease by the body having fought it off successfully previously.

Control of micro-organisms

Sterilisation is the process of killing micro-organisms on an object by making it safe to handle without fear of contamination. There are a number of different ways we can sterilise things. These include the use of:

- ✓ High temperatures or heat, disinfectants and antiseptics.

Using of heat to control micro-organisms

- **Boiling** is the simplest and best known method of sterilising thing, using heat. The objects are placed in boiling water (at 100 °C) and kept there for some time. It does not kill all microorganisms.
- The **autoclave** is used at 15 pounds per square inch of pressure, which raises the boiling point of water to 121 °C from 15–45 minutes of 'cooking'. This temperature is enough to kill all micro-organisms and sterilise the equipment.
- **Ultra high temperature (UHT)** is a way of treating food with intense heat to kill all the micro-organisms on it. The temperatures used range from around 135 °C to 150 °C for 2–6 seconds.
- **Pasteurisation** is not a method of sterilisation, because it does not kill all the micro-organisms in the food. It makes the food safe. The food is heated to either 71.6 °C for at least 15 seconds or 62.9 °C for 30 minutes.
- **Dry heat**, over a long time, kills all micro-organisms. Special **ovens** used in microbiology use temperatures of 171 °C for an hour, or 160 °C for two hours, etc.
- **Incineration** is burning substances at high temperatures in the air – also kills micro-organisms.

A chemical approach to controlling micro-organisms

Possible pathogens can be attacked chemically in a number of ways. For example, antiseptics and disinfectants kill microorganisms on the skin and in the environment around us.

- o A **disinfectant** is a chemical agent that is applied to an inanimate object to kill micro-organisms. In other words, it is used on floors and surfaces, not on people. Disinfection means reducing the number of living micro-organisms present in a sample. Bleach and calcium hypochlorite are common and widely used disinfectants.
- o **Antiseptics** are chemical agents that are applied to living tissue to kill micro-organisms. They are disinfectants for the skin.
- o **Antibiotics** are chemicals which kill bacteria but do not damage human cells. Penicillin was the first antibiotic to be discovered, and it is still in use today. Antibiotics have no effect on diseases caused by viruses.

Many micro-organisms can be grown in the laboratory. They are grown on culture medium. Culture medium must contains all the nutrients such as carbohydrate to act as an energy source, along with various mineral ions and in some cases extra protein and vitamins. The nutrients are often contained in an **agar** medium – agar is a substance which dissolves in hot water and sets to form a jelly.

Acquired immunity

Naturally acquired active immunity: Occurs in response to the exposure of antigens during the course of daily life.

Naturally acquired passive immunity: The natural transfer of antibodies from mother to her unborn baby (fetus) via the placenta or infant when mother breastfeeds her baby.

Artificially acquired active immunity: It is use of inactivated microorganisms or antigens to elicit a specific antibody response. **Vaccines** allow you to be protected from a disease without experiencing the serious effects of that illness. The immunity you need can be triggered artificially by the process known as vaccination (immunisation). Vaccination (immunisation) is the use of dead or weakened strains of pathogens to produce immunity to dangerous diseases. Your WBCs develop the antibodies to the disease. Vaccination is used to give immunity to a number of dangerous diseases. They include polio, tetanus, tuberculosis, and measles.

Artificially acquired passive immunity: It is the introduction of antibodies into the body. These antibodies come from an animal or person who is already immune to the disease. If you step on a rusty nail you are at risk of developing tetanus. If you are bitten by a dog, there is a risk of rabies. You can be given a vaccine which contains the antibodies you need to combat the specific pathogen.

Vaccines produced can be

- ✓ **Live vaccines** are made from living micro-organisms which have been treated to weaken them.
- ✓ **Dead vaccines** use micro-organisms which have been killed.
- ✓ **The surface antigens** of the pathogen.

Diseases

Whereas many diseases are caused by bacteria, viruses and fungi, some of the most damaging diseases worldwide are caused by a range of quite different organisms – protoctista and tapeworms. **Parasites** are organisms that live on or in another and take their nourishment from it.

Tapeworm (*Cestoda*): They are flatworms. They do not feed off their host, but rather rob them of their digested food. They do not have a digestive system so they have to absorb nutrients directly across their skin (cuticle). They are parasites with at least two hosts, which can include human beings. They often enter the human system when a bladder worm is ingested in under-cooked meat. They have a head with fearsome-looking hooks and/or suckers and the worm uses these to attach firmly to the gut wall. The rest of the body is made up of about 1000 very thin segments, which contain the reproductive organs. Tapeworms can be treated with anti-worm medicines that kill them and they are then passed out in the faeces. Good sanitary conditions are recommended in preventing their spread.

Tuberculosis (TB) is a bacterial disease usually affecting the **lungs**, it is known as pulmonary TB. Other parts of your body can be affected – TB can infect your kidneys, lymph nodes, joints or bones. The causative agent is the bacterium called *Mycobacterium tuberculosis*. It is transmitted through the air. It can be asymptomatic. It may present with a low-grade fever, night sweats, fatigue, weight loss and a persistent cough. TB can be cured by a long course of antibiotics and prevented by vaccination. The most important way to stop the spread of tuberculosis is for TB patients to cover the mouth and nose when coughing.

The role of vectors in disease

A **vector** is an organism that transmits disease-forming micro-organisms from one host to another. Some organisms that act as vectors simply transport an infective organism from one host to another on its body – often the feet or mouthparts. A housefly is a good example. Some animals are **biological vectors**. They are needed as part of the life cycle of an infective organism. Another well-known example is the *Anopheles mosquito*, which carries the malarial parasite.

- ✓ **Malaria** is a mosquito-borne disease caused by single-celled protozoa called *Plasmodium* parasites. *Plasmodium* spends part of its life cycle in a mosquito and part in the human body. Malaria is spread by the bite of an infected female vector *Anopheles* mosquito. It causes fevers, chills and sweating and damage to the liver and red blood cells. Use of insecticide treated mosquito netting and mosquito repellents, having screens on doors and windows to prevent mosquitoes getting and reducing the amount of standing water can greatly reduce the numbers of people infected.

Acute watery diarrhea

Acute watery diarrhea (AWD) is also known as **gastroenteritis** can be caused by viruses, bacteria and protoctists. People usually become infected with AWD by taking in contaminated food or water. The most effective method of treating this disorder is rehydration with copious fluids containing electrolytes. Good sensible hygiene practices will minimise the spread.

- ✓ **Cholera** is a bacterial disease that affects the intestinal tract causing severe diarrhoea, vomiting and dehydration. It is caused by bacteria called *Vibrio cholerae*. The cholera germ is passed in the stool. It is spread by entering or drinking contaminated food or water. Infected people may experience mild to severe diarrhoea. It can kill very quickly if it is severe. It is a particular risk in areas of overcrowding with no proper sewage disposal.
- ✓ **Typhoid fever** is a bacterial infection of the intestinal tract and sometimes the bloodstream. The bacterium that causes typhoid is a unique human strain of salmonella called *Salmonella typhi*. The germs are spread by eating or drinking contaminated water or foods. Symptoms may be mild or severe. Antibiotic treatment is recommended. Strict attention to food and water precautions is important. A vaccine is available.

Sexually transmitted diseases (STDs)

Sexually transmitted diseases (STDs) are infectious diseases that are spread through sexual contact. They were previously known as **venereal diseases (VD)**.

- ✓ **Gonorrhoea** is caused by the bacterium *Neisseria gonorrhoeae*. It is spread through sexual contact, whether this is vaginal, anal or oral sex. Infected men will have burning while urinating and yellowish-white discharge from the penis. Women with symptoms will have a vaginal discharge and burning while urinating. Antibiotic treatment is prescribed. Responsible sexual practices are also recommended.
- ✓ **Syphilis** is a bacterial infection, caused by the spiral-shaped *Treponema pallidum*. It is spread is by sexual contact with someone already infected with the bacteria. The symptoms of syphilis occur in stages called primary, secondary and late. In the earlier stages it can be treated, but in the late stages it cannot. It is treated with penicillin or tetracycline. If untreated, it can lead to destruction of soft

tissue and bone, heart failure, blindness and a variety of other conditions. It can be prevented by healthy sexual practices.

- ✓ **Chancroid** is a bacterial sexually transmitted infection. It is caused by the bacterium *Haemophilus ducreyi*. It produces painful ulcers in the genital area and in the lymph glands of the groin. It is treated by antibiotics. It can be prevented by healthy sexual practices. Having chancroid greatly increases your risk of becoming infected by HIV/AIDS.

Modern and traditional medicines

Both modern and traditional medicines can be very useful in relieving symptoms and curing diseases. It is important to use medicines carefully, taking the right dose, keeping them at the right temperature, keeping them away from children and avoiding self-medication except for the simplest conditions. If you do not follow the instructions when you are given antibiotics, antibiotic-resistant bacteria may evolve which can be very serious indeed.

Unit 5: Genetics

DNA

- stable
- large molecule
- Nucleic acids are polymers of **nucleotides** made of sugar (sugar is Deoxyribose) + phosphate + nitrogenous base
- nucleotides connected by phosphodiester bonds
- **double helix**: 2 polynucleotide strands connected by hydrogen bonds. Anti-parallel nature of the two **of DNA strand**
- polynucleotide strands are **complementary**

Nitrogenous bases include

purines:

- Adenine (A) and Guanine(G),
- double ringed structure

pyrimidines:

- Thymine(T), Cytosine(C),
- single ring structures

RNA

- Nucleic acids are polymers of **nucleotides**. **Which are made of sugar (sugar is ribose) + phosphate + nitrogenous base**
- Quickly degraded
- small molecule
- single strand
- contains Uracil instead of thymine

Nitrogenous bases include

purines:

- Adenine and Guanine,
- double ringed structure

pyrimidines:

- Uracil Cytosine,
- single ring structures

1. DNA replication

- The ability of DNA to make copy of itself which is the basis for reproduction and inheritance . Each formed new DNA molecule contains one strand from the original (old) DNA and one new strand DNA molecules the Two DNA molecules are identical

  DNA is double helix of two strands, and each strand of the original DNA molecule serves as a template for the production of the complementary strand, a process referred to as semiconservative replication. Cellular proofreading and error-checking mechanisms ensure near perfect fidelity for DNA replication.

- Several Enzymes are involved in this process and the main stages are. replication enzymes assemble on the DNA into a complex molecular machine called the **replisome**

Enzymes

- **Topoisomerase enzyme-**remove the super coiling that is building up in the double-stranded regions.
- DNA helicase enzyme - break H-bonds to reveal two single strands and unwind (open) the helix DNA
- **RPA (*replication protein A*)** is a eukaryotic stabilize single strand DNA, equivalent with **Single-Strand Binding Proteins(SSBP)** attach and keep the 2 DNA strands separated and untwisted in prokaryote
- **DNA polymerase** follows the helicase enzyme along each single-stranded region, which acts as a template for the synthesis of a new strand.
- **Primase** is the enzyme that synthesizes the RNA Primer
- **DNA Ligase-**Re-anneals the semi-conservative strands and joins Okazaki Fragments of the lagging strand.
- **Telomerase** Lengthens telomeric DNA by adding repetitive nucleotide sequences to the ends of **eukaryotic chromosomes**. This allows germ cells and stem cells to avoid the shortening of chromosome during cell division

Replication process

Initiation

This process is initiated at particular points in the DNA, known as origins which are targeted by initiator proteins. In *E. coli* this protein is DnaA; in yeast, this is the origin recognition complex

Sequences used by initiator proteins tend to be "AT-rich" (adenine and thymine bases), because A-T base pairs have two hydrogen bonds (rather than the three formed in a C-G pair) which are easier to unzip

Once the origin has been located, these initiators recruit enzymes

Elongation

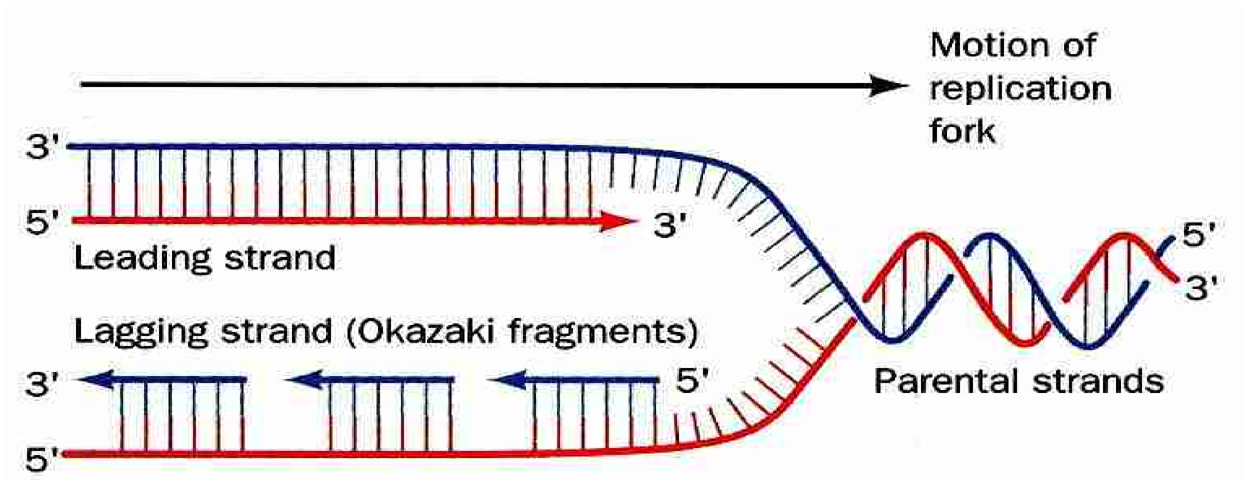
DNA polymerase has 5'-3' activity and requires a free 3' hydroxyl group before synthesis can be initiated (the DNA template is read in 3' to 5' direction whereas a new strand is synthesized in the 5' to 3' direction). Four distinct mechanisms for initiation of synthesis are recognized:

Leading strand

- is the strand of nascent DNA which is being synthesized in the same direction as the growing replication fork. A polymerase adds complementary nucleotides to the nascent leading strand on a continuous basis.
- The polymerase involved in leading strand synthesis is DNA polymerase III (DNA Pol III) in prokaryotes. In eukaryotes, leading strand synthesis is thought to be conducted by Pol δ.

Lagging strand

- The lagging strand is the strand of nascent DNA whose direction of synthesis is opposite to the direction of the growing replication fork.
- The lagging strand is synthesized in short, separated segments. On the lagging strand *template*, a primase synthesize of a short complementary RNA primer. A DNA polymerase extends the primed segments, forming Okazaki fragments. The RNA primers are then removed and replaced with DNA, and the fragments of DNA are joined together by DNA ligase.

- Primer removal is performed by DNA polymerase I (in prokaryotes) and Pol δ (in eukaryotes). Eukaryotic primase is intrinsic to Pol α. In eukaryotes, pol ε helps with repair during DNA replication
- **Termination**
- Eukaryotes have linear chromosomes; DNA replication is unable to reach the end of the chromosomes, but ends at the telomere region of repetitive DNA close to the ends. This shortens the telomere of the daughter DNA strand. Shortening of the telomeres is a normal process in somatic cells. As a result, cells can only divide a certain number of times .Within the germ cell line, which passes DNA to the next generation, telomerase extends the repetitive sequences of the telomere region to prevent degradation. Telomerase can become mistakenly active in somatic cells, sometimes leading to cancer formation.
- Termination requires that the progress of the DNA replication fork must stop or be blocked. Termination at a specific locus, when it occurs, involves the interaction between two components: (1) a termination site sequence in the DNA, and (2) a protein which binds to this sequence to physically stop DNA replication
- 

DNA replication mechanism
- replicate semi-conservatively.
- Each formed new DNA molecule contains one strand from the original (old) DNA and one new strand DNA molecules
- Two DNA molecules are identical to

2. Protein Synthesis

- is the process in which cells make proteins.
- DNA store information
- RNA work as messengers

How protein is synthesized

- Code for protein synthesis is specified by DNA .this code called **Genetic code :** triplet /sequence of three bases/. That code specific amino acid
- Since there are 4 bases, there is 43 = 64 possible codes
- only 20 amino acids are used to make all different proteins.
- Only one strands of a DNA carries the code for proteins (It is called sense strand or coding stand) and the other strand is non-coding or antisense strand.

Codon:

- **stop codons.-**Three triplets (UAA **-** UAG and UGA) do not code for amino acids . stop codes signify the end of the coding sequence
- **start codon -**In most prokaryotic and all eukaryote AUG
- **universal code –**same for organism. Example: TAT code**-** tyrosine in human, redwood tree, bacterium or in any organism
- **Degenerate code** –several codons have specify the same amino acid eg. GTT, GTC,GTA-code valine
- **Specific codon**: One codon codes for only one amino acid
- Example: UUU-code phenyl alanine, it cannot code for any other amino acid

Events during protein synthesis

i.Transcription –

- DNA code for protein is rewritten in a molecule of messenger RNA (MRNA)
- MRNA travels from nucleus to ribosome

ii. Translation –

- mRNA code is converted into a sequence of amino acids
- Free amino acids are transported from cytoplasm to ribosome by transfer RNA (tRNA) molecules
- Ribosome read mRNA code and assembles amino acids presented by tRNA into a protein .

DNA→ mRNA →protein

Transcription

- RNA polymerase binds with a section of DNA next to the gene to be transcribed.
- Transcription factors activate the enzyme. The enzymes —unwind and separate the strands of a DNA molecule.
- The polymerase assembles free RNA nucleotides on the complementary strand (antisense strand).
- mRNA (transcribed RNA) leaves the DNA; the strands of DNA rejoin & re-coil.
- RNA polymerase will read the information sequence on DNA template from $3' \rightarrow 5'$ direction,
- So RNA is synthesized antiparallel to DNA template i.e. from $5' \rightarrow 3'$ direction.

Step

- Initiation: transcription is initiated by the binding of RNA polymerase to a specific region **(promoter region)**.
- Elongation: Once RNA polymerase recognizes promoter region, it begins to synthesize a transcript (copy) of DNA template.
- Termination:
    - Ending of transcription
    - termination region which is recognized by: protein rho dependent factor and rho independent factor in prokaryotic
    - Rho dependent-G-c, rich hair pin loop
    - Rho independent- protein destabilizes interaction of mRNA and DNA
    - In eukaryotic-RNA polymerase II terminates

Translation

- mRNA code into a protein depends on the interaction within a ribosome between mRNA and tRNA has at one end a triplet of bases called anticodon
- The other end of tRNA molecule has an attachment site for the aminoacid that is specified by the mRNA codon
- Ribosomes are organized into large & small subunits. Within ribosome, there are three sites called A, P and E sites.
- The first two codons of the mRNA enter the ribosome and tRNA molecules (with amino acid attached) that have complementary anticodons to the 1st two codons of the mRNA bind to those codons.

- A peptide bond forms between amino acid carried by two tRNA molecules and dipeptide is transferred to the tRNA in the A-site.

- The Ribosome moves along the mRNA by one codon bringing the 3rd codon into the ribosome.

- The whole process is repeated until a "stop" codon is in position and translation is stopped.

Step

- Initiation-tRNA molecule with complimentary anticodon binds to codon on mRNA

- Elongation: AUG is always the start codon – it codes for the amino acid Methionine (Met)

    - Polypeptide formation begins

- Termination: Stop codon reached and translation stops

    - Release factor binds to stop codon; polypeptide is released

    - Ribosomal subunits dissociate

3. Cell division

- parent cell divides into two or more daughter cells.

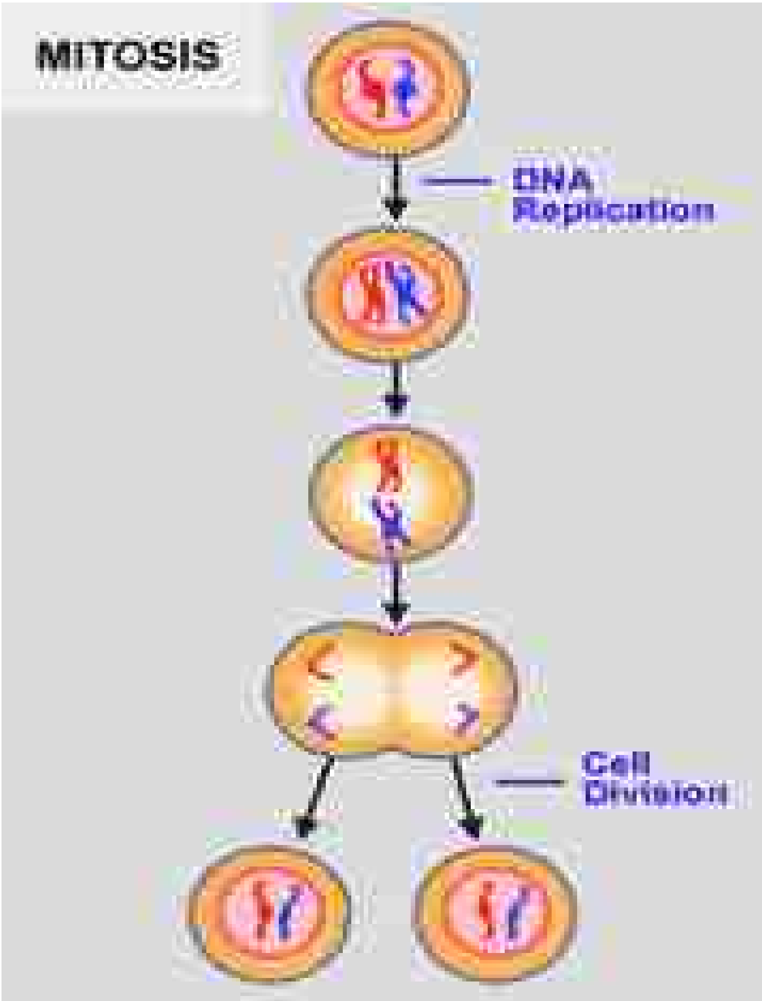
- there are two distinct types of cell division:

❖ mitosis,

- somatic division, whereby each daughter cell is genetically identical to the parent cell and Produce two daughter cells from one parent cell

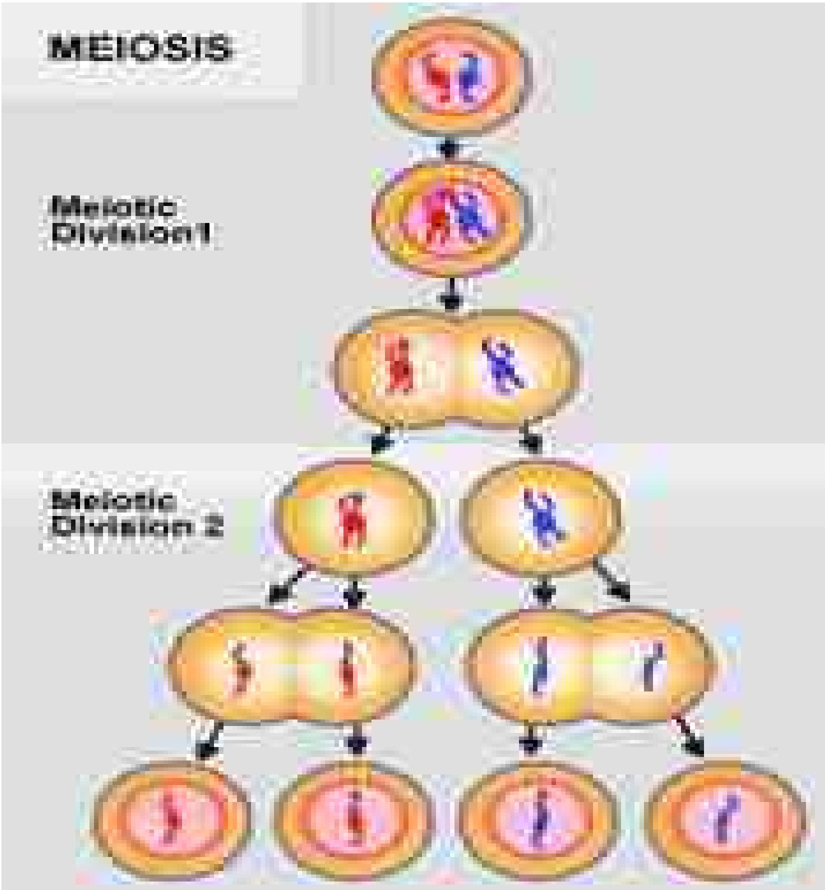
- For simple unicellular microorganisms such as amoeba, one cell division is equivalent to reproduction; an entire new organism is created. bacteria undergo a vegetative cell division known as binary fission and budding

- For multicellular organism allow continual construction and repair of the organism



❖ meiosis.

- a reproductive cell division, whereby the number of chromosomes in the daughter cells is reduced by half to produce haploid gametes
- results in four haploid daughter cells by undergoing one round of DNA replication followed by two divisions
- Homologous chromosomes are separated in the first division, and sister chromatids are separated in the second division



4. Mendelian genetics and patterns of inheritance

- traits are passed from one generation to the next, and sometimes skip generations
- By experimenting with pea plant breeding, Mendel developed three principles of inheritance that described the transmission of genetic traits, before anyone knew genes existed.
- The inheritance pattern is dominant and recessive. traits of generation i has passed down through the next generation is considered dominant, because it is observable in every generation.
- A characteristic may disappear in one generation, reappear in a subsequent one. This pattern of inheritance, in which the parents do not show the phenotype but some of the offspring do, is considered recessive.

Mendelian cross

- Mendel studied 7 characters (heritable features) each with its own distinctive trait (variant of that character)

<u>Character</u> <u>trait</u>

Seed shape --- Round (R) or Wrinkled (r)

Seed Color ---- Yellow (Y) or Green (y)

Flower color --- Purple (P) or white (w)

Pod Shape --- Inflated (I) or constricted (i)

Pod Color --- Green (G) or Yellow (g)

Flower position---Axial (A) or Terminal (a)

Plant Height --- Tall (T) or Short (t)

- Mendel started out with plant that is true bred.
  - Monohybrid, Dihybrid , trihybrid

Monohybrid

- In a monohybrid cross, the parent organisms differ in a one character.
- When Mendel allowed the F_1 plants to self-fertilize, the F_2 generation included both tall and short plants.
- The short trait, absent in the F_1, reappeared in the F_2.
- E.g. plant length(tall and short)

TTXtt

↓

F1   Tt

F2=F1XF1, TtXTt

↓

1/4TT, 2/4Tt, 1/4tt

phenotypic ratio=3:1

genotypic ratio:1:2:1

Mendel's laws

- Law of dominance : In a heterozygote, one allele may conceal the presence of another. This means the dominant allele is observed in the phenotype, recessive allele disappear

- Law of segregation: during the formation of gametes (eggs or sperm), the two alleles responsible for a trait separate from each other.
- law of Independent: Assortment alleles for *different* traits are distributed to sex cells (offspring) independently of one another.

Mutations

- Cause

❑ Mutation could occur spontaneously (accidentally) during duplication.

❑ induced mutations caused by mutagens.

- Types of mutation
    - Chromosome mutation -part/segment/ of a chromosome is change
    - Numerical change
        - polyploidy/-is a condition where an organism/ a cell has one complete set of extra chromosomes/an exact multiple of a complete set. Variation in number of chromosomes sets (one set of chromosome). E.g – Triploid ,Tetraploid
        - Aneuploidy – is a condition where an organism/a cell lost from or added to one or more chromosomes to/the normal set of chromosome . example: 2 n+1 = trisomy/47 chromosomes (Down‘s syndrome), 2n-1 = monosomics (turner syndrome/45chr), 2n+1+1 = double trisomy, 2n-2 – nullisomic, organisms that loss one homologous chromosome.
    - part/segment/ of a chromosome change
        - Deletion-in which chromosome segment removed
        - Duplication-segment of chromosome copied
        - Inversion-reversing the orientation of a chromosomal segment.
        - Insertion-segment of chromosome remove from one chromosomes and inserted to another. They are usually caused by transposable elements,
        - Translocation- interchange of genetic parts from non-homologous chromosomes.

    - Gene mutation
    - change(s) in the nucleotide/base sequence of DNA
      TYPE
    - Point mutation – a change in one base? in the DNA
        - Substitution – when one base in the sequence is replaced by the same number of bases (for example, a cytosine substituted for an adenine

- Inversion – when a base reverse
- insertion-base insert
- deletion-base removed

Unit 6: Evolution

Evolution means change, change in the form and behavior of organisms between generations. Evolution means **descent with modification**. So we can come up with a working definition of the process of evolution as:

The change in genetic composition of a population over successive generations, which may be caused by meiosis, hybridization, natural selection or mutation. This leads to a sequence of events by which the population diverges from other populations of the same species and may lead to the origin of a new species. It is the scientific theory used by biologists to study the genetic variation in a population. There are many theories about how life originated on the planet earth. Evolution, or change over time, is the process by which modern organisms have descended from ancient organisms.

The entire spectrum of life, ranging from microscopic organisms through developed forms to the most complex ones, is believed to have come about through the process of evolution. This process operates at the chemical, organismal and community levels.

The origin of life

Evolution is a process of gradual development from simpler forms through gradual changes. There are several theories and views regarding the origin of life on the Earth. Some of the major once are

Presented below:

- Special creationism
- Spontaneous generation
- Eternity of life
- Cosmozoan theory
- Biochemical origin

1.Special creationism Theory

Special creation theory attributes the origin of life to a divine event that was masterminded by the supernatural being, God. Special creation states that at some stage, some supreme being created life on Earth. Special creation is nearly always linked to religion, whereas an acceptance of evolution is linked to scientific thinking. There are fundamental differences between the two that mean it is unlikely that the difference between the scientific theory of evolution and special creation will ever be resolved. Science describes the natural world around us using a means of observation and empirical testing using instruments.

Religion mainly focuses on spiritual matters that, by their very nature, cannot be seen, touched or measured effectively. Religion deals with philosophical matter that relates to morality and concerns between humans and their God. Religion is less concerned with empirical observable facts and testable hypotheses but rather with faith, the belief in things that cannot be proven. Science relies on provable events; religion relies on believing in that which cannot be proven. There are different forms of creationism theory.

Young Earth creationism

This form of creationism today suggests that the Earth is only a few thousand years old. Young Earth creationists often believe the Earth was created in six 24-hour days. While they agree that the Earth is round and moves around the Sun, they interpret all geology in the light of Noah's flood.

Old Earth creationism

There are several types of creationism that are considered Old Earth. They vary in different aspects of how they explain the age of the Earth while still holding to the story found in Genesis. Those who believe in Old Earth creationism accept the evidence that the Earth is very old but still maintain that all life was created by God.

Day-age and gap creationism

These are similar in that each interprets the beginnings of the creation story as actually having taken much longer than six Earth days. Gap creation discusses a large gap between the formation of the Earth and the creation of all the animals and humans. The gap could be millions or billions of years. This gets around the scientific evidence that the Earth is several billion years old without having to believe in the process of evolution itself.

Progressive creationism

This type of creationism accepts the Big Bang as the origin of the Universe. It accepts the fossil record of a series of creations for all of the organisms catalogued. However, it does not accept these as part of a continuing process; each is seen as a unique creation. Modern species are not seen as being genetically related to ancient ones.

Theistic evolution/Evolutionary creationism

This view of evolution maintains that God 'invented' evolution and takes some form of an active part in the ongoing process of evolution. It also invokes the role of God in areas not discussed by science, like the creation of the human soul.

Intelligent design

This is the newest version of creationism and maintains that God's handiwork can be seen in all of creation if one knows where to look. Advocates of intelligent design offer sophisticated arguments, often based on cell biology and mathematics, to give the impression of complex scientific arguments and to create equal stature with mainstream scientific thought. These arguments attack different parts of evolutionary theory, with the idea that if one part of evolutionary theory can be found to be incorrect then it follows that all of evolution must be incorrect. The term intelligent design is used to mask the fact that it's a form of creationism cloaked in scientific-sounding ideas.

2. Spontaneous Generation = Abiogenesis Theory

This theory states that life has originated from non-living organic matter abiogenetically, i.e. without the intervention of living things.

Spontaneous generation suggests that life can evolve 'spontaneously' from non-living objects. It was only a few hundred years ago that people still believed this to be true. For example, people believed that rotting meat turned into flies and that wine produced bacteria as it went sour. Different scientists disprove this theory including the work of **Francisco Redi** to disprove the idea of rotting meat producing flies and the work of **Louis Pasteur** to finally show that not even micro-organisms could be produced by spontaneous generation. **Lazzaro Spallanzani** is also one of the famous scientist who disproved this theory.

3.The eternity of life theory

This theory regards life as eternal as matter itself. It asserts that life only change its form but is never created from dead (non-living) substances. Simply it states that life has no origin and has always existed. In this theory of life, there is no beginning and no end to life on Earth and so it neither needs special creation nor does it need to be generated from non-living matter. Supporters of this theory believe that life is an inherent property of the Universe and has always existed as has the Universe. At the time when such theories were being propounded, many eminent scientists including Albert Einstein believed that the Universe was unchanging. They reasoned that 'if life is found today in an unchanging Universe, then it must always have been there'.

4.The cosmozoan theory = Panspermia theory

It asserts that life has an extra –terrestrial origin. According to this theory, life has reached this planet Earth from other cosmological structures, such as meteorites, in the form of highly resistant spores. This idea was proposed by Richter in 1865 and supported by Arrhenius in 1908 and by other contemporary scientists. The theory did not gain any significant support as it lacks evidence. It is strongly linked to the 'eternity of life' theory of the origin of life on Earth.

5.The biochemical theory

This theory states that the first form of life evolved from a set of chemicals. The current ideas we have about how life may have evolved on Earth as a result of biochemical reactions (sometimes called abiogenesis) owe much to two biologists working early in the twentieth century:

- → Aleksandr Oparin, a Russian biologist who first put forward his ideas in 1924,
- → John Haldane, an English biologist independently put forward almost identical ideas in 1929 (before Oparin's book had been translated into English).

They both suggested that:

- ✓ the primitive atmosphere of the Earth was a reducing atmosphere with no free oxygen as opposed to the oxygen-rich atmosphere of today
- ✓ there was an appropriate supply of energy, such as lightning or ultraviolet light, and
- ✓ this would provide the energy for reactions that would synthesize a wide range of organic compounds, such as amino acids, sugars and fatty acids.

Oparin's Heterotrophic Hypothesis

He forwarded a hypothesis on the origin of the first form of life (**protobionts**). He suggested that the atmosphere of the primitive earth was not as it is known today. Oxygen was totally absent in the **primaeval** atmosphere. Oparin suggested that the simple organic compounds could have undergone a series of reactions leading to more and more complex molecules. He proposed that the molecules might have formed colloidal aggregates, or '**coacervates**' (a Latin word *acervus* meaning pile). in an aqueous environment The coacervates were able to absorb and assimilate organic compounds from the environment in a way similar to the metabolism of cells. These coacervates were the precursors of cells and would be subject to natural selection, eventually leading to the first true cells.

Autotrophs evolution on Earth

Paleontological evidence suggests that the first form of life were heterotrophic prokaryotes which were also anaerobic (respiring without O_2) and dependent on the organic molecules which had accumulated in the seas. The first organisms appeared about 4 billion years ago they were prokaryotes. They had no true nucleus. It seems likely also that they had RNA rather than DNA as their genetic material. Later the organic molecules were depleted. In such an environment organism which could survive were those able to synthesize organic substances from simple inorganic substances and these are autotrophs (either chemosynthetic or photosynthetic).

It seems likely that they gave rise to three distinct lines of evolution leading to:

• **archaebacteria** – prokaryotes including thermophilic sulphobacteria (primitive sulphobacteria use hydrogen sulphide as the energy source), methanobacteria and halophilic bacteria

• **eubacteria** – prokaryotes; ordinary bacteria and cyanobacteria (blue-green bacteria and sometimes known as blue-green algae)

• **eukaryotes** – eventually evolving into protoctistans, fungi, plants, animals (nearly all are aerobic)

One great change that affected the evolution of early life forms was the shift from the reducing atmosphere to an atmosphere containing oxygen. This took place about 2.4 billion years ago. Where did this oxygen come from? There is only one process we know of that can have produced it photosynthesis.

Cyanobacteria are photo-autotrophs; they use light as a source of energy, and CO_2 as a source of carbon (photosynthesis). They are among the earliest of **autotrophs**, using, not chlorophyll, but another pigment, phycocyanin (which gives them their blue green appearance), to capture light energy. Other primitive autotrophs used not light as a source of energy but chemical reactions and are called chemo-autotrophs. Chemoautotrophs use the energy from chemical reactions to synthesize all necessary organic compounds, starting from carbon dioxide. They generally only use inorganic energy sources. Most are bacteria or archaea that live in hostile environments such as deep sea vents and are the primary producers in ecosystems on the sea beds. Scientists believe that the first organisms to inhabit Earth were chemo-autotrophs.

Theories of evolution

Charles Darwin I 1859 wrote a book on the ***origin of species***. His paper suggested that those organisms that were best adapted to their environment would have an advantage and be able to reproduce in greater numbers than other types, and pass on the advantageous adaptations. Because he knew nothing of genetics, he was unable to suggest how this might take place.

In the mid-1700s, George Buffon challenged the idea that all species had been created about 6000 years ago and suggesting that, the Earth was much older than this, and that organisms changed over time in response to environmental pressures and random events. He suggested that the external environment has a direct influence on the structure of organisms and such changes are heritable.

Lamarck and Acquired Characteristics

Lamarck, made what is now considered to be the first major advance towards modern evolutionary thinking because he proposed a mechanism by which the gradual change in species might take place. In 1809 he published a paper entitled ‘Philosophie Zoologique’, in which he described a two-part mechanism by which change was gradually introduced into the species and passed down through generations. His theory is called the ‘theory of transformation’ or, more usually, simply ‘Lamarckism’. The two parts of his theory are:

- → Use and disuse, and
- → Inheritance of acquired traits.

Use and disuse

The development of organs and their power of action is directly proportional to their use. The disuse of organs gradually brings about their degeneration or extinction. Lamarck suggests that by continually using a structure or process, that structure or process will become enlarged or more developed. Conversely, any structure or process that is not used or is little used will become reduced in size or less developed. The classic example he used to explain the concept of use and disuse is the elongated neck of the giraffe. According to Lamarck, a given giraffe could, over a lifetime of straining to reach high branches, develop an elongated neck. However, Lamarck could not explain how this might happen. He talks about a ‘natural tendency towards perfection’ – but this is not really an explanation. Another example Lamarck used to illustrate his idea was the toes of water birds. He suggested that from years of straining their toes to swim through water, these birds gained elongated, webbed toes to improve their swimming.

Inheritance of acquired traits

All the changes in an individual during its lifetime are transmitted to its offspring by reproductive process. Lamarck believed that traits changed or acquired during an individual’s lifetime could be passed on to its offspring. Giraffes that had acquired long necks would have offspring with long necks rather than the short necks their parents were born with. This type of inheritance, sometimes called Lamarckian inheritance, has since been disproved by the discoveries of genetics.

Therefore, Lamarck proposed that the driving force of evolution is the inheritance of acquired characters. He believed that organisms change physically as they strive to meet the demands of their environment, and that these changes are eventually passed to future generations. Nowadays, his theories are not got acceptance because environmental changes brought about changes in the phenotypes and have no effect on their gametes and hence their heredity.

Charles Darwin and Natural Selection

A large number of people agree that Darwin was the greatest naturalist and philosopher of the 19th century. Just 50 years later, in 1858, Charles Darwin published his famous paper on Natural Selection. He had developed the idea some twenty years earlier, but was afraid of the ridicule the idea might receive. In 1858, another biologist, Alfred Russell Wallace, had come to similar conclusions and they jointly published the scientific paper to the Linnean Society of London that would change our thinking on the origin of species forever.

Darwin visited five of the Galapagos Islands and made drawings and collected specimens. His main task as a naturalist on the visit was to make field observation and collection of plants and animals throughout the voyage. In particular, Darwin studied the Finches found on the different islands and noted that there were many similarities between them, as well as the obvious differences. He concluded that the simplest explanation was that an 'ancestral finch' had colonized the islands from the mainland and, in the absence of predators, been able to adapt to the different conditions on the islands and, eventually, evolve into different species. Some of the finches had, he suggested, evolved into insect eaters, with pointed beaks. Others had evolved into seed eaters with beaks capable of crushing the seeds. Others had evolved into seed eaters with beaks capable of crushing the seeds. One hundred and fifty years later on and geneticists have been able to confirm Darwin's ideas and even produced a 'family tree' based on the similarity of their DNA.

Darwin summarized his observations in two main ideas:

- ✓ all species tend to produce more offspring than can possibly survive
- ✓ there is variation among the offspring

From these observations he deduced that:

- ✓ There will be a 'struggle for existence' between members of a species (because they over reproduce, and resources are limited)
- ✓ Some members of a species will be better adapted than others to their environment (because there is variation in the offspring).

Combining these two deductions, Darwin proposed:

Those members of a species which are best adapted to their environment will survive and reproduce in greater numbers than others less well adapted.

The modern theory of natural selection that was proposed by Darwin and Wallace was based on the following principal observations and deductions:

- → **Overproduction (fecundity)**- the number of offspring produced by species is greater than the number that can survive, reproduce and live to maturity. Organisms naturally have a high reproductive potential.
- → **Struggle for existence** – all population sizes are limited by various environmental factors such as food availability, space and light. This limitation of resources would result in the struggle for existence. Due to this various struggles, only those individuals which are best fitted to new conditions of life survive and the least fit are the first to perish and termed as **survival of the fittest**.
- → **Variations**- the individuals in the species are not identical, but show variations in their characteristics. These variations result in changes, which would ultimately lead to evolution.

Neo-Darwinism

Since the publication of Darwin's theory of natural selection, there have been many researches and findings that made enormous contributions and modifications to the theory. Charles Darwin knew very little of genetics. Mendel had not carried out his ground-breaking work on inheritance at the time Darwin published his book *On the Origin of Species*. Genes and gene action into the theory of natural selection to give a better understanding of what drives evolution. Genes or, more accurately, alleles of genes determine features. A collection of different genes both expressed and not expressed (all the alleles), present in a population of a particular species is called **gene pool**.

Suppose an allele determines a feature that gives an organism an advantage in its environment. The following will happen:

- o Those individuals with the advantageous allele of the gene will survive to reproduce in greater numbers than other types.
- o They will pass on their advantageous allele in greater numbers than the other types pass on their alleles of the same gene.
- o The frequency of the advantageous allele in the gene pool of the population will be higher in the next generation.

- This process repeats over many generations and the frequency of the advantageous allele in the gene pool increases with each generation that passes.

Mutations are important in introducing variation into populations. Any mutation could produce an allele which:

- → confers a selective advantage; the frequency of the allele will increase over time
- → is neutral in its overall effect; the frequency may increase slowly, remain stable or decrease (the change in frequency will depend on what other genes/alleles are associated with the mutant allele)
- → is disadvantageous; the frequency of the allele will be low and could disappear from the population.

Especially the contribution of Mendel was substantially important to upgrade Darwin's theory. This resulted in advent of new school of thought called **Neo-Darwinism** which could be defined as the theory of natural selection of inherited characteristics. This concept bases itself on modern evidence from:

- Mendelian and post-mendelian genetics
- Molecular biology
- Paleontology
- Ecology and etiology

Evidence of Evolution

Over the years of evolutionary thinking scientists have accumulated an array of evidence from the different fields of biology. These have been used to validate the modern theory of evolution. These evidence includes:

- → Evidence from paleontology (fossil study)

It is referring to the study of ancient life. Fossils are any forms of preserved remains derived from living organisms. It includes remains of entire organisms, hard skeletal materials, impressions, imprints, petrifactions moulds and casts etc. They are the main direct evidence about past life.

Fossils can have grouped into two categories:

Category 1: the remains of the dead animal or plant or the imprint left from the remains, including:

• bones, teeth, skin impressions, hair

• the hardened shell of an ancient invertebrate such as a trilobite or an ammonite

• an impression of an animal or plant, even if the actual parts are missing.

Type I fossils can be the actual organism or part of an organism, like a piece of bone or hair or feather as it actually was. For example, this spider has been trapped, completely unchanged, inside the amber for millions of years. Amber is fossilized resin from trees.

Category 2: something that was made by the animal while it was living that has since hardened into stone; these are called trace fossils and include:

• footprints, burrows, coprolite (animal faeces).

Generally, the formation of fossil is a chanceful process, depending on where organisms dies and whether the remains escape from being eaten by scavengers, rapidly decay by microorganisms and dispersal by wind or rain.

There are four main stages in fossil formation:

1. **Death without decomposition**

To start with, an animal or plant must die in or so close to water that it is covered by water immediately after, or shortly after, death. The water insulates the remains from many of the elements that contribute to decomposition. Bacteria will still decay the soft body parts over a long period but leave any hard body parts unaltered.

2. Sedimentation

As time passes, sediments (tiny particles of solid matter settling out of the water) bury the remaining hard parts of the organism. Fossilization is more likely if this happens quickly than if it happens slowly. Sudden landslides and mudslides into the water help. Sedimentation further insulates the organism from complete decay. The nature of the sediments themselves influences the nature and quality of the fossil. Very fine-grained particles, like clays, will create a more detailed fossil than coarser-grained sediments like sand. The chemical make-up of the sediments affects the colour the fossil will be. Iron-rich sediments could give the rock (and the fossil) a reddish colour. Phosphates may darken the rock so that it is grey or black.

3. Per-mineralization

As the sediments accumulate, the lower layers become compacted by the weight of the layers on top. Over time, this pressure turns the sediments into rock. If water rich in minerals percolates (seeps) through the sediments, the mineral particles stick to the particles of sediment, effectively gluing them together into a solid mass. An important point here is that these minerals are probably not the same minerals that make up the sediments (now rock). Over the course of millions of years, these mineral particles dissolve away the original hard parts of the organism, replacing the molecules of exoskeleton with molecules of calcite (calcium carbonate) or another mineral. In time, the entire shell is replaced by mineral particles and these also are compressed into rock in the shape of the original organism. As this rock is not the same as the surrounding rock, it is visible as a fossil in the exact shape of the original organism.

4. Uplift

As the continental plates move around the Earth, colliding with each other, mountains are formed. What were sea floors being lied up and become dry land. Now the fossil is buried under hundreds or even thousands of feet of rock in different strata. A stratum is a layer of sediment (or sedimentary rock) that is the same throughout the layer, but different from layers above and below.

Methods of fossil dating

Because sedimentary rocks are laid down in layers (strata) we can use the sequence of the strata and the fossils that occur in them to deduce how the organisms have changed over time. This is called **stratigraphy**. The oldest strata, and therefore the oldest fossils, will be in the lowest layers and more recent rocks and fossils in layers above them, with the most recent being nearest to the surface. The depth of the strata is related to their age. The thickness of each stratum is a measure of the time period during which that stratum was formed. To do this, we biologists use one of two techniques:

- → radiocarbon dating, or potassium–argon dating.

The commonest method used by scientists to determine the ages of rocks and hence fossils trapped in them is **radiometric dating**. This method depends on the fact that some isotopes of certain elements are **radioactive** i.e., they are unstable and decay into other stable or daughter elements.

Both these techniques rely on the principle that radioactive atoms decay into other atoms over time. Radioactive carbon atoms (C^{14}) decay into non-radioactive nitrogen atoms (N). Radioactive potassium atoms (K^{40}) decay into argon atoms (A^{40}). Each has what is known as a **half-life**. During this period, half of the radioactive atoms decay. So, starting with a certain number of radioactive potassium atoms, after one half-life, 50% will still be radioactive. After a second half-life, 50% of this 50% will have decayed and 25% of the original number will still be radioactive.

- → **Evidence from body structure/comparative anatomy**

Comparative study of the body structure of various organisms reveals evolutionary linkage between the many organisms. This is one of the strongest forms of evidence for evolution. Comparative anatomy looks at structural similarities of organisms and uses these to determine their possible evolutionary relationships. It assumes that organisms with similar anatomical features are closely related evolutionarily, and that they probably share a common ancestor.

Homologous structures – are structures having similar form, body position and embryonic development but very different in functions in different species. Because they are so similar, they indicate an evolutionary relationship and a common ancestor of the species that possess them. Perhaps the best-known example of homologous structures is the forelimb of mammals. When examined closely, the forelimbs of humans, whales, cats and bats are all very similar in structure. Each possesses the same number of bones, arranged in almost the same way, while they have different external features and they function in different ways:

- ✓ arm for manipulation in humans
- ✓ leg for running in cats
- ✓ flipper for swimming in whales =
- ✓ wing for flying in bats

By comparing the anatomy of these limbs, scientists have determined that the basic pattern called a **pentadactyl limb** (five digits) must have evolved just once and that all organisms with this kind of limb are descended from that original type – they share a common ancestor.

Sometimes organisms have structures that function in very similar ways. However, morphologically and developmentally these structures are very different. We call these **analogous structures**. Because they are so different structurally, even though they have the same function, they cannot indicate that two species share a common ancestor. They simply show superficial similarity. For example, although the wings of a bird and a mosquito both serve the same function their anatomies are very different. The bird wing has bones inside and is covered with feathers, while the mosquito wing has neither of these. They are analogous structures and have evolved separately. **Vestigial structure** – are rudimentary (reduced in size) structures in many organisms, which a have no known functions.

- → **Evidence from comparative embryology**

Embryology is the study of organisms in the early embryonic stages of development. This development shows similarities which supports a common ancestry. For example, early in development, all vertebrate embryos (including you) have gill slits and tails. However, the ‘gill slits’ are not gills; they connect the throat to the outside, but in many species they close later in development. However, in fish and larval amphibians they contribute to the development of gills.

→ Evidence from comparative biochemistry

Several biochemical studies indicated that all organisms share similar DNA molecules and certain essential proteins. Various chemicals have been studied in order to find evidence of evolutionary relationships. The idea behind this is that if organisms share very similar molecules and biochemical pathways, then they must be closely related evolutionarily. Chemicals that have been used in such analyses include:

- DNA – the base sequences of DNA from different organisms is compared
- proteins such as: cytochrome c (found in the electron transport chain of respiration) and
- haemoglobin which are compared in terms of amino acid sequences.

Species that are closely related have the most similar DNA and proteins; those that are distantly related share fewer similarities. A comparison of DNA sequences shows that it is 99.9% certain that chimpanzees are humans’ closest relatives (98% of our DNA is the same as that of chimpanzees). To measure the similarity of one species’ DNA with another species, we use a technique called DNA hybridization. The technique measures the extent to which a strand of DNA from one species can bind with (or hybridize with) a strand of DNA from another species. The information can then be used to calculate the percentage similarity of the DNA samples.

Table. Comparison between DNA of humans and other primates

Primate	Degree of relatedness
Chimpanzee	97.6%
Rhesus monkey	91.1%
Vervet monkey	84.2%
Galago	58.0%

→ **Evidence from plant and animal breeding**

Human have long been cultivating plants and animals from wild forms. This has allowed human to select some desired favorable characters. Humans have been trying to improve the yields of their crop plants and stock animals. They have done this by **selective breeding**, in which:

- those animals (or plants) that show the desired trait (for example, high milk yield or large number of seeds per pod) are selected and mated, and

- the offspring are monitored carefully and, again, only those with the desired trait are allowed to breed.

This technique is known as **artificial selection**, by which desirable characters are preserved whereas undesirable characters are eliminated. Over many generations, selective breeding can bring about significant changes to the organisms involved. One example of this is the modification by selective breeding of the wild pig (wild boar) into the many different varieties of the domestic pig.

6.3. **Speciation through natural selection/the process of evolution**

The modern view of **natural selection** is stated briefly below:

Those members of a species which are best adapted to their environment will survive and reproduce in greater numbers than others less well adapted. They will pass on their advantageous alleles to their offspring and, in successive generations, the frequency of these alleles will increase in their gene pool. The advantageous types will, therefore, increase in frequency in successive generations.

Natural selection is the 'driving force' behind evolution. It is the process that brings about changes (over time) in populations that can, eventually, lead to different populations of the same species becoming different species. To appreciate how natural selection can eventually lead to **speciation** (the formation of new species), we must be clear what we mean by a species. Speciation is a process by which one or more new species are formed from pre-existing ones. Obviously humans are a different species from chimpanzees. But the different races of humans are all members of the same species.

Species is group of similar organisms with a similar biochemistry, physiology and evolutionary history that can interbreed to produce offspring that are fertile.

This explains why all humans are members of the same species, but belong to a different species from the chimpanzee. All types of natural selection work in the same manner (as described above), but their influence on a population is different. The different types of selection include:

- → directional selection
- → stabilizing selection
- → disruptive selection

What is directional selection?

A feature may show a range of values. It operates in response to gradual changes in environmental conditions. It favors one extreme phenotype from the population, thus reducing variation and leading to a shift in the population mean for the selected characters. Individuals at one extreme could have a disadvantage whereas those at the other extreme have an advantage. For example, thicker fur (longer hair) in foxes is an advantage in a cold climate. thinner fur in foxes is an advantage in a hot climate. If the environment were to change so that it became significantly colder, or a group of the foxes were to establish a population in a new, colder environment, there would be a selection pressure in favor of the foxes with long fur and against those with short fur.
They must be the result of either:

- new mutations, or
- new combinations of alleles.

In either case, if they had existed in the original population, they would have been disadvantageous as they would prevent the foxes from being able to cool themselves effectively and so would have died.

What is stabilizing selection?

Stabilizing or **normalizing selection** occurs in all populations and favors the existing means (optimum) population, leading to a reduction in variance by eliminating the extremes from the population. In a stable environment, individuals at both ends of the range of values for a feature are the least well adapted. Selection often operates against both these extremes to reduce the variability in the population and to make the population more uniformly adapted. Birth mass in humans is an example. Babies who are very heavy or very light show a higher neonatal mortality rate (die more frequently at, or just after, birth) than those of medium mass. Over time selection is operating to reduce the numbers of heavy and light babies born.

What is disruptive selection?

Disruptive or diversifying selection is a rare kind of selection, but very important in bringing about evolutionary changes. Disruptive selection is, in effect, the converse of stabilizing selection. In this instance, individuals at both extremes of a range have some advantage over those displaying the mean value. As a result, the frequency of those individuals at the extremes of the range will increase over time and those in the middle of the range will decrease over time. Fluctuating conditions in an environment may favor the presence of more than one phenotype within the population. This leading **to polymorphism** (appearance of different types within the population).

This is part of the explanation of the evolution of Darwin's finches. A finch with an 'average' length beak may not be able to obtain insects out of cracks in the bark of trees as well as one with a longer beak.

How can natural selection lead to the formation of new species?

Natural selection provides a mechanism by which new populations of a species can arise. We have described a species as:

A group of similar, interbreeding organisms that produce fertile offspring. If two populations become so different that individuals from different populations cannot interbreed to produce fertile offspring, then we must think of them as different species. There are a number of ways in which this can occur. The two main ways are:

- **allopatric speciation, and**
- **sympatric speciation**.

As long as two populations are able to interbreed, they are unlikely to evolve into distinct species. They must somehow go through a period when they are prevented from interbreeding. Both allopatric and sympatric speciation involve isolating mechanisms that prevent different populations from interbreeding for a period of time.

What is allopatric speciation?

If interspecific speciation occurs while the populations are geographically separated by physical barriers, it is called **allopatric speciation**. In allopatric speciation, the species become isolated by some physical feature. Examples of this could include:

- a river changing course
- a mountain range being created
- a land mass separating two bodies of water

This is a type of geographical isolation. Interbreeding between the populations becomes impossible and speciation could result.

What is sympatric speciation?

Intraspecific speciation that occurs while the populations are inhabiting the same geographical area, it is termed as **sympatric speciation**. Speciation need not involve physical separation.

The two diverging populations may inhabit the same area, but be prevented from breeding in a number of ways, including:

- ✓ **seasonal isolation** (etiological)– members of the two populations reproduce at different times of the year
- ✓ **temporal isolation** – members of the two populations reproduce at different times of the day
- ✓ **behavioral isolation** – members of the two populations have different courtship patterns

Speciation following any of these methods of isolation is referred to as **sympatric speciation**.

An example of sympatric speciation is found in palm trees growing on Lord Howe Island of the east coast of Australia. The soil on the island is in parts volcanic and in other parts calcareous. Palms growing on the different soils developed different breeding seasons (as a result of nutrient availability at different times). As a result, they were reproductively isolated and developed into two different species.

Polyploidy cells have many sets of chromosomes per cell – sometimes four sets, sometimes eight or more. Some human liver cells have 92 chromosomes per cell – they are **tetraploid** – they have four sets of chromosomes per cell. Polyploidy has been important in **plant evolution** because it has allowed otherwise infertile hybrids to become fertile again. When different species form hybrids, very often the hybrid cannot produce offspring because all the chromosomes cannot form bivalents (**homologous pairs**) in meiosis. So they cannot form sex cells and cannot reproduce. Hybridization and polyploidy have both been important in the evolution of modern wheat from wild grasses. *Triticum vulgare* is one form of modern wheat. Polyploidy, in addition to restoring fertility to infertile hybrids, often results in bigger plants with more and bigger seeds.

What is divergent evolution?

Divergent (**adaptive radiation**) evolution is the accumulation of characteristics that improve species' ability to survive and reproduce. Divergent evolution is another name for a process we have already met – adaptive radiation. In divergent evolution, a basic type 'diverges' along different lines because of different selection pressures in different environments. If different selection pressures are placed on populations of a particular species, a wide variety of adaptive traits may result. There are major categories of adaptation: **structural**, **physiological** and **behavioral**. Divergent evolution leads to the development of a new species. Examples of divergent evolution (adaptive radiation) include:

- ✓ the evolution of the different species of finches on the Galapagos Islands

- ✓ the evolution of the different forms of the pentadactyl limb

What is convergent evolution?

This is a phenomenon that occurs where two or more distantly related organisms become more alike as they develop (evolve) similar adaptation. **Convergent evolution** takes place when different organisms occupy similar niches. The selection pressures on the populations are the same and so similar adaptations evolve over time. One example is the convergent evolution of the giant armadillo, giant pangolin, giant anteater and spiny anteater. Convergent evolution is also responsible for the wings of a bird, a bat and the extinct pterodactyl.

The evolution of humans

There is often a lot of very loose language used in describing human evolution. There has been a 'line of evolution' for millions of years that has given rise to old world monkeys, new world monkeys, the great apes and the different species of humans that have lived. But, we are *Homo sapiens* and we are the latest of several humans to live on the planet. We have two features in particular that distinguish us from other primates. These are:

- a very large brain, and
- bipedalism – the ability to truly walk on just two legs.

Humans and chimpanzees both evolved from a common ancestor that lived about 6 million years ago. There were other humans before us and, before them, what we might call '**pre-humans'**. All humans belong to the genus ***Homo***. Ethiopia has been in the evolution of humans. Fossils of many of the species along the early part of the timeline were found in Ethiopia. It is indeed the '**cradle of mankind'**.

Both Lucy and Ardi are important fossils in explaining the evolution of modern humans and chimpanzees from a common ancestor. Lucy was discovered by Donald Johanson and Tom Gray in 1974 at Hadar in Ethiopia. Lucy is a fossil dated at about 3.2 million years. She was an adult female of about 25 years and belonged to the species *Australopithecus afarensis*. Her skeleton was about 40% completed, an unusually high proportion for a fossil skeleton. However, there is also evidence that Lucy was also partly arboreal (tree-dwelling). She was about 107 cm (36ft) tall and about 28 kg (62 lbs) in weight.

The Ardi fossil (together with many other similar fossils) was first discovered in 1992, in the Afar dessert in Ethiopia, but it was only in 2009, after many years' analysis, that research papers were finally published that gave Ardi a unique position in human evolution. Ardi was 1.2 million years older than Lucy, was also female and belonged to the species *Ardipithecus ramidus*. One significant feature about Ardi was that she was also bipedal.

How has brain size changed during human evolution?

During the course of human evolution, the brain has got bigger. We know from comparing fossils that the cranial capacity has increased with each new hominid species that evolved. However, that is not the whole story. Besides becoming bigger overall, the brain has increased in size as a proportion of body mass. Whereas species of Australopithecus have a brain that is between 0.7% and 1.0% of their body mass, modern humans have a brain that is between 1.8% and 2.3% of their body mass. The brain of Homo sapiens uses 25% of the resting energy requirement, compared with 8% in the great apes.

A larger brain allows humans to:

- → run faster and in a more upright posture
- → plan in advance to avoid attack
- → develop and use tools and weapons

These abilities clearly also depend on other physical adaptations such as longer legs, nimbler fingers and a straighter spine, but, without the larger brain to co-ordinate the activities, the physical changes would not confer the same advantage.

Are we still evolving?

Homo sapiens (**modern human**s) first appeared in Africa and have since migrated to all other parts of the world. As humans moved from Africa into different areas of the world, they encountered different environments. Different selection pressures in the different environments resulted in the different human populations evolving along different lines. For example, as humans encountered colder climates, body features that gave a survival advantage by helping to conserve heat were selected for. These included:

- o a shorter, squatter body shape; this reduces the surface-area-to volume ratio and so reduces the rate of heat loss by radiation
- o an increased layer of adipose tissue under the skin to act as insulation
- o increased hairiness; this reduces heat loss by convection

Humans have been evolving into different ‘races’ for thousands of years. The classification of these races is difficult and there is some disagreement about their exact nature. One classification is given below. In this there are three main races with several subdivisions. This is based on a recent genetic analysis of the different races.

- **African** (**Negroid**), 100 million people from Africa and Melanesians of the South Pacific.
- **Eurasian** (**Caucasoid**), 1000 million people with variable skin colour ranging from white to dark brown. Three subdivisions exist:

– Nordic – often tall, blonde and narrow-headed; includes people from Scandinavian and Baltic countries, Germany, France, Britain

– Mediterranean – usually lighter in body build, dark and narrow-headed; includes people from Southern France, Spain, Italy, Wales, Egypt, Jews, Arabs, Afghanistan, Pakistan, India

– Alpine – usually broad-headed, square jaws, olive skin, brown hair; includes people from countries from the Mediterranean to Asia

- **East Asian** (**Mongoloid**), most numerous of the present-day populations and split into three groups:

– Eastern Siberians, Eskimos and the Northern American Indians

– Japanese, Koreans and Chinese

– Indonesians and Malays

However, this classification does not include the Central African pigmies, the Bushmen and the Australoids.

Unit 7: Biotechnology

Biotechnology is the use of microorganisms to make things that people want, often involving industrial production. Biotechnology has always been extremely important. It involves ways of making and preserving foods and making alcoholic drinks. Traditional applications of biotechnology involve brewing beers, making wines, making bread, and making cheese and yoghurt. Modern applications of biotechnology include using genetic engineering to change crops and animals; producing new medicines; and helping to provide new energy sources. It has enormous significance in helping people to improve and control their lives. Biotechnology is based on **microbiology** - the study of microorganisms which are tiny living organisms including **bacteria**, **viruses**, **fungi** and **protoctista**, which are usually too small to be seen with the naked eye. Some microorganisms **cause disease**; others are enormously **useful** to people for example, they play a vital role in decay and the recycling of nutrients in the environment. With the arrival of new technologies such as genetic engineering, microorganisms are becoming more useful all the time.

Bacteria are single-celled organisms that are much smaller than the smallest plant and animal cells. In ideal conditions, they can reproduce very quickly. **Viruses** are even smaller than bacteria. They do not carry out any of the normal functions of living things. Moulds and yeasts are both **fungi** living organisms which obtain their food from other dead or living organisms. Yeasts are single celled organisms, while moulds are made up of thin, thread-like structures called hyphae.

Bacteria are used in the manufacture of *irgo* (yoghurt) and *Ayib* (cheese). Yeast is used to make many traditional Ethiopian fermented foods, including *injera*, and also to produce alcoholic drinks, such as *tej* and *tella*.

The application of biotechnology is broadly classified as **traditional** biotechnology and **modern or new** biotechnology.

i) Traditional biotechnology

It is the traditional techniques of using living organisms to yield new products or modify foods or other useful products. One of the most useful microorganisms is **yeast**. The yeasts are single-celled organisms. Each yeast cell has a nucleus, cytoplasm and a membrane surrounded by a cell wall. The main way in which yeasts reproduce is by **asexual budding** – splitting into two, to form new yeast cells. Just one gram of yeast contains about 25 billion cells!

When yeasts have plenty of oxygen, they respire aerobically (with oxygen), breaking down sugar to provide energy for the cells, and producing water and carbon dioxide as waste products. But yeasts are useful because they can also respire **anaerobically** (without oxygen). When yeast cells break down sugar in the absence of oxygen, they produce **ethanol** (commonly referred to as alcohol) and carbon dioxide.

Aerobic respiration provides more energy than anaerobic respiration, allowing yeast cells to grow and reproduce. However, once they exist in large numbers, yeast cells can survive for a long time in low-oxygen conditions, and will break down all the available sugar to produce ethanol. The anaerobic respiration of yeast is sometimes referred to as **fermentation**. We have used yeast for making bread and alcoholic drinks almost as far back as human records go. Here in **Ethiopia** yeast (known locally as *ershoo*) has been used to make *injera* (bread) possibly since even earlier times.

***Injera* needs yeast**

Natural yeasts start to grow and respire in the dough. At first the yeast respires aerobically, although this may change to anaerobic respiration. The yeast produces carbon dioxide, making the mix rise a little and giving it a tangy flavor. When you cook the mixture, the bubbles of gas expand in the high temperature, giving *injera* its typical texture, which is so good for soaking up the food. The yeasts are killed during the cooking process.

Making alcoholic drinks

When fruits fall to the ground and begin to decay, wild yeasts on their skin break down the fruit sugar to form ethanol and carbon dioxide. These fermented fruits can cause animals to become drunk when they eat them and this is probably how our ancestors discovered alcohol! We now use this same reaction in a controlled way to make drinks such as beer, *tej* and wine. In both cases the yeast has to be supplied with carbohydrates to act as an energy source for respiration.

When you make *tej*, you need honey, water and *gesho* leaf or stick. *Gesho* gives a bitter edge to the brew, and wild yeasts found on the plant start the fermentation going. The yeasts use the honey as a source of food. As the yeast colonies grow they start to respire anaerobically, and this produces ethanol and carbon dioxide. The alcohol content of *tej* varies from about 6 to 11%. *Tej* and *tella* are the most commonly consumed alcoholic drinks in Ethiopia.

In opposing, winemaking uses natural sugar, found in fruit such as grapes, as the energy source for the yeast. Once the fruit is pressed it is mixed with yeast and water. Then let the yeast respire anaerobically until most of the sugar has been used up. At this stage, you filter the wine to remove the yeast and put it in bottles, where it will remain for some time to mature before it is sold. Most commercially sold wine is made from grapes, but wine can be made from almost any fruit or vegetable – the yeast doesn't care where the sugar it uses comes from! Interestingly, alcohol in large amounts is poisonous to yeast as well as to people. This is why the alcohol content of wine is rarely more than 14% – once it gets much higher, it kills all the yeast and stops the fermentation.

Food production using bacteria

People have used milk from many different types of animals. However, there is one big drawback in using milk as part of the diet. It very rapidly goes off, smelling and tasting disgusting! It didn't take people long to discover ways of changing milk, turning it into milk-based foods with a much longer life than the original milk. These changes depend on the action of microorganisms. There are so many fermented food products made in Ethiopia including:

→ **Making yoghurt (irgo)**

Traditionally, yoghurt is fermented whole milk. Yoghurt is formed by the action of bacteria on the **lactose** (milk sugar) in the milk. To make yoghurt, you add a **starter culture** of the right kind of bacteria to warm milk. Often this starter culture is just a small amount of yoghurt you have already made. The mixture needs to be warm so the bacteria begin to grow, reproduce and ferment. As the bacteria break down the lactose in the milk, they produce **lactic acid**, which gives the yoghurt its sharp, tangy taste. This is known as **lactic fermentation**. The lactic acid produced by the bacteria causes the milk to **clot and solidify** into yoghurt. The action of the bacteria also gives the yoghurt a smooth, thick texture. Once the yoghurt forming bacteria have worked on the milk, they also help prevent the growth of other bacteria that normally send the milk bad. Yoghurt, if it is kept cool, will last almost three weeks before it goes bad. Ordinary milk lasts only a few days – and then only if it's kept really cold. Once you have made your basic yoghurt, you can mix in flavorings, spices and fruit. In Ethiopia, olive tree used as gourd giving the yoghurt a pleasant flavor, this disinfects the vessel so that only good bacteria grow in the milk.

→ **Cheese making**

Cheese making depends on the reactions of bacteria with milk changing the texture and taste, and also preserving the milk. Cheese making is very successful in preserving milk, and some cheeses can survive for years without decay. Around 900 different types of cheese are made around the world, but the basis of the production method is the same for them all. Just as in yoghurt making, you add a starter culture of bacteria to warm milk. The difference is in the type of bacteria added. The bacteria in cheese making also convert lactose to lactic acid, but they make much more lactic acid. As a result, the solid part (**curds**) is much more solid than in yoghurt. Enzymes are also added to increase the separation of the milk. These often come from the stomachs of calves or other young animals. When it has completely curdled, you can separate the curds from the liquid **whey** (known as *aguat* here in Ethiopia). Then you can use the curds for cheese making. The whey is often used in other dishes. The curds can be used fresh, and can be seasoned or flavored. This is the basis of *ayib*.

Here in Ethiopia cheese is traditionally made by first making yoghurt from fresh milk, extracting the butter by continuous agitation, and finally boiling the remaining part to make the cheese.

ii) New applications of biotechnology

Modern or new biotechnology involves the manipulation (modification) of the genetic materials of living organisms to produce the desired products at industrial scale in **fermenters**. They react to changes, keeping the conditions as stable as possible. This, in turn, means we can obtain the maximum yield. Industrial fermenters usually have:

- an oxygen supplies = to provide oxygen for respiration by the microorganisms
- a stirrer = to keep the micro-organisms in suspension, maintain an even temperature, and make sure oxygen and food are distributed evenly through the culture
- a water-cooled jacket = to remove the excess heat produced by the respiring microorganisms – any rise in temperature is used to heat the water, which is constantly removed and replaced with more cold water
- measuring instruments = for continuous monitoring of factors such as pH and temperature so that adjustments can be made if necessary

Some new applications of biotechnology also take place in an industrial setting. Many advances in agriculture are the result of one of the most important new areas of biotechnology **genetic engineering** (also known as **genetic modification**). Genetic engineering is used to change an organism and give it new characteristics which people want to see.

Genetic engineering involves changing the genetic material of an organism. Genetic material carries the instructions for a new organism, found in the nucleus of every cell. You take a small piece of information – a gene – from one organism and transfer it to the genetic material of a completely different organism. So, for example, a gene from one of your human cells can be 'cut out' using enzymes, and transferred to the cell of a bacterium. Your gene carries on making a human protein, even though it is now in a bacterium. There is a limit to the types of protein that bacteria are capable of making. Scientists have found that genes from one organism can be transferred to the cells of another type of animal or plant at an early stage of their development. As the animal or plant grows, it develops with the new, desired characteristics from the other organism. Some of the application areas of biotechnology are:

7.2. Agricultural biotechnology

For many years, selective breeding is used to change livestock and crops to get big grains, resistance to disease or plenty of milk, and breed from them. But selective breeding takes time, and there are limitations to it.

By using genetic engineering, we can introduce new characteristics very rapidly. Engineered genes can be used to improve the growth rates of plants and animals. They can be used to improve the food value of crops. Genetic engineering has been used to make crop plants that are resistant to drought and to disease, and to produce plants that make their own pesticide chemicals. Glowing genes from jellyfish have even been used to produce crop plants that give off a blue light when they are attacked by insects so the farmer knows they need spraying! This means the farmer has to use less insecticide (chemicals that kill insects), which saves money and protects the environment.

The Ethiopian Agricultural Research Institute is using modern biotechnology to improve teff, coffee, fruit plants and some of our forest trees for commercial cultivation.

However, there are some possible problems with the new biotechnologies, so we must be careful. Insects may become pesticide-resistant if they eat a constant diet of pesticide-forming plants. Genes from genetically modified plants and animals might spread into the wildlife of the countryside, which could make difficulties. Genetically modified crops are often not fertile, which means farmers have to buy new seed each year. But if these problems can be overcome, biotechnology offers us the hope of better crops and more food, both for our own people and to sell internationally.

Animals that have had their DNA manipulated to possess and express an extra (foreign) gene are known as **transgenic animals**. Transgenic rats, rabbits, pigs, sheep, cows and fish have been produced, although over 95 per cent of all existing transgenic animals are mice. How can man benefit from such modifications?

- ✓ Normal physiology and development
- ✓ Study of disease
- ✓ Biological products
- ✓ Vaccine safety
- ✓ Chemical safety testing

7.3. Medical biotechnology

Medical Biotechnology is the use of living cells and cell materials to research and produce pharmaceutical and diagnostic products that help treat and prevent human diseases. Biotechnology is extremely important in modern medicine. It is used to develop vaccines and to create new medicines. The first medicine that really relied on microbiology was penicillin which makes life easier. This antibiotic is one of the best-known medicines in the world, and has revolutionized medicine in the time since it was first manufactured.

In 1928 Alexander Fleming, a young researcher at St Mary's Hospital in the UK, left some plates on which he was culturing bacteria uncovered near an open window. He found bacteria were growing on the surface. Fleming also noticed spots of mould growing, and around these were clear areas of agar. The bacteria were no longer growing there. Whatever had blown in through the window and started growing on his plates was producing a chemical that killed the bacteria.

Fleming found that the microorganism which had invaded his Petri dishes was a common mould called Penicillium notatum. He managed to extract a tiny amount of the chemical that killed the bacteria, and used it to treat an infected wound. He called his extract penicillin. But it was very hard to extract, and very unstable once extracted, so Fleming decided he wouldn't be able to obtain useful amounts of penicillin from his mould. They wanted to manufacture it in large amounts, but the yield of drug was very poor.

Modern strains of Penicillium mould give even higher yields. We grow the mould in a sterilized medium, containing sugar, amino acids, mineral salts and other nutrients, which is made from soaking corn in water. It is grown in huge 10 000 dm3 fermenters, and still saves many thousands of lives every year. What is more, it grew relatively easily in deep tanks, making large-scale production possible. By 1945, enough penicillin was made each year to treat seven million people.

When genetically engineered bacteria are cultured on a large scale, they can make huge quantities of protein. This helps to make a number of drugs and hormones used as medicines. These genetically engineered bacteria make exactly the protein needed, in exactly the amounts needed, and in a very pure form. For example, people with diabetes need supplies of the hormone insulin. It used to be extracted from the pancreas of pigs and cattle, but it wasn't quite the same as human insulin, and the supply was quite variable. Both problems have now been solved by the introduction of genetically engineered bacteria that can make human insulin. Biotechnology also makes it possible to develop vaccines more easily.

A number of sheep and other mammals have been engineered to produce life-saving human proteins in their milk. For example, genetically modified sheep can make special blood-clotting proteins in their milk. These can be used for people with hemophilia, so they are no longer at risk from receiving contaminated blood.

It is applied to manufacture pharmaceuticals like enzymes, antibiotics and vaccines, and its use for molecular diagnostic. Genome research and proteome research are among the most important plate form technologies of biotechnology. The recombinant DNA technological processes have made immense impact in the area of healthcare by enabling mass production of safe and more effective therapeutic drugs.

Genetically Engineered Insulin

Management of adult-onset diabetes is possible by taking insulin at regular time intervals. Insulin used for diabetes was earlier extracted from pancreas of slaughtered cattle and pigs. Insulin from an animal source, though caused some patients to develop allergy or other types of reactions to the foreign protein. You can easily grow a large quantity of the bacteria and make as much insulin as you need.

Gene Therapy

If a person is born with a hereditary disease, can a corrective therapy be taken for such a disease? Gene therapy is an attempt to do this. Gene therapy is a collection of methods that allows correction of a gene defect that has been diagnosed in a child/embryo. Here genes are inserted into a person's cells and tissues to treat a disease. Correction of a genetic defect involves delivery of a normal gene into the individual or embryo to take over the function of and compensate for the non-functional gene.

Molecular Diagnosis

You know that for effective treatment of a disease, early diagnosis and understanding its pathophysiology is very important. Using conventional methods of diagnosis (serum and urine analysis, etc.) early detection is not possible. Recombinant DNA technology, Polymerase Chain Reaction (PCR) and Enzyme Linked Immuno-Sorbent Assay (ELISA) are some of the techniques that serve the purpose of early diagnosis. Presence of a pathogen (bacteria, viruses, etc.) is normally suspected only when the pathogen has produced a disease symptom. By this time the concentration of pathogen is already very high in the body. However, very low concentration of a bacteria or virus (at a time when the symptoms of the disease are not yet visible) can be detected by amplification of their nucleic acid by PCR.

7.4. Applications of biology in food (Industry)

Industrial biotechnology is biotechnology applied to industrial and other production processes. The new biotechnology is often used in food processing. One of the biggest changes is that enzymes are produced by genetically engineered bacteria, and the enzymes are then used in the production of processed foods and drinks. Enzymes are used to clarify beer. They are used to break down starch and convert the sugars into glucose syrup. They are used to make meat more tender, and to break down the food used to make commercial baby food.

Biotechnology plays a big part in food production. It has even been used to create a completely new food based on fungi, known as **mycoprotein**, which means '**protein from fungus'**. It is produced using the fungus *Fusarium*, which grows and reproduces rapidly on a relatively cheap sugar syrup in large, specialized fermenters. It needs aerobic conditions to grow successfully, and can then double its mass every five hours or so. The fungal biomass is harvested and purified. Then it is dried and processed to make mycoprotein, a pale yellow solid with a faint taste of mushrooms. It is a high protein, low-fat meat substitute used by vegetarians, people who want to reduce the fat in their diet, and people who just want to eat cheap protein.

Applications of biology in energy production

Everyone needs fuel of some sort to provide them with energy. However, there is only a limited amount of fossil fuels such as coal, oil and gas for us to use. Even wood and peat are becoming scarce. So, other renewable forms of fuel are needed. The generation of biogas from human and animal waste is becoming increasingly important in both the developing and the developed world. This depends on biotechnology.

What is biogas?

Biogas is a flammable mixture of gases, formed when bacteria break down plant material, or the waste products of animals, in anaerobic conditions. It is mainly methane, but the composition of the mixture varies depending on what is put into the generator and which bacteria are present.

Table. The components of biogas

Components	Percentage in the mixture by volume
Methane	50–80
Carbon dioxide	15–45
Water	5
Hydrogen sulphide	0–3
Other gases including hydrogen	0–1

Biogas is produced from dung or plant material, which contains a high level of carbohydrates. This is added into a **biogas generator or digester**. Then you add a mixed population of many different types of bacteria which are needed to digest the carbohydrate. The bacteria you use are similar to those in the stomachs of ruminants such as cows or sheep. Some of the bacteria break down the cellulose in plant cell walls. Others break down the sugars formed, to produce methane and other gases. The biogas produced is passed along a pipe into your home, where you burn it to produce heat, light or refrigeration.

The bacteria involved in biogas production work best at a temperature of around 30 °C, so biogas generators tend to work best in hot countries. However, the process generates heat (the reactions are **exothermic**). Some generators are so simple, they are little more than a big plastic bag and some pipes. Yet they can make a big difference to our lives.

More biofuels

In countries such as Ethiopia, plants grow quickly. Sugar cane grows about 4–5 meters in a year, and has a juice which is very high in carbohydrates, particularly sucrose. Maize and sweet potatoes also grow fast. We can break down the starch in maize kernels or potato tubers into glucose, using the enzyme carbohydrase. We can convert the carbohydrates we grow into clean and efficient fuels.

Ethanol-based fuels

If sugar-rich products from cane and maize are fermented anaerobically with yeast, the sugars are broken down incompletely to give ethanol and water. You can extract the ethanol from the products of fermentation by distillation, and you can then use it in cars and other vehicles as a fuel. Car engines need special modification to be able to use pure ethanol as a fuel, but it is not a major job. Many cars can run on a mixture of petrol and ethanol without any problems at all.

Advantages and disadvantages of ethanol as a fuel

In many ways, ethanol is an ideal fuel. It is efficient, and it does not produce toxic gases when you burn it. It is much less polluting than conventional fuels, which produce carbon monoxide, sulphur dioxide and nitrogen oxides. In addition, you can mix ethanol with conventional petrol to make a fuel known as gasohol. This is increasingly being done, and reduces pollution levels considerably, although there is still some pollution from the petrol part of the mix. Using ethanol as a fuel is a **carbon-neutral activity**. This means there is no overall increase in carbon dioxide in the atmosphere when you burn ethanol. The original plants removed carbon dioxide from the air during photosynthesis. When you burn the ethanol, you simply return it.

The biggest difficulty with using plant-based fuels for our cars is that it takes a lot of plant material to produce the ethanol. As a result, the use of ethanol as a fuel has largely been limited to countries with enough space, and a suitable climate, to grow a lot of plant material as quickly as possible. Here in Ethiopia, we have that capability.

Unit 8: Human biology and health

8.1. Food and nutrition

We are **heterotrophs** – we cannot make our own energy supply by photosynthesis so we have to eat other living things.

Food is the source of nutrients and energy for the body. Food is a complex mixture of different chemical substances or nutrients which provides our bodies requirements. It usually comes from animals or plants and is taken into the body where it is broken down to provide the nutrients needed by the body. We use our food in three main ways:

- → To provide energy for our cells to carry out all the functions of life.
- → To provide the raw materials for the new biological material needed in our bodies to grow and also to repair and replace damaged and worn out cells.
- → To provide the resources needed to fight disease and maintain a healthy body.

Some types of food are needed in large amounts – these are known as the **macronutrients**. There are six main classes of food needed by the body. The main macronutrients are carbohydrates, proteins and fats. Other substances are equally important in your diet, but only in tiny amounts. They are known as the **micronutrients** and they include minerals and vitamins. Water is another crucial required for living organisms. most foods are composed of a number of usable chemical compounds called **nutrients**. Among these groups of nutrients are:

Carbohydrates

Carbohydrates are the main source of energy. Each gram of carbohydrate produces 17KJ or 4 K calories of heat. Your body stores very little carbohydrate apart from glycogen, which is found in your liver, muscles and brain. The basic structure of all carbohydrates is the same. They are made up of carbon, hydrogen and oxygen.

Carbohydrates are classified chemically according to the length and size of their molecular structure. The basic structural unit of carbohydrates is the **saccharides** or sugar unit ($C_6H_{12}O_6$). The different classes of carbohydrates are **monosaccharides (**simple sugars**)**, **disaccharides** (double sugars) and **polysaccharides** (complex sugars).

The simple sugars

In these simple sugars there is one oxygen atom and two hydrogen atoms for each carbon atom present in the molecule. Monosaccharides are called simple sugars and consist of only one sugar unit that can have up to six carbon atoms. This can be written as a general formula: $(CH_2O)_{n.}$ The best-known simple sugar is glucose, which has the chemical formula $C_6H_{12}O_6$. There are lots of other simple sugars, including fructose, the sugar found in fruit and galactose.

The double sugars

Double sugars are made up of two simple sugars joined together. When two simple sugars join together to form a double sugar, a molecule of water (H_2O) is removed. This type of reaction where water is produced is known as a **condensation reaction.** The most common disaccharides are,

sucrose = cane sugar = table sugar (the substance you know as sugar). It is formed by a molecule of glucose joining with a molecule of fructose.

Lactose or milk sugar, is the combination of glucose and galactose. This is the main carbohydrate found in milk.

Maltose or malt sugar, is the combination of two glucose units. Found in germinating seed such as barley.

Most simple and double sugars have two important properties in common.

- → They dissolve in water and
- → they taste sweet.

The complex sugars

They consist of a long chain of many sugar units. The most complex carbohydrates are formed when many single sugar units are joined to form a long chain. The sweet taste that is common to simple and double sugars is lost – and so is the ability to dissolve in water. But linking lots of sugar monomers (single units, in this case simple sugars) produces some complex polymers (long chain molecules made up of lots of smaller repeating units). They often form very compact molecules that are ideal for storing energy. And as complex sugars are physically and chemically very inactive, storing them does not interfere with the other functions of the cell. The most common types are starch, glycogen, chitin and cellulose. These polysaccharides differ from each other in the type and number of simple sugars they contain as well as the way the units are linked together. These **polymers** or **complex sugars** have some very important biological properties.

Starch is one of the best-known complex sugars. It is particularly important as an energy store in plants. The sugars produced by photosynthesis are rapidly converted to starch. Particularly rich sources are plant storage organs such as potatoes.

Glycogen is sometimes referred to as 'animal starch'. It is the only carbohydrate energy store found in animals. It is found mainly in muscle and liver tissue, which is very active and needs a readily available energy supply at all times.

Cellulose is an important structural material in plants. It is the main constituent in plant cell walls. Just like starch and glycogen it consists of long chains of glucose – but in this case the glucose molecules are held together in a slightly different way. This is very important, because human beings, and indeed most other animals, cannot break down these linkages and so they cannot digest cellulose.

Proteins

Proteins are compounds that are made up of small chemical units called **amino acids**. They are used for body-building. They are broken down in digestion into amino acids that are then rebuilt to form the proteins you need. About 17–18% of your body is made up of protein – a high percentage second only to water. Your hair, skin, nails, the enzymes that control all the reactions in your cells and digest your food, many of the hormones that control your organs and their functions, your muscles and much, much more depends on these complex molecules. Protein differ from each other in the number and type of amino acid they contain, the sequence of amino acids and the actual shape of the molecule.

Just like carbohydrates and fats, proteins are made up of the elements carbon, hydrogen and oxygen, but in addition they all contain **nitrogen**. Some proteins also contain **sulphur** and various other elements. Proteins are polymers, made up of many small units joined together. These small units are called **amino acids**. In the same way that monosaccharide units join together to form polysaccharides, so amino acids combine in long chains to produce proteins. There are about 20 different naturally occurring amino acids and they can be joined together in any combination. Amino acids are joined together in a condensation reaction and a molecule of water is lost. The bond formed is known as a **peptide link**. The long chains of amino acids then coil, twist, spiral and fold in on themselves to make the complex structures we know as proteins.

Protein can provide energy and structural proteins are needed for building and repairing damaged tissues and muscles. Some proteins are insoluble in water and are very tough, which makes them ideally suited to structural functions within living things. These proteins are found in connective tissue, in tendons and the matrix of bones (**collagen**), in the structure of muscles, in the silk of spiders' webs and silkworm cocoons and as the keratin that makes up hair, nails, horns and feathers. Others are soluble in water. These form antibodies, enzymes and some hormones, and are also important for maintaining the structure of the cytoplasm in your cells.

The complicated way in which the structures of proteins are built up means that they can be relatively easily damaged and **denatured**. The relatively weak forces that hold the different parts of the amino acid chains together can be disrupted very easily. A rise in **temperature** of a few degrees or a change in **pH** is enough to destroy the 3-D structure of cellular proteins – and so destroy life itself.

Lack of protein in the diet may well be linked to an overall lack of energy intake, and results in a number of diseases known as protein-energy **malnutrition**. The best known of these are marasmus and **kwashiorkor**. It is a severe deficiency of protein in children. It is characterized by discolored hair, skin, bloated belly due to fluid imbalance, and thin legs.

Lipids (Fats and Oils)

Another group of organic chemicals that make up your body cells are the fats and oils, also known as the **lipids**. Lipids include some of the highest profile chemicals in public health issues at the moment – **cholesterol** and fat. Lipid-rich foods include anything containing large amounts of fats and oils. They are an important source of energy in your diet and they are the most effective energy store in your body – they contain more energy per gram than carbohydrates or proteins. Fats contain twice as much energy as carbohydrates i.e., 1 gram of fat yields 9.5 K cal or 38 KJ and best suited for storing energy. Combined with other molecules, lipids also play vital roles as hormones, in your cell membranes and in the nervous system.

All lipids are insoluble in water, but dissolve in organic solvents. This is important because when they are present in your cells they do not interfere with the many reactions that go on in the cytoplasm, because the reacting chemicals are all dissolved in water. The best-known lipids are the **fats and oils**. They are chemically extremely similar, but fats, e.g. butter, are solids at room temperature and oils, e.g. niger seed oil (nug), are liquids at room temperature. The lipids found in animals are much more likely to be solid at room temperature than plant lipids.

Just like the carbohydrates, the chemical elements that go into all lipids are carbon, hydrogen and oxygen. There is, however, a considerably lower proportion of oxygen in lipid molecules. Fats and oils are made up of combinations of two types of organic chemicals, **fatty acids and glycerol**.

Glycerol is always the same, with the chemical formula $C_3H_8O_3$. On the other hand, there is a wide range of fatty acids. Over seventy different ones have been extracted from living tissues and the nature of the lipid depends a lot on which fatty acids are in it. All fatty acids have a long hydrocarbon chain – a pleated backbone of carbon atoms with hydrogen atoms attached. There are two main ways in which fatty acids vary; the length of the carbon chain can differ, and the fatty acid may be **saturated** or **unsaturated**.

In a saturated fatty acid each carbon atom is joined to the one next to it by a single covalent bond. In an unsaturated fatty acid, the carbon chains have one or more double bonds in them. Unsaturated fatty acids are more common in plant lipids.

Recent medical research seems to indicate that high levels of fat, and particularly saturated fat, in our diet are not good for our long term health. Fatty foods are very high in energy, and so a diet high in fats when food is in plentiful supply is likely to result in obesity. Worse than this, however, is the implication that saturated fats found particularly in animal products such as dairy produce and meat – can cause problems in your metabolism. They seem to cause raised levels of a lipid called **cholesterol** in your blood.

Cholesterol is a substance which you make in your liver. It gets carried around your body in your blood. You need it to make the membranes of your body cells, your sex hormones and the hormones which help your body deal with stress. Without cholesterol, you wouldn't survive. However, high levels of cholesterol in your blood seem to increase your risk of getting heart disease or diseased blood vessels. The cholesterol builds up in your blood vessels, forming fatty deposits which can even block the vessels completely.

Minerals

Mineral salts are needed by the body in very small quantities and are not found in major food substances. Mineral salts are needed in minute amounts, but lack of them in your diet can lead to a variety of unpleasant conditions. Mineral salts of various kinds are essential for the proper functioning of the body. They yield no energy but are important constituents of certain tissues, besides playing a major role in the regulation of metabolic activities. However, if some of them are entirely missing from the diet, certain defect occurs in the body and produce diseases called **deficiency diseases**.

Table. Some of the mineral elements needed by the body

Mineral	**Foods contain them**	**Use in the body**	**Deficiency diseases**
Sodium (Na)	Table salt, beef, spinach	Nerve conduction, pH value	Muscle strain
Potassium (K)	Banana, potato, spinach, orange, beans	Nerve conduction, muscle contraction	
Calcium (Ca)	Milk, cheese, fish, leafy vegetables	Strong bones and teeth	Weakness of bones and teeth
Phosphorus (P)	Meat, dairy products, whole praikns milk	Strong bones and teeth with calcium	Rickets
Chlorine (Cl)	Cabbage, table salt ,cheese, eggs	HCl formation in the stomach, water balance	
Iron (Fe)	Liver, eggs, legume, teff, beef	Hemoglobin synthesis	Anemia, low RBC
Iodine (I)	Iodinated table salt, sea foods, onions	Thyroxine hormone synthesis	Goiter enlarged thyroid gland
Sulphur (S)	Meat, fish, egg, legumes	Synthesis of amino acids and proteins	

Vitamins

Vitamins are organic compounds necessary in small amounts for proper growth. They are usually complex organic substances that are nevertheless capable of being absorbed directly into your bloodstream from the gut. If any particular vitamin is lacking from your diet in the long term it will result in a **deficiency disease**. Different foods are rich in different vitamins and it is important to take in a range of all the important vitamin-rich foods in your diet.

Table. Major vitamins, their source and the deficiency diseases due to their limitations

Vitamins	**Foods rich in vitamins**	**Deficiency diseases**
A (Retinol)	Green pepper, carrots, leafy vegetables	Night blindness, poor growth, xeropthalmia (dryness of cornea of the eye)
B1 (Thiamin)	Whole cereals, sprouted beans, milk, liver	Loss of appetite, disease of muscles, nerve and heart called beri-beri
B3 (Niacin)	Milk, yeast, meat, fresh vegetables	Pellagra, which leads to mental disorder, memory loss and depression
B2 (Riboflavin)	Meat, milk, green vegetables, liver, peas	Slow growth, eye disease and sour mouth, inflammation of tongue
C (Ascorbic acid)	Vegetables, green peppers, lemons, oranges	Scurvy- pains in muscles and joints, bleeding gums, slow healing
D (Calciferol)	Fish liver oil, eggs, sun shine skin	Rickets – distorted legs in children, softening of bones in adults
E (Tocopherol)	Cereal oils, milk, egg yolk, lettuce, seeds	Sterility in animals such as rat, effect unknown in humans
K (Phylloquinone)	Green leafy vegetables	Prolonged blood clotting time

The role of water

Water is needed in large quantities in the diet even though it has no food value (calorie). It is vital constituent of a balanced diet. An average person can survive with little or no food for days if not weeks, but a complete lack of water will bring about death in 2–4 days, depending on other conditions such as temperature. Your body is actually between 60 and 70% water, depending on your age, how much you have drunk recently, etc. So it is not surprising that water is crucial in your body for a number of reasons, including:

- → All of the chemical reactions which take place in your body take place in solution in water
- → Water is involved in the transport of substances around the body food, hormones, waste
- → Water is involved in temperature regulation as you lose heat through sweating
- → Water is involved in the removal of waste materials in the urine and in the sweat
- → Water is a reactant in many important reactions in the body (hydrolysis reactions)

→ Water is needed for the osmotic stability of the body

Fiber in the diet

A final important part of a healthy diet is something that you can't even digest or absorb. **Roughage** or fibre cannot be broken down in the human gut, yet it is an essential part of your diet because it provides bulk for the intestinal muscles to work on. It also absorbs lots of water. In a diet low in roughage the movements of the gut which transport the food through it (**peristalsis**) are sluggish and the food moves through the gut relatively slowly. This can result in constipation.

What is nutrition?

Nutrition is the sum total of processes by which living organisms receive and utilize the materials necessary for survival, growth and repair of worn out tissues. Nutrition is obtaining food in order to carry out life processes. All living organism must take in some raw materials from which they can obtain energy and synthesis the various organic molecules needs to stay alive.

There are two main kinds of modes of nutrition.

Autotrophic nutrition- capable of synthesizing their own food via photosynthesis.

Heterotrophic nutrition – animals and non-green plants which cannot make their own foods.

The right balance of food is of enormous importance to your overall health and well-being. A **balanced diet** includes enough of all the major food groups (carbohydrates, proteins, lipids, minerals, vitamins and water) to supply the energy and nutrients needed to maintain the cells, tissues and organs of your body in a healthy state. A balanced diet supports healthy growth and development of your body when it is needed. If too little food is eaten (**undernutrition**) or too much food is taken in (**over nutrition**), or any one element of the diet is lacking then you will suffer from **malnutrition**. Malnutrition results when too much, too little or the wrong kinds of food is eaten.

If you eat too little food, your body becomes weak and thin. As a result, the growth and repair processes slow down and the body loses the ability to fight against infection. Too much food consumption results in a condition called **obesity**. Therefore, obesity is clearly caused by excess of food or energy input over energy output. This condition may damage the cardiovascular system, i.e., the heart and the blood vessels.

8.2. Non communicable diseases

Non communicable diseases (NCDs), also known as chronic diseases caused due multiple causes, are not passed from person to person. They are of long duration and generally slow progression. It accounts for a large and increasing burden of disease worldwide. It is currently estimated that non communicable disease accounts for approximately 60% of global deaths and 43% of global disease burden.

Communicable diseases on the other hand can be defined as:

An infectious disease transmissible (as from person to person) by direct contact with an affected individual or the individual's discharges or by indirect means (as by a vector). Some of the commonest types are:

- Measles
- Dengue
- Typhoid

Chronic conditions are characterized by the following:

→ Do not result from an (acute) infectious process
→ Are “not communicable” or Non-contagious origin
→ Cause premature morbidity, dysfunction, and reduced quality of life
→ Usually develop and progress over long periods
→ Often initially insidious
→ Once manifested there is usually a protracted period of impaired health
→ Complex etiology (causes)
→ Multiple risk factors
→ Long latency period
→ Functional impairment or disability
→ Incurability

Types of NCDs

There are different types of NCDs in the world. Some of them are mentioned below and discussed:

- Cardiovascular disease (Coronary heart disease, Stroke)
- Cancer
- Chronic lung disease
- Diabetes
- Chronic neurologic disorders (Alzheimer’s, dementias)

- Arthritis/Musculoskeletal diseases

More than nine million of all deaths attributed to non-communicable diseases (NCDs) occur before the age of 60. Around the world, NCDs affect women and men almost equally.

Risk factors

- ✓ Smoking
- ✓ Consumption of alcohol
- ✓ Bad Life style pattern (E.g.: Diet, Physical activity etc.)
- ✓ Insufficient health services
- ✓ Environmental factors (E.g.: air & water pollution, etc.)
- ✓ Stress conditions
- ✓ Hereditary characteristics

Cardiovascular diseases (CVD)

Cardiovascular disease is caused by disorders of the heart and blood vessels, and includes coronary heart disease (heart attacks), cerebrovascular disease (stroke), raised blood pressure (hypertension), peripheral artery disease, rheumatic heart disease, congenital heart disease and heart failure. Although heart attacks and strokes are major killers in all parts of the world, 80% of premature deaths from these causes could be avoided by controlling the main risk factors: tobacco, unhealthy diet and physical inactivity. Cardiovascular disease causes more than half of all deaths across the European Region. Around 80% of premature heart disease and stroke is preventable.

A contributing factors for this disease are:

- A person’s genetic make-up
- The foundations of adult health are laid in early life
- Socioeconomic group
- Mental health
- Diet
- Overweight and obesity
- Inactivity
- Tobacco and alcohol
- Diabetes
- Globalization and urbanization

Prevention

The main prevention ways are focusing on a combination of risk factors for cardiovascular disease and implementing medical screening for individuals at risk as well as providing effective and affordable treatment to those who require it.

Treatment

Effective measures are available for people at high risk. For example, combination drug therapy (such as aspirin, beta blocker, diuretic and statin) can lead to a 75% reduction in myocardial infarction (heart attack) among those at high risk of having one. But many such interventions are not being implemented, and about half of coronary patients in the world still require more intensive blood pressure management.

Cancer

Cancer is the uncontrolled growth and spread of cells that arises from a change in one single cell. The change may be started by external agents and inherited genetic factors and can affect almost any part of the body. The transformation from a normal cell into a tumor cell is a multistage process where growths often invade surrounding tissue and can metastasize to distant sites. Interaction between a person's genetic factors and any of three categories of external agents:

- **physical carcinogens**, such as ultraviolet and ionizing radiation or asbestos
- **chemical carcinogens**, such as vinyl chloride, components of tobacco smoke, aflatoxin (a food contaminant) and arsenic (a drinking-water contaminant) and
- **biological carcinogens**, such as infections from certain viruses, bacteria or parasites.

The majority of cancer deaths are occurred in lung, breast, colorectal, stomach and liver cancers. In high-income countries, the leading causes of cancer deaths are lung cancer among men and breast cancer among women. In low- and middle-income countries including Ethiopia cancer levels vary according to the prevailing underlying risks. In sub-Saharan Africa, for example, cervical cancer is the leading cause of cancer death among women.

The main associated risk factors for cancer includes tobacco use, unhealthy diet, insufficient physical activity, the harmful use of alcohol. Moreover, infections (hepatitis B, hepatitis C (liver cancer), human papillomavirus (HPV; cervical cancer), *Helicobacter pylori* (stomach cancer), radiation, variety of environmental and occupational exposures of varying importance are to mention a few.

At least one third of the 10 million new cases of cancer each year are preventable through reducing tobacco and alcohol use, moderating diet and immunizing against viral hepatitis B. Early detection and prompt treatment where resources allow can reduce incidence by a further one third. Effective techniques are sufficiently well established to permit comprehensive palliative care for the remaining more advanced cases.

Chronic respiratory diseases

According to the WHO Global Status Report on NCDs 2010, smoking is estimated to cause about 71% of all lung cancer deaths and 42% of chronic respiratory disease worldwide. Over half of all children aged 13–15 years in many countries in the European Region are exposed to second-hand tobacco smoke at home. Second-hand smoke causes severe respiratory health problems in children, such as asthma and reduced lung function; and asthma is now the most common chronic disease among children throughout the world. Over 12% of infant deaths in the world are due to respiratory diseases.

Indoor air pollution from biological agents related to damp and mould increases the risk of respiratory disease in children and adults. Children are particularly susceptible to the health effects of damp, which include respiratory disorders such as irritation of the respiratory tract, allergies and exacerbation of asthma. Damp is often associated with poor housing and social conditions, poor indoor air quality and inadequate housing hygiene. Increasing evidence suggests that allergic sensitization, which is the most common precursor to the development of asthma, can already occur antenatally. Emphasis on the health, nutrition and environment of the pregnant woman and the unborn child are therefore essential. Ozone pollution causes breathing difficulties, triggers asthma symptoms, causes lung and heart diseases

Diabetes

Diabetes is a chronic disease that occurs when the pancreas does not produce enough insulin (a hormone that regulates blood sugar) or alternatively, when the body cannot effectively use the insulin it produces. About 347 million people worldwide have diabetes. There is an emerging global epidemic of diabetes that can be traced back to rapid increases in overweight, obesity and physical inactivity. Diabetes is predicted to become the seventh leading cause of death in the world by the year 2030. Total deaths from diabetes are projected to rise by more than 50% in the next 10 years. More than 80% of diabetes deaths occur in low- and middle-income countries.

Elevated blood sugar is a common effect of uncontrolled diabetes, and over time can damage the heart, blood vessels, eyes, kidneys, and nerves. Diabetes increases the risk of heart disease and stroke; 50% of people with diabetes die of cardiovascular disease (primarily heart disease and stroke).

Prevention

To help prevent type 2 diabetes and its complications, people should:

- Achieve and maintain healthy body weight
- Be physically active at least 30 minutes of regular, moderate activity on most days
- Early diagnosis can be accomplished through relatively inexpensive blood testing.

Treatment of diabetes involves lowering blood sugar and the levels of other known risk factors that damage blood vessels. Tobacco cessation is also important to avoid complications.

Control

People with type 1 diabetes require insulin; people with type 2 diabetes can be treated with oral medication, but may also require insulin. Blood pressure control and foot care are possible.

Obesity

It is abnormal or excessive fat accumulation that presents a risk to health. It is the most prevalent form of malnutrition and is one of the most significant contributors of ill health. Central fat distribution or abdominal fat distribution or android obesity is more serious than gynoid fat distribution. Obesity is the second-leading cause of preventable death, surpassed only by smoking. Obesity is a major risk factor for a number of serious health conditions, including: Coronary heart disease, cancer, diabetes, fatty liver disease, gallbladder disease, high blood pressure, stroke and other breathing problems.

Body mass index (BMI) is a simple and widely used method for estimating body fat mass. BMI is calculated by dividing the subject's weight in kg by the square of his or her height in meter. Depending on this parameter, BMI <18.5 is underweight, between 18.5–24.9 is normal weight, between 25.0–29.9 overweight, between 30.0–34.9 is class I obesity, and between 35.0–39.9 is class II obesity.

It is mainly caused by poor physical inactivity, diet, drugs, medical conditions and genetics.

8.3. The digestive system

The digestive system consists of a system of tube called the **alimentary canal** (gut) and the associated digestive glands. The link between what comes in and what the body needs is the digestive system. The food we eat usually arrives in the system as large chunks bitten off by the teeth, chunks that contain large insoluble molecules such as starch, proteins and fats. These large molecules cannot be absorbed into the bloodstream and used by your body so they need to be broken down into smaller, simpler, soluble molecules. This is the main job of the **digestive system** – food substances are broken down into small soluble molecules as they pass through the gut. The digestive canal extends from the mouth to the anus, opening to the exterior at both ends. The wall of the tube is mainly muscular and is made up of layers of involuntary muscles.

The working of your digestive system is based on two things:

1. The **physical (or mechanical**) breakdown of the food: The food you eat is physically broken down into smaller pieces in two main ways. Your teeth bite and chew the food up in your mouth. Then your gut, which is a muscular tube, squeezes the food and physically breaks it up, while mixing it with various digestive juices to make it easier to move. By breaking the food up in this way, there is a much larger surface area for the digestive enzymes to work on.
2. The **chemical breakdown** of the food: The large insoluble food molecules must be broken down by hydrolysis reactions into small, soluble molecules so they can be absorbed into your body. This chemical breakdown is controlled by **enzymes**. This is called **chemical digestion**. Enzymes are proteins that speed up (catalyze) other reactions. They do not actually take part in the reaction or change it in any way except to make it happen faster. Enzymes are biological catalysts that usually work best under very specific conditions of temperature and pH.

Enzymes

Enzymes are complex protein molecules produced by living organisms. Enzymes play a vital role in digestion. They bring about changes and speed up (catalyze) chemical reactions but they are not themselves changed at the end of the reaction. They are also called **biological catalysts**. For life to carry on successfully it is important that the hundreds of reactions that occur in your body, making new materials and breaking things down, take place in a rapid and controlled way. This control is brought about by biological catalysts known as enzymes.

Enzymes are **very specific** – each type of reaction that takes place in your body is controlled by a specific enzyme that does not catalyze any other type of reaction. Some enzymes work inside your cells (**intracellular enzymes**) and some of them are secreted into organs of your body such as the gut where they catalyze specific reactions (**extracellular enzymes**). The digestive enzymes are extracellular- they work outside your cells in the lumen of your gut. Enzyme names usually (but not always) end in –ase, e.g. amylase breaks down starch, lipase breaks down fats, catalase breaks down hydrogen peroxide – but pepsin breaks down proteins!

The important characteristics and properties of enzymes are:

- → Enzymes are protein
- → Speed up chemical reactions remain unchanged at the end of the reaction
- → Enzymes are specific
- → Enzymes are sensitive to temperature and pH

The working of the gut

Ingestion is the act of taking of in food. The first stage is ingestion, or taking foodstuff into your body through the mouth. We bite off a chunk of food using our teeth, and then physically chop the food up into smaller pieces by chewing it. Your teeth play a very important role at the beginning of the process of digestion, physically breaking down your food and providing a greater surface area for your digestive enzymes to work on. This process is known as **mastication**.

Teeth have evolved to be very strong – in fact the **enamel** that covers them is the strongest substance made by the human body. Enamel is the hardest structure in the body that resist trauma and decay. Teeth are needed for a variety of different jobs – gripping food, tearing food and chewing food, for example. The shape of different teeth means they are ideally suited to their different functions. Because humans have a very varied diet (we are omnivores so we eat animals and plants) we also have a variety of different types of teeth. The incisors and canines are used for biting while the premolars and molars are used for chewing and crushing food.

The top surface is covered by a layer of non-living enamel, and under this is the living **dentine**.

It looks like a bone but softer than enamel. It contains living tissues. In the center(middle) of the tooth is the **pulp cavity**, which contains nerves and blood vessels. It is sensitive to heat, cold and pain. Your teeth are set into your jaw bone, and they are held in place by a layer of fibrous **cement**. This cement keeps your teeth firmly in place but at the same time allows a certain amount of flexibility as you are chewing.

Your adult teeth should last you all through your life. This doesn't always happen, because your teeth can be affected by the bacteria that cause **dental caries**. These bacteria, combined with food and saliva, form a thin film known as **plaque** on your teeth. If these bacteria are given a sugar-rich diet (in other words, if you eat a lot of sweet, sugary food) they produce a lot of acid waste. This acid attacks and dissolves the tough enamel coating of your teeth. The bacteria will reproduce and feed, eating away at your tooth until they reach the nerves of the pulp cavity causing **toothache**.

The same bacteria can affect your gums, causing **periodontal disease**. The symptoms include tender gums, bleeding when you clean your teeth and eventually the possible loss of all your teeth, not from tooth decay but from gum disease. Taking in lots of acidic food and drink, such as fruits and cola, can also weaken the enamel on your teeth.

Both problems be avoided, especially if you have good dental care available. Ways to avoid tooth decay include:

- ✓ Regular brushing of your teeth and gums twice a day. This removes the plaque from the teeth, preventing the build-up of a sticky, acidic film over the enamel.
- ✓ Avoiding sweet, sugary foods – if the bacteria in your teeth are deprived of sugar, they cannot make acidic waste and your teeth are safe.

If they are available:

Have regular dental check-ups. A dentist can clean your teeth more thoroughly than you can, and any early signs of decay can be treated. Your teeth won't heal themselves, but any tooth decay can be removed and replaced by a filling.

Moving foods in

Food enters the alimentary canal at the mouth or oral cavity. Food is mixed with saliva in the mouth. There are three major pairs of salivary glands under the tongue and behind the jaws that send their juices by way of ducts to the mouth. Your food is also coated in saliva from the salivary glands. Saliva contains a **carbohdrase** enzyme called **amylase**. Carbohydrases break down carbohydrates. The amylase in your saliva begins the digestion of the starch in complex carbohydrates such as bread or potatoes, turning it into simpler sugars. The saliva coated chunk of food (known as a **bolus**) moves to the back of your throat to be swallowed. Swallowing is a reflex action that takes place when food reaches the back of your throat. As you swallow, your epiglottis closes over the trachea, preventing food going down into your lungs; you can't swallow and breathe in at the same time. When your food is swallowed it travels down the **oesophagus** or **gullet**, squeezed along by muscular contractions known as **peristalsis**. It is responsible for the movement of the food along the entire digestive tract. Peristalsis is not confined to your oesophagus – it is important all the way through your gut to move the food through as it is digested, to mix the food with the digestive enzymes produced in the various parts of the gut and to continue the physical break-up of the food. The walls of your gut have a layer of circular muscles forming rings around it and a layer of longitudinal muscles that run the length of the gut. Waves of alternate contraction and relaxation of the different muscles move food through from one end of the gut to the other.

Stomach churning activity

At the lower end of the oesophagus your food passes through a ring of muscle called a **sphincter** into your **stomach**.as the swallowed food reaches the stomach, it is gradually mixed with gastric juice produced by the gastric glands. This is done by a churning movement (alternate contraction and relaxation of the muscles in the stomach walls). The gastric juice is a solution which consist of **hydrochloric acid**, **mucus**, and few e**nzymes**. The main protease made in the stomach is **pepsin** and **rennin**. The acid kills most of the bacteria that are taken in with our food. The acid also helps indirectly in the breakdown of the protein in your food, because pepsin works best in acid conditions. Your stomach also makes a thick layer of mucus, which protects the muscle walls from being digested by the protease enzymes and attacked by the acid.

Bile

Bile is a greenish-yellow alkaline liquid that is produced in the liver (a large reddish-brown organ that carries out lots of important jobs in the body). It is made by the liver cells and then stored in the **gallbladder** until it is needed. As food comes into the duodenum from the stomach, bile is squirted onto the stomach contents. The bile does two important jobs:

- It neutralizes the acid from the stomach and makes the semi-digested food alkaline. This is ideal for the enzymes in the small intestine, which work most effectively in an alkaline environment.
- Bile also **emulsifies** the fats in your food – it breaks down large drops of fat into smaller droplets. This provides a much bigger surface area of fats for the **lipase** enzymes to work on to break down the fats completely into fatty acids and glycerol.

As soon as the food leaves the stomach it enters the **duodenum**, the upper portion of the small intestine. The first part of the small intestine (the duodenum) cannot make its own enzymes. In the duodenum the food is acted upon by bile and digestive juices from the **pancreas** called **pancreatic juice**. The rest of the pancreas makes and stores enzymes that digest carbohydrates, proteins and fats. As food enters the small intestine from the stomach these enzymes are released to be mixed with the food paste by muscle action. The pancreatic juice contains three important enzymes, **trypsin**, **lipase** and **pancreatic amylase** which act upon proteins, fats and starch respectively.

The rest of the small intestine is a long (6–8 m) coiled tube that produces carbohydrase, protease and lipase enzymes of its own. The tube is coiled up to fit inside the body cavity. Your food, which is rapidly becoming completely digested in the alkaline environment, is moved along by peristalsis.

Once the food molecules have been digested, giving glucose, amino acids, fatty acids and glycerol, they are absorbed by your body (**absorption**). It is the process by which digested food passes through the walls of small intestine. They leave the small intestine by diffusion and go into the blood supply to be carried around the body to the cells that need them. The lining of the small intestine is specially adapted to allow as much diffusion as possible and as rapidly as possible. It has many finger-like projections of the lining (called **villi**) to increase the surface area for diffusion, and each individual villus in turn is covered in even smaller projections called **microvilli**. The villi also have a rich blood supply that carries away the digested food molecules and maintains a steep diffusion gradient. The diffusion distances are very small, and the whole process takes place in a water-based solution. All of these factors make the absorption of the digested food molecules from the small intestine into the blood supply very efficient.

The glucose molecules and amino acids go directly into the blood. The fatty acids and glycerol move initially into the **lacteals** (dense network of blood capillaries in the villi), which are part of the lymph system. The lymphatic fluid with its load of fatty acids and glycerol then eventually drains into the blood as well. Once the digested food molecules have all been taken into the blood they are taken in the **hepatic portal vein** to the liver, which processes some of the food. The remaining products of digestion are carried around the body to the cells where they are needed. They are built up into the molecules required by the cells. This is known as **assimilation**.

The end of the story

After the digested food molecules have been absorbed into the blood, a watery mixture of enzymes, undigested food (mainly cellulose), bile pigments, dead cells and mucus is left in the small intestine and is moved along by muscle contractions into the large intestine. This waste i.e., the undigested foods having no nutritive value pass into the large intestine. It is about 1 m long in man. By the end of the large intestine the thick paste that remains is known as the **faeces**. The journey ends as the faeces leave the body through the **rectum** and the **anus** as a result of a final set of muscle contractions. This removal of the faeces from your body is called **egestion** or **defecation**. It is not

excretion because excretion involves the removal of the waste products from the cells, and the final contents of your gut have never been inside your cells.

Constipation

If the faeces remain in your large intestine for too long, too much water is removed from them. They become compacted, hard and difficult to evacuate from your body. This is constipation and the most common causes are a lack of fiber in the diet and not drinking enough water. Straining to pass faeces can cause hemorrhoids (piles) or a tear in the anus. Constipation can usually be treated relatively easily. This may involve eating more fiber or having a proper roughage in the diet, drinking plenty (so the faeces remain soft) and sometimes taking laxatives (chemicals which stimulate the gut to contract and force out the faecal material). If the faeces become completely compacted (which happens very rarely) they can block the gut. This is a very serious situation which may have to be relieved by surgery.

Diarrhea

On the other hand, if an infection causes the gut to contract more strongly or more rapidly than usual, the faeces that are produced may be very loose and watery. This is known as diarrhea. Often this condition clears up within 24 hours, but in the very young and the very old – and anyone if it persists – diarrhea can be fatal as it causes dehydration of the tissues. It can be treated very simply by giving the sufferer frequent drinks of water with rehydration salts (mainly salt and sugar). These replace the fluids that are being lost and keep the body tissues hydrated until the immune system overcomes the infection. Millions of people around the world, particularly children and old people, die from untreated diarrhea every year.

Food hygiene

It is not only the balance of food in your diet that can affect your health. There are a number of food-borne diseases. Bacteria growing on food that you eat can make you very ill and even kill you. For example, raw meat and raw eggs can contain bacteria such as salmonella that cause **diarrhea and sickness** (vomiting). In most people food-borne diseases are not too serious, but young children, the elderly and anyone who has other health problems can be very seriously affected. You need to maintain very strict food hygiene when you are preparing food to avoid these diseases. Store raw meat and eggs separately from salad vegetables and fruit. Wash the knives used to cut meat and the work surfaces on which it is prepared before preparing salads or cutting cheese. Disinfect work surfaces regularly. And most important of all, anyone preparing food must wash their hands between handling different types of food and when they have been to the toilet. Gut bacteria from the faeces can be transferred from the hands to the food very easily and cause stomach upsets to spread around a family or a community.

8.4 The respiratory system

Breathing is the mechanical process of taking oxygen into the body and giving off carbon dioxide as a waste product. All mammals have lungs as a breathing organs. Your respiratory system is beautifully adapted for the job it has to do. Human breathing system consists of the nasal cavity, pharynx, trachea, bronchi bronchioles and alveoli within the lungs. Your nose contains the **nasal cavity (**passages), which have a large surface area, a good blood supply, lots of hairs and a lining that secretes mucus. The hairs and mucus filter out much of the dust and small particles such as bacteria and pollen that we breathe in, whilst moist surfaces increase the humidity of the air we breathe into our bodies and the rich blood supply warms it. All this means that the air we take in is already warm, clean and moist before it gets into the delicate tissue of our lungs.

Air leaving the nasal cavity goes into the **pharynx**, the space behind the nasal cavity and the mouth. From here air goes into the trachea or wind pipe. As the air leaves the pharynx, it enters the **trachea** or wind pipe. The wall of the trachea contains rings of cartilage that keep the tube open for the passage of air. air can – and does – make its way down into your gut, this doesn't matter as you can simply bring it back up in the form of a burp. However, it is very important that food does not get into your lungs. It can block the airways or cause a fatal infection and so the **epiglottis** closes off your trachea every time you swallow in a reflex action. Since pharynx is the common passage for both food and air, epiglottis closes the opening of trachea during swallowing.

At the top of your trachea sits your **larynx** or **voice box** which contains the vocal cords. By directing air leaving the lungs over the vocal cords (flaps of muscle) in the larynx, the vibration of this cords produce the sounds that you use in speech. The trachea itself has a series of incomplete rings of cartilage (shaped like the letter C) that support it and hold it open. They are incomplete so that you can swallow your food. The cells that line the trachea are also covered in hair-like cilia that beat to move the mucus with any trapped micro-organisms and dirt away from your lungs and towards your mouth. This mucus is then either swallowed and digested or coughed up.

The trachea splits into two tubes; the left and right **bronchi** (singular bronchus), one leading to each lung. The bronchi are also supported by rings of cartilage.

+Inside your lungs, the bronchi divide into smaller tubes known as the **bronchioles**. The bronchioles are much smaller than the bronchi, dividing into ever smaller tubes until they reach the main structures of the lungs – the **alveoli** (singular alveolus). There are millions of these tiny air sacs, giving a massive surface area for the main exchange of gases in the lungs to take place.

The exchange of gases between the lungs and the blood occurs at alveoli. For your respiratory system to work you need to move air into your lungs and then move it out again. This is brought about by movements of the **ribcage**. Breathing is the movement of air into and out of the lungs. It is caused by the action of muscles between the ribs known as **intercoastal** muscles and the **diaphragm**. The movement of oxygen into the blood and carbon dioxide out of the blood takes place at exactly the same time – there is a swap or exchange between the two and so this process is known as **gaseous exchange**.

The mechanism of gas exchange in the alveoli depends on:

- large surface area
- moist surfaces
- short diffusion distances, and
- rich blood supply maintaining steep concentration gradients.

There are two types of breathing movements. These are **inspiration** (the act of inhaling or taking in air into the lungs) and **expiration** (the act of exhaling or expelling air from the lungs). If we analyze the gases in inhaled and exhaled air, we can compare their composition and show the levels of oxygen and carbon dioxide change.

Table approximate composition of air inhaled and exhaled air

Atmospheric gas	Air breathed in	Air breathed out
Nitrogen	About 80%	About 80%
Oxygen	21%	16%
Carbon dioxide	0.04%	4%
Water vapor	Less	More

What affects your breathing rate?

The average resting breathing rate for an adult human being is around 12–14 breaths per minute. This supplies the oxygen needed for all of the normal activities of your cells, but it does not use up all of the capacity of your lungs. When you are breathing normally at rest, you take about 500 cm3 of air in and out each time you breathe – this is only about 15% of your possible maximum. This is known as your **tidal volume** of air. The **vital capacity** of your lungs is the absolute maximum amount of air you can take into or breathe out of your lungs. Anything that increases the oxygen requirements of your body will tend to increase your breathing rate. The main factors known to have an effect are exercise, anxiety, drugs, environmental factors, altitude, weight and smoking.

When breathing fails

Sometimes breathing fails. This can be the result of a number of different things, including an accident, drowning or a heart attack. Once breathing stops, death will result in a matter of minutes as the brain in particular is starved of oxygen. However, it is possible to take over breathing for a casualty in this situation, and this may be enough to keep them alive until medical support arrives.

It is very important that mouth-to-mouth resuscitation should ONLY be given when the casualty has stopped breathing, not just when they are unconscious. The procedure for this is as follows:

1. **Call for help loudly**. Use a phone to get help if you can.

2. **Check to see if the casualty is conscious** – use their name if you know it, ask their name and ask if they can hear you. NEVER use artificial respiration on a conscious patient. Call for help. If you are sure the patient is unconscious.

3. **Open the airway**. Remove any obstacles from the mouth which might block the airway, e.g. water weed, vomit. Tilt the head back and lift the chin. This opens the airways and may be enough to start breathing again. **Call for help again**.

4. Check for breathing. Put your head near the casualty's nose and mouth. Observe for at least 5 seconds before you decide the person is not breathing. Call for help. NEVER use artificial respiration on a casualty who is breathing.

5. Make sure the airway is open and the head is tilted back. Pinch the casualty's nostrils closed with one hand. Keep the chin lifted with the other hand.

6. Use a clean piece of cloth over the mouth to avoid the transfer of HIV through contact and other infections. Take a deep breath and then seal your mouth around the person's mouth. Breathe out firmly into the person's mouth until you see the chest rise. This will show you that you are getting air into their lungs.

7. Remove your lips and let the chest fall naturally.

8. Repeat these steps at about 12 breaths per minute – a steady rate. The colour should return and the person may begin breathing for themselves. If not, continue until medical help arrives.

8.5. The circulatory system

Small, single-celled organisms rely on simple diffusion to exchange materials between the outside world and the inside of their cells. The diffusion distances are short, so diffusion works really well. The bigger the organism, the less effective simple diffusion becomes as a means of transport. Because our **surface area to volume ratio** is such that diffusion simply cannot cope.

The human transport system is the blood circulation system. The **circulatory system** of the human body consists of tubes of various sizes called **blood vessels (**the pipes**)**, fluid tissues called **blood (**the medium**)**, and a pumping organ, the **heart (**the pump**)**. Human beings are made up of billions of cells, most of them a very long way from a direct source of food or oxygen, so a more complex transport system is required to supply the needs of the body cells and remove the waste material they produce.

A double circulation

We have a **double circulation**, one carrying blood from the heart to the lungs and back again to exchange oxygen and carbon dioxide with the air, the other carrying blood all around the rest of the body and back again. This gives us a very effective way of getting oxygen into the blood and then supplying it to all the body cells. In the **pulmonary circulation**, blood flows from the heart to the lungs and back again. In the **systemic circulation** blood is pumped from the heart all around the body and back to the heart again.

A double circulation like this is very important in warm-blooded, active animals like ourselves because it is very efficient. It lets our blood get fully oxygenated in the lungs before it is sent off to the different parts of the body. In animals like fish that have a **single circulation**, as soon as the blood has picked up oxygen it starts to lose it again to the tissues, so very few parts of the body receive fully oxygenated blood.

The blood vessels

A very important element of any transport system is the pathways along which the transport takes place. The three main types of blood vessels, **arteries**, **veins** and **capillaries**, which are adapted to carry out particular functions within the body, although they are all carrying the same blood.

The **arteries** carry blood away from the heart so they have to be able to withstand the pumping of the heart forcing the blood out into the circulation. This is usually oxygenated blood so it is bright red. Most arteries carry blood that is rich in O_2 and food. Arteries have thick walls that contain muscle and elastic fibers, so that they can stretch as the blood is forced through them and go back into shape afterwards. Because the blood in the arteries is under pressure, it is very dangerous if an artery is cut because the blood spurts out rapidly every time the heart beats. This means blood is lost very rapidly and the bleeding is difficult to stop. The **pulmonary artery** carries deoxygenated blood from the right ventricle to the lungs. The largest artery is **aorta** and the smallest arteries are called **arterioles**.

The **veins** carry blood towards your heart – it is usually low in oxygen and so is a deep purple-red colour. The veins return blood to the heart. They have much thinner walls than arteries and the blood in them is under much lower pressure because it is a long way away from the thrust of the heart. They do not have a pulse, but they often have valves to prevent the back-flow of blood as it moves from the various parts of the body back to the heart. The only veins that carry bright red blood are the **pulmonary veins**, which carry oxygenated blood back from your lungs to the left-hand side of your heart, and the umbilical vein, which carries oxygenated blood from the placenta back to the developing foetus to supply it with the food and oxygen it needs to grow. The smallest veins are called **venules** and **vena cava** are the largest veins.

Capillaries are blood vessels that connect the smallest arteries with the smallest veins. Between the arteries, that bring blood from the heart, and the veins, that take it back to the heart, are very narrow, thin-walled blood vessels called capillaries. The capillaries link the other two types of blood vessels. These take the blood into all the organs and tissues of the body. The capillaries are the site of the exchange of substances within the body. Blood from the arteries passes into the capillaries, which have very thin walls and a massive surface area.

The human heart

The contraction of the powerful muscles of the heart provides most of the force required to keep blood in circulation. The human heart is a bag of reddish-brown muscle that beats right from the early days of our development in the uterus until the end of our life, sending blood around the body. The heart is made up of two pumps that beat at the same time so that blood can be delivered to the body about 70 times each minute. The heart is made up of a unique type of muscle known as **cardiac muscle**, which can contract and relax more or less continuously without fatiguing. The contraction is stimulated in heart itself by specialized tissue called the **pacemaker**.

The walls of the heart are almost entirely muscle. These muscular walls are supplied with blood by the **coronary arteries**, so that they have a constant supply of glucose and oxygen and the carbon dioxide produced is not allowed to build up in the tissue. The deoxygenated blood is carried away in the coronary veins, which feed back into the right **atrium**.

The walls of the atria are relatively thin, so they can stretch to contain a lot of blood. The walls of the **ventricles** are much thicker, as they have to pump the blood out through the major blood vessels. The muscle walls of the left-hand side of the heart are thicker than on the right. This is because the left hand side of the heart has to pump blood around the whole body whilst the right-hand side pumps only to the lungs.

The working of the heart

The two sides of the heart fill and empty at the same time to give a strong, coordinated beat, but to understand what happens it is easier to follow a single volume of blood around the heart.

- → Deoxygenated blood, which has supplied oxygen to the cells of the body and is loaded with carbon dioxide, comes into the right atrium of the heart from the veins of the body.
- → The atrium contracts and forces blood into the right ventricle.

- → The right ventricle contracts and forces blood out of the heart and into the lungs where it is oxygenated – it picks up oxygen.
- → Oxygenated blood returns to the left-hand side of the heart from the lungs and the left atrium fills up.
- → The left atrium contracts forcing blood into the left ventricle.
- → The left ventricle contracts forcing oxygenated blood out of the heart and around the body.

Inside the heart there are many different **valves**. Their names describe their appearance – bicuspid (two parts) tricuspid (three parts) and semilunar (half-moon). Each time the muscular walls of the heart contract and force blood out, some of these valves open to allow the blood to flow in the right direction, and other valves close to make sure that the blood does not flow backwards. The noise of the heartbeat we can hear through a stethoscope is actually the sound of these valves transporting the surging blood.

Diastole is when the heart muscles relax and it fills with blood. **Systole** is when the heart muscles contract and force the blood out of the heart. It is the contraction of auricle or ventricles of the heart. A heart beat constitutes a complete **cardiac cycle** made up of systole followed by diastole. A normal blood pressure is 120 mmHg/80 mmHg – usually quoted as 120 over 80 or 120/80. Blood pressure is used as a measure of the health of both the heart and the blood vessels.

The flexible heart

When we are resting our heart beats steadily at around 70 beats every minute, supplying all the needs of the cells. However, physical exercise means that muscles need more food and oxygen to work, and so the heart needs to supply more blood. It does this in two ways. The heart beats faster – the pulse rate can easily go up from rest to 120 or even 140 beats a minute, increasing the amount of blood flowing around the body. The heart can also increase the amount of blood pumped out at each heartbeat. Age, exercise, anger, disease and drugs affect the rate of the heartbeat.

The blood

The heart and the blood vessels are there to carry the transport medium around your body – and the transport medium is your blood. Your blood is a complex mixture of cells and liquid that carries a huge range of substances around the body. The blood carries nutrients, respiratory gases (CO_2

and O_2), metabolic wastes, and other substances. It consists of a liquid called the **plasma**, which carries **red blood cells**, **white blood cells** and **platelets**.

The **plasma** is a pale yellow liquid that transports all the blood cells that contain about 90% water. The remaining 10% consists of dissolved and suspended substances such as digestive end products, vitamins, mineral salts, antibodies, hormones nitrogenous wastes (urea) and plasma protein. Carbon dioxide produced in the organs of the body is carried in the plasma back to the lungs. Similarly, urea, a waste product from the breakdown of excess proteins formed in the liver, is carried in the plasma to the kidneys where it is removed from the blood to form urine.

One of the main components of your blood is the **red blood cell** = RBC (**erythrocytes**)s. There are more red blood cells than any other type of blood cell. They are superbly adapted to their role in carrying oxygen around your body and supplying it to the cells where it is needed. They are disk-shaped structure and their shape increases their surface area. They are formed in the **bone marrow** ribs and vertebrae and they lose their nucleus. This means that there is more room to carry extra haemoglobin – another adaptation to their all-important function. Each RBC contains a pigmented molecule called **hemoglobin**, which picks up oxygen. RBCs are small, about 7.5 microns in diameter.

Hemoglobin is a very special red pigment, a large protein molecule folded around four iron atoms. In a high concentration of oxygen, such as in the lungs, the haemoglobin reacts with oxygen to form **oxyhemoglobin**. This is bright scarlet, which is why most arterial blood is bright red. In areas where the concentration of oxygen is lower, such as the cells and organs of the body, the reaction reverses. The oxyhemoglobin splits to give purple-red haemoglobin (the colour of venous blood) and oxygen. The oxygen then passes into the cells where it is needed by diffusion. This reversible reaction makes active life as we know it possible by carrying oxygen to all the places where it is really needed.

$$\text{haemoglobin + oxygen} \xleftrightarrow[\text{low oxygen concentration}]{\text{high oxygen concentration}} \text{oxyhemoglobin}$$

There are about 5 million RBCs per cubic millimeter of human blood. The life span of RBCs is 120 days in males and 110 days in females after which they are destroyed and removed in the liver and the spleen. Because the haemoglobin in your red blood cells is based on iron, it is important to eat enough iron in your diet. Without it, the body cannot make enough red blood cells and you suffer from **anemia**. People who are anemic are pale and lack energy, because they cannot carry enough oxygen around the body for their needs.

Another important component of your blood is the **white blood cells** = WBCs (**leukocytes**). They are much bigger than the red cells and there are fewer of them. WBCs are irregularly shaped colorless cells that have nuclei. They produced in bone marrow, lymph nodes and spleen. There are only 8000 WBCs per cubic millimeter (mm^3) of human blood. Their number increased when the body is infected and form part of the body's defense system against microbes. Some white blood cells – the lymphocytes form antibodies against microbes whilst others – the **phagocytes and lymphocytes** engulf (eat) invading bacteria.

Blood Platelets (**thrombocytes**) are another component of your blood. They are small fragments of cells and they are very important in helping your blood to clot at the site of a wound. They are non-nucleated and colorless bodies produced in the red bone marrow. When platelets arrive at a wound site they are involved in the formation of a network of protein threads. Then as more platelets and red blood cells pour out of the wound they become entangled in the mesh of threads forming a jelly-like clot. This soon dries and hardens to form a scab. The clotting of the blood is a very important process activated by thromboplastin in the presence of calcium. It prevents you from bleeding to death from a simple cut. It also protects your body from the entry of bacteria and other pathogens (disease-causing micro-organisms) through an open wound, and protects the new skin from damage as it grows.

Human blood groups

One way of typing blood is the **A-B-O** system. Using this system, the four blood types are A, B, AB and O. these four types of blood are called **blood groups**. A number of special proteins called **antigens** are found on the surface of all cells. They allow cells to recognize each other and also to recognise cells from different organisms. If the cells of your immune system recognise a foreign antigen on a cell in your body, they will produce **antibodies**. These antibodies will join on to the antigen and destroy the foreign cells. This is how your immune system recognises and fights the organisms which cause disease.

A number of different antigens are found specifically on the surface of the red blood cells. This gives us the different human blood groups. In this system there are two possible antigens on the red blood cells – antigen A and antigen B. There are also two possible antibodies in the plasma, known as antibody A and antibody B. Unlike most other antibodies, these antibodies are present in your body all the time. They are not made in response to a particular antigen.

Table. Antigens and antibodies of different blood groups

Blood group	**Antigen on red blood cells**	**Antibody in the plasma**
A	A	B
B	B	A
AB	AB	none
O	none	ab

Blood transfusion- is the transfer of blood, parts of blood or solution into a person's blood. If the blood from different blood groups is mixed together, there may be a reaction between the antigen and the complementary antibody which makes the red blood cells stick together (**agglutinate**). This means they cannot work properly. They block the capillaries and even larger blood vessels. Most of the time this is not important since everyone keeps their own blood in their own circulatory system.

Before a transfusion it is vital to know the blood groups of both the person giving the blood (the **donor**) and the person receiving the blood (the **recipien**t). This means the right type of blood can be given to prevent agglutination. The blood groups must be **compatible**. For example, blood group O has no antigens so it can be given to anyone, but someone who has blood group O has both antibodies so they can only receive group O blood! On the other hand, someone with blood group AB which has no antibodies can receive any type of blood!

Table. Transfusion of blood groups

Blood group	**Can be transfused into**	**Can be receive blood from**
A	A and AB	A and O
B	B and AB	B and O
AB	AB only	All groups
O	All groups	O only

Two common problems of the circulatory system

One common problem of the circulatory system is a condition called **anemia**. If you are anemic you have too few red blood cells in the body, or the levels of the oxygen-carrying red pigment haemoglobin in your blood are too low. There are a number of causes of anemia. The most common is a lack of iron in the diet.

Hypertension is another common complaint of the circulatory system. Hypertension is the medical name for high blood pressure. Blood pressure is considered high if the systolic pressure is greater than 140 mmHg or the diastolic pressure is greater than 90 mmHg. For 90% of the cases of hypertension, the cause is unknown. For the other 10%, hypertension is a symptom of another disease, such as chronic kidney diseases or diseases in the arteries supplying the kidneys, chronic alcohol abuse, hormonal disturbances or tumors. There are many factors mean that your blood vessels are likely to be getting narrower, or becoming more rigid, both of which increase your blood pressure. These factors include: increasing age, being overweight, excessive salt intake, excessive consumption of alcohol, sedentary (inactive) lifestyle, smoking, kidney diseases, diabetes and certain medicines, such as steroids. There is also evidence to suggest that hypertension may be genetic (i.e. run in the family).

Treatment of hypertension

For many people hypertensions can be managed through lifestyle adjustments. Losing weight, lowering the salt levels in the diet becoming more active will lower the blood pressure back within normal level for some people. Some common medication ones include **diuretics**, which increase the frequency of urination. These remove water from the body, which reduces the blood volume and so lowers the blood pressure. There are other drugs that block the nerves which narrow the arteries. These are known as **beta blockers**, while there are other drugs which act directly on the brain. Once people start using medication for hypertension, they will usually need it for many years or life. Because of the long timescale for treating hypertension, cost is an important consideration in the choice of drugs.

8.6. The nervous system

In the simplest form, the **nervous system** is an organ system specifically designed to sense the environment and to produce a response to changing conditions. The nervous system is very important in helping to maintain the homeostasis (balance) of the human body. A series of sensory receptors work with the nervous system to provide information about changes in both the internal and external environments. The human nervous system is a complex of interconnected systems in which larger systems are comprised of smaller subsystems each of which have specific structures with specific functions.

The nervous system has a number of receptors designed to accumulate information about the environment. Examples of these receptors include: taste buds, rods and cones on the retina, pressure sensors in the skin. The nervous system transmits signals from one part of the body to another (taste to brain) by using neurons. The brain acts as the main filter for information coming from all over the body. The brain then has to prioritize information that is more important than others. The brain has to then decide upon a set of actions to respond the environment. The brain can cause a multitude of reactions to respond to the environment such as: the movement of a muscle to avoid a moving object the increase of heart rate to escape from a bear the increase in pupil sight to see in the dark. **Electrochemical impulses** transmit signals to other parts of the nervous system. There is an all or none response to stimulus (either the nerve cell decides to send a message, or it remains inactive). There is no difference in the strength of the impulse. Once it decides to send a message, the message cannot be recalled.

The nervous system in man and in other higher animals is composed of 2 major components:

- → **Central nervous system (CNS)**

Central nervous system consists of brain and spinal cord. CNS = brain + spinal cord.

- → **Peripheral nervous system (PNS)**

Peripheral nervous system consists of nerves that arise from brain and spinal cord (CNS) and spread in different parts of body. PNS = nerves.

All these components are made of neurons, it means CNS (brain & spinal cord) and PNS (nerves) all are made of neurons. A neuron is the smallest unit of the nervous system. Every part of the nervous system is composed of specialized neurons. There are different parts of the neuron. Neuron or nerve cell and it is the unit of nervous system. The human nervous system consists of billions of neurons plus supporting cells called **neuroglial cells**. Human nervous system = neurons + neuroglial cells. Neurons are cells, just like other cells of the body, but they are specialized cells because they transmit information from one part of the body to the other in the form of electrical impulses. In this way they communicate with each other and with other types of body cells. This means that neuron communicates with other neurons in nervous system and neuron also communicates with other cells of body such as heart cells, muscle cells etc. This communication occurs through junctions called **synapses**.

Neurons have 3 distinct parts:

- ✓ **Cell body (soma)**

The Cell Body is the center of the cell. Here most chemical reactions occur, DNA is in the nucleus, most of the organelles are located here. Nucleus and most of the cytoplasm of the neuron is located in its cell body.

- ✓ **Axon**

The axon transmits the message along the rest of the neuron to the next neuron. Axons conduct impulses away from the cell body.

- ✓ **Dendrites**

Dendrites receive information. This can come from two sources, other neurons or specialized receptors (like taste buds). Dendrites conduct impulses toward cell body

Schwann cells are special neuroglial cells located at regular intervals along axons. Myelin sheath; in some neurons schwann cells secrete a fatty layer over axons called myelin sheath. Nodes of [redacted]

Types of neurons

There are three basic types of neurons. These are:

- Sensory neurons = they conduct sensory information from receptors towards CNS. They have one dendrite and one axon.
- Interneurons = Form brain and spinal cord. They receive information, interpret them and stimulate motor neurons. They have many dendrites and axons.
- Motor neurons = Carry information to muscles or glands (effectors). They have many dendrites but only one axon.

Nerve is a union of several axons that are enveloped by a covering made of lipid. Based on the property of axons, nerves are classified into 3 types.

- ❖ Sensory nerves: contains the axons of sensory neurons only.
- ❖ Motor nerves: contain the axons of motor neurons only.
- ❖ Mixed nerves; contain the axons of both sensory and motor neurons.

A nerve is an enclosed, cable-like bundle of nerve fibers called axons, in the peripheral nervous system. A nerve transmits electrical impulses and is the basic unit of the peripheral nervous system.

Peripheral nervous system is composed of nerves and ganglia. A ganglion is a group of neuron cell bodies in the peripheral nervous system. In certain parts of body, the cell bodies of many neurons form a group enveloped by a membrane, this is called **ganglion**. Ganglia are ovoid structures containing cell bodies of neurons and glial cells supported by connective tissue. Ganglia function like relay stations - one nerve enters and another exits. A ganglion (pl. ganglia) is a mass of nerve cell bodies found outside of the central nervous system (CNS) along with some glial cells and connective tissue.

Nerves arise or lead to brain and spinal cord, so they are named as cranial and spinal nerves. There are 12 pairs of cranial nerves and 31 pairs of spinal nerves. Some cranial nerves are sensory, some are motor and some are mixed. All spinal nerves are mixed nerves.

8.7. Sense organs

The **human sense organs** contain receptors that relay information through sensory neurons to the appropriate places within the nervous system. Each sense organ contains different receptors. Sensory organs have special receptors that allow us to smell, taste, see, hear, and maintain equilibrium or balance. Information conveyed from these receptors to the central nervous system is used to help maintain homeostasis. The organs used for these functions are eye, ear, tongue and skin. General receptors are found throughout the body because they are present in skin, visceral organs, muscles, and joints. Special receptors include chemical receptors found in the mouth and nose, photoreceptors (light receptors) found in the eyes, and mechanoreceptors found in the ears.

The Eye

The eye is a slightly asymmetrical globe, about an inch in diameter. The front part of the eye includes:

- The **iris** (the pigmented part) - The iris regulates the size of the pupil.
- The **cornea** (a clear dome over the iris). transparent covering of the front of the eye. Allows for the passage of light into the eye and functions as a fixed lens.
- The **pupil** (the black circular opening in the iris that lets light in)
- The **sclera** (the white part) - a tough white layer of connective tissue that covers all of the eyeball except the cornea.
- The **conjunctiv**a (an invisible, clear layer of tissue covering the front of the eye, except the cornea). External cover of the sclera — keeps the eye moist
- **Choroid**: thin, pigmented layer lining the interior surface of the sclera. – Prevents light rays from scattering and distorting the image. Anteriorly it forms the iris.

- **Retina**: lines the interior surface of the choroid. – Contains photoreceptors. Except at the optic disk (where the optic nerve attaches).

Embedded in the retina are millions of light sensitive cells, which come in two main varieties: rods and cones. Rods are good for monochrome vision in poor light, while cones are used for color and for the detection of fine detail. Cones are packed into a part of the retina directly behind the retina called the fovea. When light strikes either the rods or the cones of the retina, it's converted into an electric signal that is relayed to the brain via the optic nerve. The brain then translates the electrical signals into the images we see.

Structure and Function of the Human Eye

Vertebrates have single-lens eyes.

Focusing Light

The lens and ciliary body divide the eye into two cavities. The anterior cavity is filled with aqueous humor produced by the ciliary body. The posterior cavity is filled with vitreous humor. The lens, the aqueous humor, and the vitreous humor all play a role in focusing light onto the retina. Accommodation is the focusing of light in the retina. Mammals focus by changing the shape of the lens. The lens is flattened for distant objects. The lens is rounded for near objects.

Vision -Rhodopsin (retinal + opsin) is the visual pigment of rods. The absorption of light by rhodopsin initiates a signal-transduction pathway Receptor potential is hyper-polization.

Color reception is more complex than the rhodopsin mechanism. Three types of cone cells each with unique photopsin (green cones, red cones, blue cones). Brain's analysis of color depends on relative responses of each type of cone. Colorblindness is due to a deficiency, or absence, of one or more photopsins.

The Ear

The ear consists of three basic parts - the outer ear, the middle ear, and the inner ear. Each part of the ear serves a specific purpose in the task of detecting and interpreting sound. **The outer ear** serves to collect and channel sound to the middle ear. **The middle ear** serves to transform the energy of a sound wave into the internal vibrations of the bone structure of the middle ear and ultimately transform these vibrations into a compressional wave in the inner ear. **The inner ear** serves to transform the energy of a compressional wave within the inner ear fluid into nerve impulses that can be transmitted to the brain. The three parts of the ear are shown below.

The outer ear consists of an earflap and an approximately 2-cm long ear canal. The earflap provides protection for the middle ear in order to prevent damage to the eardrum. The outer ear also channels sound waves that reach the ear through the ear canal to the eardrum of the middle ear. Because of the length of the ear canal, it is capable of amplifying sounds with frequencies of approximately 3000 Hz. As sound travels through the outer ear, the sound is still in the form of a pressure wave with an alternating pattern of high and low pressure regions. It is not until the sound reaches the eardrum at the interface of the outer and the middle ear that the energy of the mechanical wave becomes converted into vibrations of the inner bone structure of the ear.

The middle ear is an air-filled cavity that consists of an eardrum and three tiny, interconnected bones - the hammer, anvil, and stirrup. The eardrum is a very durable and tightly stretched membrane that vibrates as the incoming pressure waves reach it. As shown below, a compression forces the eardrum inward and a rarefaction forces the eardrum outward, thus vibrating the eardrum at the same frequency of the sound wave. Being connected to the hammer, the movements of the eardrum will set the hammer, anvil, and stirrup into motion at the same frequency of the sound wave. The stirrup is connected to the inner ear; and thus the vibrations of the stirrup are transmitted to the fluid of the inner ear and create a compression wave within the fluid. The three tiny bones of the middle ear act as levers to amplify the vibrations of the sound wave. Due to a mechanical advantage, the displacements of the stirrup are greater than that of the hammer.

The inner ear consists of a cochlea, the semicircular canals, and the auditory nerve. The cochlea and the semicircular canals are filled with a water-like fluid. The fluid and nerve cells of the semicircular canals provide no role in the task of hearing; they merely serve as accelerometers for detecting accelerated movements and assisting in the task of maintaining balance. The cochlea is a snail-shaped organ that would stretch to approximately 3 cm. In addition to being filled with fluid, the inner surface of the cochlea is lined with over 20 000 hair-like nerve cells that perform one of the most critical roles in our ability to hear. These nerve cells differ in length by minuscule amounts; they also have different degrees of resiliency to the fluid that passes over them.

As a compressional wave moves from the interface between the hammer of the middle ear and the oval window of the inner ear through the cochlea, the small hair-like nerve cells will be set in motion. Each hair cell has a natural sensitivity to a particular frequency of vibration. When the frequency of the compressional wave matches the natural frequency of the nerve cell, that nerve cell will resonate with a larger amplitude of vibration. This increased vibrational amplitude induces the cell to release an electrical impulse that passes along the auditory nerve towards the brain. In a process that is not clearly understood, the brain is capable of interpreting the qualities of the sound upon reception of these electric nerve impulses.

The Tongue

The receptors for taste, called taste buds, are situated chiefly in the tongue, but they are also located in the roof of the mouth and near the pharynx. They are able to detect four basic tastes: salty, sweet, bitter, and sour. The tongue also can detect a sensation called "umami" from taste receptors sensitive to amino acids. Generally, the taste buds close to the tip of the tongue are sensitive to sweet tastes, whereas those in the back of the tongue are sensitive to bitter tastes. The taste buds on top and on the side of the tongue are sensitive to salty and sour tastes.

At the base of each taste bud there is a nerve that sends the sensations to the brain. The sense of taste functions in coordination with the sense of smell. The number of taste buds varies substantially from individual to individual, but greater numbers increase sensitivity. Women, in general, have a greater number of taste buds than men. As in the case of color blindness, some people are insensitive to some tastes.

The Nose

The nose is the organ responsible for the sense of smell. The cavity of the nose is lined with mucous membranes that have smell receptors connected to the olfactory nerve. The smells themselves consist of vapors of various substances. The smell receptors interact with the molecules of these vapors and transmit the sensations to the brain. The nose also has a structure called the vomeronasal organ whose function has not been determined, but which is suspected of being sensitive to pheromones that influence the reproductive cycle. The smell receptors are sensitive to seven types of sensations that can be characterized as camphor, musk, flower, mint, ether, acrid, or putrid. The sense of smell is sometimes temporarily lost when a person has a cold. Dogs have a sense of smell that is many times more sensitive than man's.

Like the sense of taste, it's a chemical sense. They are called chemical senses because they detect chemicals in the environment, with the difference being that smell works at dramatically larger distances than that of taste. The process of smelling goes more or less like this:

- Vaporized odor molecules (chemicals) floating in the air reach the nostrils and dissolve in the mucus (which is on the roof of each nostril).
- Underneath the mucus, in the olfactory epithelium, specialized receptor cells called olfactory receptor neurons detect the odor. These neurons are capable of detecting thousands of different odors.
- The olfactory receptor neurons transmit the information to the olfactory bulbs, which are located at the back of the nose.
- The olfactory bulbs have sensory receptors that are actually part of the brain which send messages directly to: The most primitive brain centers where they influence emotions and memories (limbic system structures), and "Higher" centers where they modify conscious thought (neo-cortex).
- These brain centers perceive odors and access memories to remind us about people, places, or events associated with these olfactory sensations.

The Integumentary System (Skin)

The integument as an organ, and is an alternative name for skin. The integumentary system includes the skin and the skin derivatives hair, nails, and glands. The integument is the body's largest organ and accounts for 15% of body weight. The derivatives of the integument:

Hair: functions include protection & sensing light touch. Hair is composed of columns of dead, keratinized cells bound together by extracellular proteins. Hair has two main sections: The shaft-superficial portion that extends out of the skin and the root- portion that penetrates into the dermis. Surrounding the root of the hair is the hair follicle. At the base of the hair follicle is an onion-shaped structure called the bulb Papilla of the hair and the matrix within the bulb produce new hair.

Nails: participate in the grasp & handling of small things. Nails are plates of tightly packed, hard, keratinized epidermal cells. The nail consists of: nail root: -the portion of the nail under the skin, nail body: -the visible pink portion of the nail, the white crescent at the base of the nail is the lunula, the hyponychium secures the nail to the finger, the cuticle or eponychium is a narrow band around the proximal edge of the nail and free edge: -the white end that may extend past the finger.

49. Glands participate in regulating body temperature. There are three main types of glands associated with the integument:

Sebaceous - Oil glands. Located in the dermis, and secrete sebum.

Sudoriferous - Sweat glands. Divided into two main types: – Eccrine - Most common, main function is regulation of body temperature by evaporation, and – Apocrine - Responsible for "cold sweat" associated with stress.

Ceruminous – Lie in subcutaneous tissue below the dermis, secrete cerumen (ear wax) into ear canal or sebaceous glands.

Functions of the Skin

- → Thermoregulation - Evaporation of sweat & Regulation of blood flow to the dermis. Cutaneous sensation - Sensations like touch, pressure, vibration, pain, warmth or coolness.
- → Vitamin D production - UV sunlight & precursor molecule in skin make vitamin D.
- → Protection – The sin acts as a physical barrier.
- → Absorption & secretion – The skin is involved in the absorption of water-soluble molecules and excretion of water and sweat.
- → Wound healing - When a minor burn or abrasion occurs basal cells of the epidermis break away from the basement membrane and migrate across the wound. They migrate as a sheet, when the sides meet the growth stops and this is called 'contact inhibition'.
- → In deep wound healing - A clot forms in the wound, blood flow increases and many cells move to the wound. The clot becomes a scab; granulation tissue fills the wound and intense growth of epithelial cells beneath the scab. The scab falls off and the skin returns to normal thickness.

Sensory Receptors = The skin contains numerous **sensory receptors** which receive information from the outside environment. The sensory receptors of the skin are concerned with at least five different senses: **pain, heat, cold, touch, and pressure**. The five are usually grouped together as the single sense of touch in the classification of the five senses of the whole human body. The sensory receptors vary greatly in terms of structure. For example, while pain receptors are simply unmyelinated terminal branches of neurons, touch receptors form neuronal fiber nets around the base of hairs and deep pressure receptors consist of nerve endings encapsulated by specialized connective tissues. Receptors also vary in terms of abundance relative to each other. For example, there are far more pain receptors than cold receptors in the body. Finally, receptors vary in terms of the concentration of their distribution over the surface of the body, the fingertips having far more touch receptors than the skin of the back. Nerve fibers that are attached to different types of skin receptors either continue to discharge during a stimulus "slowly-adapting" or respond only when the stimulus starts and sometimes when a stimulus ends "rapidly-adapting". In other words, slowly-adapting nerve fibers send information about ongoing stimulation; rapidly- adapting nerve fibers send information related to changing stimuli. The Pacinian corpuscle receptor is a classic example of a rapidly- adapting type receptor. The Ruffini nerve ending is a slowly- adapting type receptor.

8.8. Endocrine glands

A structure which makes hormones in the body is called **endocrine glands**. They are also called **ductless glands** because they do not have ducts to secrete their hormones. A group of endocrine glands which produces various hormones is called an **endocrine system**. It is also called hormonal system. Endocrine system helps in coordinating the activities of our body.

Hypothalamus [redacted]ituitary gland [redacted]hyroid gland [redacted]arathyroid [redacted]hymus [redacted]ancreas [redacted]drenal gland [redacted]estes [redacted]varies

The hypothalamus is a portion of the brain that contains a number of small nuclei with a variety of functions. One of the most important functions of the hypothalamus is to link the nervous system to the endocrine system via the pituitary gland. The hypothalamus is responsible for certain metabolic processes and other activities of the autonomic nervous system. It synthesizes and secretes certain neurohormones, often called **releasing hormones** or hypothalamic hormones, and these in turn stimulate or inhibit the secretion of pituitary hormones. The hypothalamus controls body temperature, hunger, fatigue, sleep, etc.

The pituitary gland, or hypophysis, is an endocrine gland about the size of a pea and weighing 0.5 grams in humans. It is composed of three lobes: anterior, intermediate, and posterior. It involves in the growth, blood pressure in some aspects of pregnancy and childbirth including stimulation of uterine contractions during childbirth, breast milk production, sex organ functions in both males and females, thyroid gland function, the conversion of food into energy (metabolism), water and osmolarity regulation in the body, water balance via the control of reabsorption of water by the kidneys, temperature regulation and pain relief.

The thyroid gland or just thyroid is one of the largest endocrine glands and consists of two connected lobes. Each lobe is about 5 cm long, 3 cm wide and 2 cm thick. The thyroid gland is a butterfly-shaped organ. The thyroid gland is found in the neck, below the thyroid cartilage (which forms “Adam’s apple”). It secretes throxine hormone also called T4. The thyroid also produces calcitonin, which plays a role in calcium homeostasis. The thyroid gland controls how quickly the body uses energy, makes proteins, and controls how sensitive the body is to other hormones. These hormones regulate the growth and rate of function of many other systems in the body. Thyroid hormones act throughout the body, influencing metabolism, growth and development, and body temperature. During infancy and childhood, adequate thyroid hormone is crucial for brain development.

There are four **parathyroid glands**, and they are each about the size of a grain of rice. Though they’re located near each other, the parathyroid glands are not related to the thyroid gland. **Parathyroid hormone** (PTH) has a very powerful influence on the cells of your bones by causing them to release their calcium into the bloodstream. Parathyroid hormone regulates the body’s calcium levels. The parathyroid essentially helps the nervous and muscular systems function properly. Calcium is the primary element that causes muscles to contract, and calcium levels are very important to the normal conduction of electrical currents along nerves. The most common disease of parathyroid glands is hyperparathyroidism, which is characterized by excess PTH hormone.

The thymus is a specialized organ of the immune system. The thymus is composed of two identical lobes and is located anatomically in the anterior superior mediastinum, in front of the heart and behind the sternum. Each lobe of the thymus can be divided into a central medulla and a peripheral cortex which is surrounded by an outer capsule. The thymus is largest and most active during the neonatal and pre-adolescent periods. The thymus produces and secretes thymosin. Helping the body protect itself against autoimmunity, which occurs when the immune system turns against itself. The thymus plays a vital role in the lymphatic system (your body’s defense network) and endocrine system. Protects the body from certain threats, including viruses and infections.

The adrenal glands are two glands that sit on top of your kidneys that are made up of two distinct parts- The adrenal cortex and The adrenal medulla. They are also known as suprarenal glands. The adrenal glands are two, triangular-shaped organs that measure about 1.5 inches in height and 3 inches in length. The adrenal cortex and the adrenal medulla have very different functions. One of the main distinctions between them is that the hormones released by the adrenal cortex are necessary for life; those secreted by the adrenal medulla are not.

The pancreas is unique in that it's both an endocrine and exocrine gland. In other words, the pancreas has the dual function of secreting hormones into blood (endocrine) and secreting enzymes through ducts (exocrine). The pancreas is a 6-inch-long flattened gland that lies deep within the abdomen, between the stomach and the spine. It is connected to the duodenum, which is part of the small intestine. It secretes insulin. The pancreas maintains the body's blood glucose (sugar) balance. Primary hormones of the pancreas include insulin and glucagon, and both regulate blood glucose. Diabetes is the most common disorder associated with the pancreas.

The testes (or testicles) are a pair of sperm-producing organs that maintain the health of the male reproductive system. The testes are twin oval-shaped organs about the size of a large grape. They are located within the scrotum, which is the loose pouch of skin that hangs outside the body behind the penis. The testes secrete testosterone, which is necessary for proper physical development in boys. In adulthood, testosterone maintains libido, muscle strength, and bone density. Disorders of the testes are caused by too little testosterone production.

The ovaries are oval shaped and about the size of a large grape. They are located on opposite ends of the pelvic wall, on either side of the uterus. The ovaries are each attached to the fimbria (tissue that connects the ovaries to the fallopian tube). Ovaries produce and release two groups of sex hormones— progesterone and estrogen. The ovaries maintain the health of the female reproductive system. Diseases associated with the ovaries include ovarian cysts, ovarian cancer, menstrual cycle disorders, and polycystic ovarian syndrome.

8.9. The reproductive system

The human **reproductive system** involves separate male and female reproductive systems. In many ways, the female system is more complicated than that of the male. Gonads are organs such as the testes (male), which produce sperm, and ovaries (females) that produce eggs(ova). These reproductive cells are known as **gametes**.

Why do we need to reproduce?

- ✓ To ensure survival of the species
- ✓ To produce egg and sperm cells
- ✓ To transport and sustain these cells
- ✓ To nurture the developing offspring
- ✓ To produce hormones

Male Reproductive System

Male Testes - produce sperm - also known as testicles and gonads. Male Duct System Vas Deferens - transports mature sperm to the urethra Epididymis - sperm mature in epididymis. Male Seminal vesicles – attached to vas deferens – produce a sugar- rich fluid that provides energy to sperm. Male Prostate Gland – makes fluid. Male Urethra – tube that carries urine from the bladder to outside of the body – also carries sperm out of the body

Female Reproductive System

Female Vagina – canal that joins the cervix to the outside of the body – also is known as the birth canal.

Female Uterus – hollow organ that is the home to a developing fetus. The uterus is a muscular organ that holds and nurtures a developing fetus Size/shape of a pear (when not pregnant). The lining of the uterus is known as the endometrium. The upper end of the uterus connects to the fallopian tubes and the lower end connects to the cervix.

Female Ovaries – produce eggs and hormones – oval-shaped glands that are located on either side of the uterus. The two ovaries are involved in Oogenesis, which is the production of ova/egg cells. In general, ovaries switch, producing one egg per ovary each month. Each ovary contains specialized structures called **follicles**. Follicles contain 2 types of cells: **1. Egg Cells 2. Follicular Cells**. Each month 1 follicle releases 1 ovum into a fallopian tube (ovulation). Any remaining follicles deteriorate and are reabsorbed within the ovary. Female Fallopian Tubes – tunnels for the egg cell to travel from the ovaries to the uterus – where fertilization happens.

Puberty occurs around ages 9-13 in females, and 10-13 in males where the reproductive system starts to develop maturely.

Unit 9: Food making and growth in plants

9.1. Plant Organs

- The flowering plant is a complete organism with organs carrying out particular functions.
- There are four main organs of a flowering plant.
    - **Flowers:**
        - Contain the reproductive organs
    - L**eaves:**
        - Use light energy, carbon dioxide and water to make food by photosynthesis.
    - S**tem:**
        - Provides support and a transport system for water and minerals to the leaves and flowers.
        - It also transports food from the leaves to the roots and flowers.
    - **Roots:**
        - Anchor the plant to the ground and absorb water and minerals.

A photosynthesizing machine

- Plants take inorganic molecules carbon dioxide and water and use them to produce organic molecule glucose along with inorganic oxygen in the presence of energy from light
- This amazing process is the basis of all life on Earth – it provides the food we eat and the oxygen we breathe. And it all takes place in the leaves of plants.
- Plant leaves are perfectly adapted to allow the maximum possible amount of photosynthesis to take place whenever there is light available.

Adaptations of a leaf for photosynthesis

- The **leaf** is flat and wide, giving a large surface area to collect light and short distances for gases to diffuse. The veins bring water from the soil to the cells.

- The **waxy cuticle** is a waterproof layer found on the surface of many leaves to help prevent water loss.
- The **palisade mesophyll** is the main photosynthetic tissue of the plant. There are many cells, closely packed together near the surface of the leaf to get as much light as possible. Each cell has many chloroplasts – hundreds of them – which are spread out through the cytoplasm of the cell when light levels are high but which cluster at the top of the cell when light levels are low.
- The **spongy mesophyll** has fewer cells with fewer chloroplasts. However, there are lots of air spaces and a big surface area for gas exchange. Some photosynthesis takes place here but more importantly it is where the carbon dioxide needed for photosynthesis moves into the cells, and the oxygen moves out. The water lost in transpiration evaporates from the cells here as well.
- The **lower epidermis** has openings known as **stomata** which allow carbon dioxide to diffuse into the leaf and oxygen and water vapour to diffuse out. The **guard cells** open and close to control the entry of carbon dioxide into the leaf and also to control the loss of water by transpiration.
- The **vascular bundles** contain the **xylem**, dead tissue which brings water from the soil to the cells of the leaves, and the **phloem**, living tissue which carries the products of photosynthesis away from the leaves to all of the cells of the plant.
- Each **chloroplast** contains stacks of membranes and chlorophyll to give an increased surface area for photosynthesis to take place.

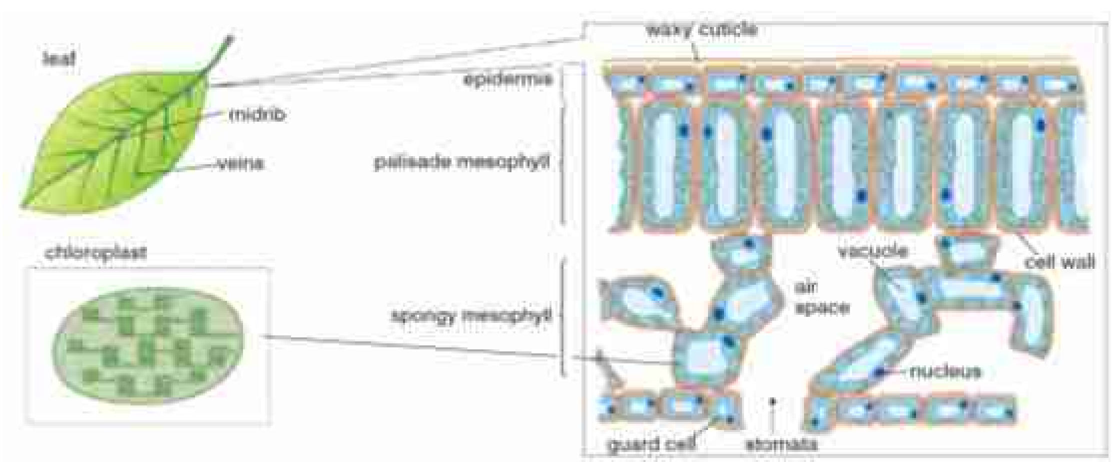


Figure 4.1: This cross section of a leaf shows that leaves of plants are perfectly adapted to make the best possible use of the light that falls on them.

9.2. Photosynthesis

- **Photosynthesis** is a plant chemical process of making food (sugars) and oxygen, from carbon dioxide and water, in the presence of light
- Like all living organisms plants need food to provide them with the energy for respiration, growth and reproduction.
- Many organisms, including all animals, eat food to get the energy they need to live known as **heterotrophs** (feeding on others).
- In contrast, plants produce their own food in a process of **photosynthesis** and they are known as **autotrophs** (feeding themselves).
- Photosynthesis takes place in the green parts of plants, especially the leaves, in the presence of light.
  - ☞ Photosynthesis can be summed up in the following equation:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{light energy}]{\text{chlorophyll}} \text{glucose} + \text{oxygen}$$

The chemical equation for the same process is:

$$6CO_2 + 6H_2O \xrightarrow[\text{light energy}]{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$$

- During photosynthesis light energy from the sun is absorbed by a green substance called **chlorophyll** that is found in the chloroplasts of some plant cells.
- The energy that is captured is used to convert carbon dioxide from the air and water from the soil into a simple sugar, glucose, with oxygen as a by-product.
- Some of the glucose produced during photosynthesis is used immediately by the cells of the plant for respiration to provide energy for cell functions, growth and reproduction.
- The energy released in respiration is used to build up smaller molecules into bigger molecules:
  - ✓ Sugars like glucose are built into starch for storage.
  - ✓ Sugars like glucose are built into molecules like fructose (fruit sugar) and sucrose (a double sugar unit) to be transported around the plant.
  - ✓ Sugars like glucose are built up into more complex carbohydrates like cellulose to make new plant cell walls.

- ✓ Sugars, along with nitrates and other nutrients that the plant takes up from the soil, are used to make amino acids. These amino acids are then built up into proteins to act as enzymes and make up much of the cytoplasm of the cells.
- ✓ Sugars may be built up into fats and oils (lipids) for storage in seeds and to make up part of the cell membranes.
- ✓ Sugars may be used to build up important large molecules such as chlorophyll, using minerals such as magnesium taken up from the soil.

- Some of the glucose produced by photosynthesis is always converted into starch for storage, at least as a first step. This is because glucose is soluble and so could affect the water balance within the plant. If the concentrations of glucose vary in different parts of the plant then osmosis takes place to correct this and this could upset the whole organism.
- Starch is insoluble, which means that it does not dissolve, so it has no effect on the concentration of solutions. This means that it can be stored in different places without having any effect on the water balance of the plant.

What is needed for photosynthesis?

- For photosynthesis to occur successfully the inorganic molecules carbon dioxide and water are needed, along with a supply of light energy and the means to capture that energy in the form of the green pigment chlorophyll.

The need for light

- Plants need light for photosynthesis – but in fact that is not completely true.
- The simple equation we use for photosynthesis represents many different chemical reactions that go on in the chloroplasts of a plant to convert carbon dioxide and water into glucose and oxygen. And while light is absolutely necessary for some of those reactions, others can continue even if there is no light at all.
- The light-dependent place without light energy. reactions cannot take
- The light energy is absorbed by chlorophyll molecules through activation of their electrons and used to split water molecules into hydrogen and oxygen. Adenosine triphosphate (ATP) for energy is produced as well. The hydrogen is used in the rest of the process, and the oxygen is given off as a gas. It is a waste product of the light reactions of photosynthesis.

- The hydrogen and ATP produced in the light reaction are then used in a series of reduction reactions that convert carbon dioxide into glucose. This stage of the process does not need light to take place and is known as the light-independent reaction.

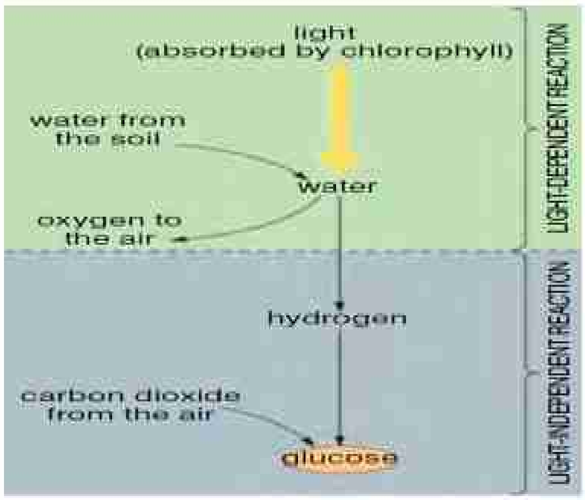


Figure 4.4 The light-dependent and -independent reactions of photosynthesis can be summarised like this. They both take place in the chloroplasts.

The need for carbon dioxide

- A source of carbon is needed for the plants to synthesise sugars.
- There are lots of carbon-containing chemicals in existence, but carbon dioxide from the air or in solution in water is the only form that plants can use in photosynthesis.
- Carbon dioxide is found more or less everywhere. It is even produced by the plants themselves as a result of cellular respiration, so getting hold of it isn't usually a problem.
- However, although there is always sufficient carbon dioxide available for some photosynthesis to take place, sometimes the levels are too low for plants to take full advantage of the light available.
- As the carbon dioxide level increases, the rate of photosynthesis goes up. With plenty of raw materials the plant is able to take full advantage of the light energy falling on it.

The need for water

- Carbon dioxide alone is not sufficient to produce carbohydrates.
- Hydrogen is needed too, and water is the only source of hydrogen that plants can make use of
- All the cells of a plant have a constant supply of water both as a waste product of respiration and from the transpiration stream so there is always plenty of water for photosynthesis.

- Water is vital to all the functions of a plant.
- Oxygen gas produced during photosynthesis comes from the splitting of the water molecules using light energy. This is known as photolysis (splitting using light).

The need for chlorophyll

- ✓ The final requirement for photosynthesis to take place is a way of capturing the energy from the sun and this is carried out by the green pigment chlorophyll.
- ✓ The simplest way to demonstrate that chlorophyll is needed for photosynthesis to take place is to consider the leaves of a variegated plant.
- ✓ Variegated leaves have areas that contain chlorophyll and areas that do not.
- ✓ The chlorophyll-free regions are usually yellow or creamy-white in colour.
- ✓ If a destarched variegated plant is then exposed to light for several hours and you test one of the leaves for the presence of starch, the iodine solution changes colour only in those regions of the leaf that were green. This shows that without chlorophyll photosynthesis did not take place.

The importance of photosynthesis

- ☞ Photosynthesis is one of the most important reactions on Earth.
- ☞ It is through photosynthesis that the ultimate source of energy for the Earth – in other words, the sun – is tapped and converted into chemical energy which is available to life.
- ☞ Around 35×10^{15} kg of new biological material is produced every year as a result of photosynthesis. This new material can then be used as a food source by billions of living organisms, including people.
- ☞ On the land, it is plants that photosynthesis and makes food.
- ☞ It is easy to forget that actually almost two-thirds of the surface of the Earth is covered in water, and much of the photosynthesis of the world goes on in large bodies of water.
- ☞ The organisms that carry out photosynthesis in water may be true plants, such as water weeds but they also include many algae and most importantly of all, the photoplankton (also known as phytoplankton). These are tiny organisms, protists and bacteria, which carry out photosynthesis and produce over half of the biomass of the Earth. That is a lot of material – remember the total biomass made by photosynthesis each year is around 36.8×10^{13} kg!
- ☞ At the moment people rely mainly on the photosynthesis which takes place on land to supply them with their food. Most of our food crops such as teff, sorghum, millet, corn, barley, beans and other pulses are all plants grown in the soil.
- ☞ Photosynthesis is very important as the source of energy for almost all living organisms, because of the way in which photosynthesis provides us with new biological material.
- ☞ Almost all living organisms need oxygen for cellular respiration.
- ☞ That oxygen is produced as a waste product of photosynthesis.

- ☞ Living organisms produce carbon dioxide as a waste product when they respire.
- ☞ Carbon dioxide is a greenhouse gas – it helps to trap heat from the sun around the surface of the Earth. It is also poisonous at high levels. However, carbon dioxide is also vital for photosynthesis to take place.
- ☞ Plants and other photosynthesizing organisms remove carbon dioxide from the atmosphere all the time. So photosynthesis is very important for maintaining the balance of oxygen and carbon dioxide in the atmosphere.

9.2. Transport in plant

- Trees are obviously supported by their woody trunks. But many plants do not have woody tissue, and so they have no structural support. They rely on having cells which are rigid and firm. These firm cells are maintained by the movement of water into the cells by osmosis to create turgor. This is one reason why osmosis is so important for plants.

- Osmosis is not only vital for keeping the plant cells turgid. It is also very important for moving water around within the plant itself.

- Plants take up water through their roots. The water in the soil has a very low concentration of dissolved minerals. In other words, there is a very high concentration of water. Water moves into the plant root cells across the cell membrane along a concentration gradient. The roots are covered with special cells, which have tiny hair-like extensions called the **root hairs**. These root hairs increase the surface area for osmosis to take place. Once water has moved into the root hair cells, the cytoplasm of the root hair cells is more dilute than the cytoplasm of the surrounding cells.

- Water moves into the neighbouring cells by osmosis (figure 4.10). These cells now have more dilute cytoplasm than the cells next to them, and the water moves on by osmosis until it reaches the xylem and the transpiration stream.

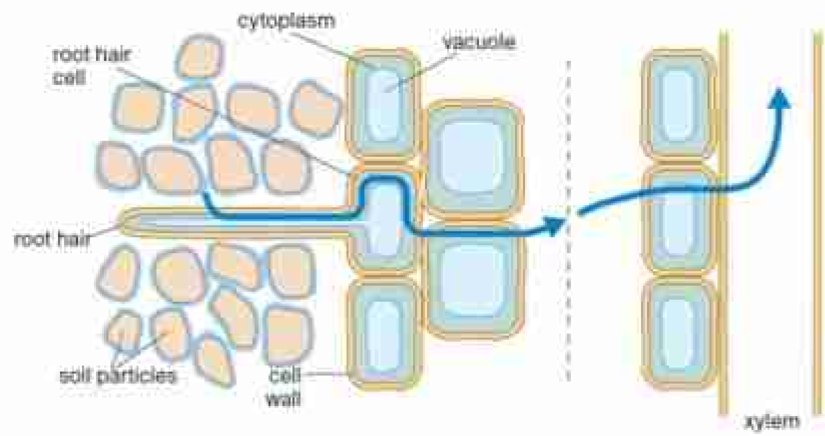


***Figure 4.10** Water moves across the tissues of a plant by osmosis. It moves along a water potential gradient.*

Active transport in plants

- ✓ Plants don't just rely on osmosis and diffusion.
- ✓ Active transport is also widely used in plants.
- ✓ There are some situations where active transport is particularly important. For example, the mineral ions in the soil are usually found in very dilute solutions – more dilute than the solution within the plant cells.
- ✓ By using active transport plants can absorb these mineral ions, needed for making proteins, and other important chemicals from the soil, even though it is against a concentration gradient.
- ✓ Active transport like this involves the use of energy produced by respiration in the cells.

Transport of materials around the plant

- As you have seen in this unit, plants make food by photosynthesis in the leaves and other green parts but it is needed all over the plant.
- Similarly water and minerals move into the plant through the roots in the soil, but they are needed by every cell in the body of the plant.
- Plants need a transport system to move substances around their bodies.

A double transport system

- o There are two separate transport systems in plants.

- **Phloem**:
  - Is Made up of living tissue and it is involved in the transport of organic materials – the nutrients made by photosynthesis – from the leaves to the rest of the plant.
  - Phloem cells are thin walled and are regularly replaced when they are worn out.
  - They contain a liquid rich in sugar.
  - When insect pests such as aphids attack plants, they stick their feeding parts into the phloem to suck up the food-rich liquid.
  - By depriving much of the plant of food, these pests can destroy crops and cause terrible hardship.
  - The plant has to use energy to move substances around the phloem, and food substances can move both up and down the plant.
  - The nutrients are carried to all the areas of the plant including the growing regions where they are needed for making new plant material, and the storage organs where they are needed to provide a store of food for the winter.
- **Xylem:**
  - Is the other transport tissue.
  - It carries water and mineral ions from the soil around the plant.
  - The xylem tissue is dead and there is no active transport taking place.
  - The movement of the water in the xylem is due to **transpiration** and it is **passive**. This means it uses no energy from the plant. Water only moves up from the roots to the leaves.

The need for transport in plants

- The importance of moving the food made by photosynthesis around the plant is obvious – all the cells need glucose for cellular respiration as well as materials for growth.
- The sugars that are produced in the leaves and carried all around the plant can also be stored.
- However, plants cannot store sugars, because they have an osmotic effect. If a cell had lots of sugar in it, lots of water would move into it by osmosis. So sugars are converted into starch, which is osmotically inert. This means that a cell can contain lots of starch and it has no effect on the movement of water by osmosis into or out of the cell.
- The starch stored in plant cells is broken down to sugars again to provide them with energy when the need arises – for example, when there isn't enough light to photosynthesis.

- One of the main places where starch is stored is in the storage organs of plants.
- Root tubers, stems and leaves can all be filled with starch to form storage organs. These enable plants to survive difficult conditions and also to reproduce.
- Starch is also deposited in large amounts in many fruits and seeds. In fruits the starch provides a reason for animals – including people to eat the fruit and the seeds, helping to disperse the seeds. In the seeds, starch is one of the energy stores for the developing embryo to use as the seed starts to develop.
- The movement of water and minerals from the roots is just as important as the movement of food. The minerals are needed for the production of proteins and other molecules within the cells.
- The water is needed for two main reasons. One is that water is needed for photosynthesis and without water photosynthesis cannot take place. Less obviously, but just as important, water is needed to maintain the turgor pressure within the cells. Water moves into plant cells by osmosis. This produces turgor so the cytoplasm presses against the cell walls. In fact for young plants and non-woody plants this is the main method of support. This pressure in the cells is very dependent on water moving up through the xylem from the soil. It is also very important in keeping the leaves firm and spread out to catch the sunlight. If the supply of water stops, the whole plant, or just the leaves, will wilt and all the chemical processes of photosynthesis and respiration will be affected.

The transpiration stream

- ✓ Water is taken into a plant through the roots and moves by osmosis to the xylem tissue. There is no active transport in the xylem. So how is water moved from the roots of a plant up to the uppermost leaf, a distance which can be many meters? The transport of water through a plant is the result of the transpiration stream.
- ✓ Plants lose water vapour from the surface of their leaves. This loss of water vapour is known as transpiration.

- ✓ Most of the transpiration takes place through the tiny holes in the surface of the leaf known as stomata.
- ✓ The stomata are there to allow air containing carbon dioxide into the leaf for photosynthesis.
- ✓ They can be opened and closed by the guard cells which surround them
- ✓ Losing water through the stomata is a side effect of opening them to let carbon dioxide in, but it is vital for transpiration.
- ✓ Most of the stomata are found on the underside of the leaf.
- ✓ Guard cells contain chloroplasts so they can photosynthesise, unlike the other cells in the epidermis layer. So when there is sunlight, the concentration of sugar in the guard cells goes up as a result of photosynthesis. Water then moves into the guard cells by osmosis from the epidermal cells around them.
- ✓ The sausage-shaped guard cells become very turgid, and as they swell up they bend, opening a gap – the stoma – between them. The pore closes by the reverse process – water moves out of the guard cells by osmosis into the surrounding cells and as the level of turgor in the guard cells falls, the stoma closes.

Moving water through the plant

- As water evaporates from the surface of the leaves, water is pulled up through the xylem to take its place. This constant moving of water molecules through the xylem from the roots to the leaves is what is known as the transpiration stream.
- There is pressure pushing the water up from the bottom – the root pressure – as water moves in by osmosis.
- In the xylem, two physical forces help the water to move upwards.
- There are **adhesive forces** between the water and the walls of the xylem which support the whole column of water, no matter how tall it is. And as molecules evaporate away from the surface of the leaf, the following molecules are pulled upwards by **cohesive forces** between the water molecules. In other words, the water molecules tend to stick together and get pulled upwards like a string of beads.

- However, the main pull which moves water up from the roots to the leaves is the almost constant evaporation of water from the leaves.
- When water reaches the xylem in the leaves, there is a reversal of the situation in the roots.
- Now the solution in the xylem has a much higher concentration of water than the solution in the mesophyll cells in the leaf. Water moves out from the xylem into the mesophyll cells and so across the leaf by osmosis. When it reachesma mesophyll cell which is surrounded by air, water evaporates from the surface into the air and diffuses out through the stomata along a concentration gradient.

Factors affecting the role of transpiration

- Because the transpiration stream is driven mainly by the evaporation of water from the leaves, anything which affects the rate of evaporation will affect transpiration.
- Conditions which increase the rate of evaporation also increase the rate of transpiration.
- The higher the temperature, the more evaporation takes place.
- Water evaporates more rapidly into dry air than into humid air.
- If the air is moving – it is windy – then water vapour- rich air is always being removed from around the leaf. This maintains a good concentration gradient for diffusion and increases evaporation. So transpiration is more rapid in hot, dry and windy conditions than it is in still or humid conditions.
- Plenty of light also speeds up transpiration. In good light conditions, lots of photosynthesis takes place and so the stomata are opened to allow plenty of carbon dioxide in.
- When the stomata are open, lots more water can evaporate from the surface of the leaves.

Reducing water loss

- If a plant begins to lose water faster than it is replaced by the roots, it runs the risk of wilting.
- The stomata in the leaves will close to stop this if possible. To make sure that water is not lost from the surface of the leaf generally, most leaves have a waxy, waterproof layer (known as the **cuticle**) to prevent uncontrolled water loss.
- In very hot environments the cuticle may be very thick and shiny.

- The fact that the stomata are on the underside of the leaf also helps because this means that they are not as exposed to the heat of the sun as they would be on the top of the leaf.

Adaptations of plants to reduce water loss in difficult environments

- Plants manage to grow and survive in many different environments.
- In many places survival is a real struggle.
- Plants need to balance opening the stomata to allow photosynthesis to take place with the loss of water which takes place when the stomata are open.
- Plants which live in very hot areas like Somali, or in areas where there is relatively little water, often have adaptations which help them to balance up their different needs.
- They may have very thick, waxy cuticles to reduce any water loss through the overall leaf surface to an absolute minimum.
- Others have developed very hairy leaves, which trap a micro-atmosphere around the stomata and reduce water loss. Yet other plants have reduced their leaves to very narrow spikes to reduce the surface area over which water may be lost.
- On some plants the stomata are sunk into pits.
- Another way of preventing water loss, which you often see in grasses, is for the leaves to be rolled, trapping a micro-environment of moist air inside.
- The purpose of all these adaptations is to reduce the loss of water from the leaves by transpiration, so the plant can photosynthesis and avoid wilting whatever the conditions around it.

Transpiration and agriculture

- ✓ Transpiration has many implications for the way we grow our crops – and the crops we choose to grow.
- ✓ If our crop plants do not get enough water, then they will not be able to transpire and they will wilt. This means the cells will not work properly and the crops will not grow as well as they should. So, whenever possible we need to irrigate our fields and water the plants so that they can transpire fully, which allows them to photosynthesis and grow as much as possible.
- ✓ It is not only the level of sunlight and the temperature which affects transpiration rates in our plants. Wind also increases the rate of transpiration. If we can grow our crops in relatively

sheltered places, the rate of water loss will be slower and so our crops are more likely to grow well.

- ✓ The final way in which transpiration affects agriculture is in our choice of crop plants. Some plants are more resistant to water loss by transpiration than others.

9.3. Response in plant

- ➢ All living organisms need to be able to respond to their surroundings. This may be to find food, move towards the light or avoid danger. To take in information about the surroundings and then react in the right way is known as co-ordination.
- ➢ It is easy to see why animals need to respond, and you will be looking at coordination in animals later in this section. But plants need to be coordinated too. They need to respond to factors such as light, water and gravity to make sure that they grow the right way up, and that they make as much food by photosynthesis as possible.
- ➢ Plants achieve their co-ordination and responsiveness through a system of **hormones**.
- ➢ Hormones are chemical messengers which are produced in one part of an organism and have an effect elsewhere.
- ➢ Plant hormones (phytohormones) have several effects on plants. For example, they co-ordinate flowering, cell division and cell elongation. These are essentially growth processes and plant responses of this type are called growth responses. Since growth is a slow process, most plant responses are slow.

The germination of seeds

- In most flowering plants, growth starts when the seed begins to germinate.
- Seeds come in many different sizes and shapes, but the basic structure of seeds always contains certain things:
    - Food storage tissue known as the **endosperm**.
    - An embryo plant made up of three main parts – the **plumule** (embryonic shoot), the **radicle** (embryonic root) and the **cotyledons** (embryonic leaves).
    - The **testa** – the seed coat, which may be thin and papery like the covering on a groundnut or very strong and hard like the shell of a nut.

- It is the number of these embryonic leaves that are present which gives us the main division of the angiosperms into monocotyledons (one seed leaf) and dicotyledons (two seed leaves).
- In monocots the main food store is the endosperm and the embryo remains a very small part of the seed.
- In dicots the endosperm moves food into the cotyledons which become the main food store. By the time the seed is mature the endosperm has all but disappeared.
- The embryo with its food swollen leaves takes up most of the seed.
- Once the food store has been laid down and the embryo has developed the seed dries out (dehydrates). It loses much of its wet mass and becomes dormant.
- The following is a summary of changes which occur during the germination of a bean seed – a dicot seed.

1. The seed absorbs water through the micropyle (small hole) and swells.
2. The testa (seed coat) bursts and the radicle emerges. The radicle continues to elongate and gives rise to many side roots.
3. As the radicle elongates it pushes the seed out of the ground. The curved part of the radicle which protrudes is called the epicotyl. The seed coat is discarded and the two cotyledons (seed leaves) open out and begin to photosynthesis.
4. The plumule emerges from in between the cotyledons and produces the first true leaves. At this stage, the young plant is called a seedling.

Epigeal (dicot) and hypogeal (monocot) germination

- ✓ Seeds germinate in different ways. When the bean seedling emerges from the soil it is curved. The curved portion, the **hypocotyl**, pushes through the soil. As germination continues, the hypocotyl straightens and carries the cotyledons and the plumule above the soil surface. This type of germination, where the cotyledons are carried above the soil, is called **epigeal germination**.
- ✓ Most dicotyledonous plants have seeds which exhibit epigeal germination. Such seeds include castor oil seeds, groundnuts, cotton and Bambara nuts.
- ✓ Epigeal germination also occurs in a few monocotyledonous seeds such as onions and lilies.
- ✓ Germination of a maize grain follows a different pattern from that of a bean seed.
- ✓ The plumule pushes its way out of the soil while the cotyledon remains underground.

- ✓ The plumule does not form a hook as in bean seeds. This type of germination in which the cotyledons remain underground is called **hypogeal germination**. Other examples of grains exhibiting hypogeal germination are wheat, sorghum and millet.
- ✓ A few dicotyledonous seeds such as kidney beans and broad beans exhibit hypogeal germination.

Plant hormones and growth

- ➢ Growth in plants is influenced by chemical messengers called plant hormones. Examples of plant hormones are **auxins** (including indole-acetic acid, IAA), **gibberellic acid**, **cytokinin**, **ethylene** and **abscisic acid**. Some of these hormones promote growth, others inhibit it.

- ➢ **Auxin** (IAA) is the best-known plant hormone and it is involved in general plant growth. It stimulates the elongation of the new plant cells, so they get longer and bigger. It is also involved in **apical dominance**. IAA is made at the tip of the main shoot and as it moves down the stem it slows down the growth of side shoots. So the main shoot dominates the whole plant. If you cut off the growing tip of a plant it will bush out. The side shoots grow quickly once you remove the apical dominance from the auxins produced by the main shoot. Auxin also stimulates the growth of roots. If auxin is applied to a cut stem it will stimulate new roots to grow – this is widely used by gardeners and farmers in some parts of the world to help them take successful cuttings. The best-known function of auxins is in the responses of plants to the world around them. The responses of plants towards things such as light and gravity are called **tropisms** and you will be looking at these in more detail later in this section.

- ➢ Another group of plant hormones are the **gibberellins**. These hormones stimulate the growth of plant stems. If you take a dwarf plant and give it IAA, nothing much will happen. If you give it gibberellins the stems will grow until the plant is a normal size. Gibberellins also help seeds to break their dormant period and start to grow. Scientists think they do this by stimulating the production of the enzymes needed to break down the food stores in the seeds.

- **Cytokinins** are hormones that stimulate cell division in plants so they are very important in plant growth. The balance between auxins and cytokinins in a tissue culture of plant cells decides whether roots or shoots will grow.

- **Ethylene**, a plant hormone, is a gas at room temperature and it causes fruit to ripen. It also causes fruit and leaves to fall from the plant in some species.

- **Abscisic acid** (**ABA**) is another important plant hormone. It inhibits growth and plays a major role in leaf fall. It is also involved in seed dormancy. There is some evidence that it may be involved in geotropisms, but it plays a small part compared to IAA.

Tropic responses

- Plants need light for photosynthesis, and they grow towards the light.
- When a seed germinates the roots grow downwards and the shoots grow upwards. These responses to gravity are vital if the new plant is to be anchored firmly in the soil, and the shoots and leaves held above the ground in the sun.
- Responses to stimuli that come from one direction are known as tropisms.
- Type of response in which shoots grow towards the light is termed positive **phototropism**.
- Roots of seedlings which were vertically placed continued to grow downwards and their shoots continued to grow upwards.
- Whichever way up you put the seeds the roots grow downwards and the shoots upwards. This suggests that the normal direction of growth of roots downwards and shoots upwards is affected by the force of gravity.
- Movement in response to the stimulus of gravity is called **geotropism**.
- Roots are positively geotropic (they grow towards gravity) while shoots are negatively geotropic (they grow away from gravity).
- Light and gravity both have an important effect on the growth of plants.

- Water is also very important, and so it is not surprising that plants respond to water as well.
- The type of response by which roots grow towards water is termed **hydrotropism**.

- The growth of roots upwards towards water against the force of gravity suggests that water as a stimulus has a greater influence on root growth than gravity.

How are tropic responses brought about?

- As you can see from your earlier experiments, plants respond to unilateral stimuli.
- Further experiments have allowed scientists to find out more about these responses.
- Maize grains germinate to produce a straight shoot called a coleoptile.
- Coleoptiles are widely used in experiments to investigate the role of hormones in shoot growth.
- It is known that the growth region of a shoot is some distance below the tip. This fact suggests that removal of the tip would not affect the growth of the shoot. However, when the tips of the coleoptiles are removed (they are decapitated), they don't grow. Since we know that the growth of a shoot is promoted by auxins, failure of decapitated seedlings to grow suggests that the auxins are probably produced in the tip. It has been found out that the growth hormone, auxin, produced in the tip is **indole-3-acetic acid** (**IAA**).
- IAA diffuses from the tip to the growth region to initiate growth. In the decapitated seedlings, although the source of IAA production was removed, the seedling grew for a while and then stopped. This is because some IAA had already diffused away from the tip before decapitation. This amount of IAA was responsible for the slight growth.
- The fact that IAA promotes growth in shoots suggests that it is also involved in the responses of the shoots to light and gravity.
- IAA promotes growth so it seems likely that the shaded side of shoots affected by one-sided light had more IAA than the illuminated side.
- The downward growth of the root is also influenced by IAA, but in the root tip the hormone inhibits growth, rather than stimulating it.
- The force of gravity causes an accumulation of IAA on the underside of the root, resulting in reduced growth in that region.
- The corresponding upper side of the root, which had very little or no IAA, grows faster than the underside.
- This differential growth results in the downward curvature of the roots.

Importance of tropic and nastic responses

- ✓ In tropisms, some stimuli to which plants respond positively are the basic requirements for the plant's life.
- ✓ Water, for example, is one of the important requirements for photosynthesis. This means that when positive hydrotropism occurs, roots come into close contact with water. This makes it possible for them to absorb as much water and mineral salts as possible for the plant.
- ✓ In addition to water, plants require light for photosynthesis.
- ✓ When a plant responds positively to light its leaves become well exposed to it. This maximizes the amount of light available for photosynthesis.

Unit 10: Ecology and conservation of natural resources

10.1. Definitions

All those things external to the organism that in any way act upon it is called organism's **environment**. It has two main components i.e., the **physical environment** and the **biotic environment**. The study of the relationships between organisms and their environments is called **ecology**. Ecology deals with biological organization beyond organismic level i.e., the population, the community and ecosystem. The many different species of living things interact with the physical world of rocks, soil and rivers and these interactions make up the ecology of the world. **Ecosystem** is all of the biotic (living) and abiotic (non-living) things in a particular habitat and how they interact with each other. An ecosystem is a life-supporting environment. Ecosystem can be of any size from a drop of water, a fallen log, or a field to an island or even a continent. A forest, a grass land, a desert, a lake, or a pond can be an ecosystem. Generally, an ecosystem is the home or **habitat** of the living organisms within it.

The physical or abiotic components

The term abiotic means no-living. The major physical components are climate, edaphic and physiographic factors. They include the amount of sunlight, and the amount of rainfall. Each of these factors will affect which living organisms can survive there. Temperature is an important abiotic component which often affects whether animals and plants can survive in an ecosystem. Other abiotic factors include the type of soil and rocks, the drainage of the soil and the pH (acidity). Water, the levels of oxygen dissolved, current and winds are also other important abiotic factors that affects the survival of organisms.

Biological (Biotic components)

These refers to the living components of the ecosystem which affect the ability of an organism to survive there. that has a big effect on the numbers of other organisms in the area. A pride of lions in an area will affect the numbers of prey animals that survive, and the number of caterpillars will make a difference to the number of plants that survive and reproduce. The amount of food available is another important biotic factor, which particularly affects animals. Biotic components of an ecosystem also include the numbers of parasites and diseases.

Natural resources include anything that is found naturally in the country which is useful to human beings. **Habitats** may be on land – when they are known as **terrestrial habitats** or they may be in water, when they are called **aquatic habitats**. In turn there are two main types of aquatic habitat – the **marine habitat**, which is the salt water of the seas and oceans, and the **freshwater** habitat of lakes, ponds, rivers, and streams.

10.2. Cycling matter through ecosystems

Recycling in nature involves the continuous exchange of materials between the living and non-living components of the ecosystem. Materials are always being 'moved around' within an ecosystem. Nutrients are always being taken in by organisms and materials are lost when they breathe and excrete. All the organisms in the ecosystem are interdependent and interact with their physical environment. Materials are moved around an ecosystem when organisms, feed, excrete, respire and breathe and die and are decomposed. Without recycling of element life in the ecosystem could not have existed continually.

Decomposers (bacteria and fungi) are key in returning nutrients to the ecosystem. Important mineral elements such as nitrogen and phosphorus are returned to plants as a result of the action of decomposers. Decomposers feed by a method known as **saprobiotic nutrition**. They feed on dead matter – and so do you. To do this, they secrete enzymes onto the dead matter. The enzymes digest the complex organic molecules into simpler, smaller ones and the micro-organisms absorb these products of digestion (just like you). Their **extracellular digestion** does not take place in a gut, it takes place in the soil, or wherever the dead matter happens to be.

Many of the decomposers have an enzyme that releases the amino group from amino acids and converts it to ammonia. This is known as **ammonification** and is important in the **nitrogen cycle**. Ammonification is carried out by a range of bacteria and fungi as a way of obtaining energy from organic, nitrogen-containing compounds. The ammonia, vital to the nitrogen cycle, is just a useless by-product to these micro-organisms. This is typical of many of the chemical reactions that take place in all the nutrient cycles.

The carbo cycle

The two basic life processes involved in carbon cycle are **respiration** and **photosynthesis**.

The main processes involved in cycling carbon through ecosystems are:

- ✓ photosynthesis – the process that fixes carbon atoms from an inorganic source (carbon dioxide) into organic compounds (for example, glucose)

- ✓ feeding and assimilation – feeding passes carbon atoms already in complex molecules to the next trophic level in the food chain where they are assimilated into (become part of) the body of that organism
- ✓ respiration – this releases inorganic carbon dioxide from organic compounds
- ✓ fossilization – sometimes living things do not decay fully when they die due to the conditions in the soil, and fossil fuels (for example, coal, oil and peat) are formed
- ✓ combustion – fossil fuels are burned, releasing carbon dioxide into the atmosphere

The nitrogen cycle

The primary source of nitrogen cycle is the atmosphere. Nitrogen is found in many biological compounds. It is present in proteins, amino acids, DNA, RNA (all kinds) and adenosine triphosphate (ATP) as well as ADP. Without nitrogen, organisms could not synthesize:

- their genetic material (DNA)
- their principal structural materials (proteins)
- their principal energy transfers molecule (ATP)

The main processes in the cycle are:

- → plants absorb nitrates from the soil
- → the nitrates are then used to form amino acids, which are used to synthesize proteins
- → the plants are eaten by animals, the proteins digested and the amino acids absorbed and assimilated into animal proteins
- → both plants and animals die, leaving a collection of dead materials (**detritus**) which contain the nitrogen still fixed in organic molecules; in addition, excretory products such as urea also contain nitrogen
- → decomposers decay the excretory products and detritus, releasing ammonium ions (NH_4^+) into the soil; this process is often referred to as **ammonification**
- → nitrifying bacteria oxidize the ammonium ions to nitrates (NO_3^-) (which are taken up by the plants) in a process called **nitrification**; in this process there is an intermediate product called nitrite (NO_2^-)

These processes recycle nitrogen that is already in biological molecules of one kind or another. But besides this, two other processes, denitrification and nitrogen fixation, decrease or increase, respectively, the amount of nitrogen in circulation.

Denitrifying bacteria reduce nitrate to nitrogen gas that escapes from the soil. This decreases the total amount of nitrogen available to the plants, and, therefore, to all the other organisms also.

Nitrogen fixing bacteria 'fix' nitrogen gas into ammonium ions. This happens in two main situations:

- Nitrogen fixing bacteria free in the soil (belonging to the genera *Azotobacter* and *Klebsiella*) reduce nitrogen gas into ammonium ions in the soil. These ammonium ions can be oxidized immediately into nitrates by nitrifying bacteria, adding to the amount of nitrogen available to the plants and, therefore, the other organisms also.
- Nitrogen fixing bacteria in nodules on the roots of legumes (belonging to the genus Rhizobium) form ammonium ions that are passed to the legumes and used by them to synthesize amino acids. The extra nitrogen only becomes available to other organisms when the legumes die and are decomposed.

The phosphorus cycle

The core phosphorus cycle is much the same as the core nitrogen cycle. Phosphorus is present in organisms in the form of phosphates.

- phosphate is absorbed from the soil (or water) by plants
- these are passed along food chains to various herbivores and carnivores
- on death, their bodies are decomposed and phosphate ions are released from compounds like phospholipids, ATP, DNA and RNA and are returned to the soil or water
- phosphates also enter the soil (or water) as a result of the weathering of rocks and in the form of fertilizers, which, themselves, contain phosphates that have been obtained from rocks
- over millions of years, phosphate ions can leach into the seas and become part of newly forming sedimentary rock.

The sulphur cycle

The core cycle is between the soil, plants, animals and special decomposers. There are also components that relate to long-term rock formation and weathering as well as the formation of sulphur dioxide when fossil fuels are burned.

- sulphate ions in the soil are taken up by plants and incorporated in plant tissue (many proteins include some sulphur-containing amino acids, such as methionine and cysteine)
- these are passed to animals by feeding and digestion

- on death of the plants and animals, sulphate-reducing bacteria release the sulphur in the proteins in the form of hydrogen sulphide (with the smell of ‘bad eggs’); the most important genus of bacteria involved in this process is *Desulphovibrio*; this process requires anaerobic conditions
- in some aquatic environments the hydrogen sulphide is oxidized to sulphur by photosynthetic sulphur bacteria; this reaction is the equivalent of the photolysis of water in the photosynthesis of higher plants
- sulphur bacteria, mainly of the genus iobacillus, then oxidise the hydrogen sulphide (or sulphur) to sulphate (SO_4^{2-}), with sulphite (SO_3^{2-}) as an intermediate step; this is an oxygen requiring process that needs aerobic conditions and makes sulphate ions available once again to be taken up by plant roots from the soil
- sulphur can also become incorporated in rocks, including those that yield fossil fuels
- combustion of fossil fuels oxidises the sulphur to sulphur dioxide (SO_2); this is a serious pollutant of the atmosphere and a major contributor to the formation of acid rain in the atmosphere, the sulphur dioxide becomes further oxidized to sulphite and sulphate which dissolve in rainwater to form a mixture of sulphurous and sulphuric acid: acid rain

The water cycle

When rain falls, some of it is absorbed by plants, and evaporates in the process of transpiration. Animals drink water and give off water when they exhale. Some rain falls directly into ponds and streams. Some runs off the surface of the land into rivers and some flow underground in the soil. Water is essential to all living organisms in all kinds of ways:

- ✓ it makes up 70% of all cells
- ✓ it is an essential requirement of photosynthesis
- ✓ it is the basis of all transport systems in organisms
- ✓ it provides a means of removing excretory products
- ✓ to wash our clothes, our dirty dishes and our dirty selves
- ✓ to make products such as paper, steel and beer
- ✓ to generate electricity using a range of devices that convert the motion of water into electrical energy
- ✓ in a system, called ‘hydroponics’, to grow plants in a soil-free medium

10.3. Ecological succession

Community is built over a period of time. As time passes communities change. During this time there will be an orderly and progressive replacement of one community by another still stable community is established. This gradual change in a community is called **succession**. The very presence of the lichens must change the abiotic conditions, making them less harsh. The living lichens grow into the rock causing it to crumble. When the lichens die, decomposers act on the remains to release mineral ions into the crumbled rock. The mixture of dead remains, crumbled rock and mineral ions forms a primitive soil. This less harsh environment is suitable for mosses (provided that there is sufficient water).

This is the essence of succession:

- Organisms colonize an area
- They change the abiotic (physical) conditions in the area
- The changed abiotic conditions allow other species to colonize the area
- The new species compete with the ones there before and become dominant
- They also then change the abiotic conditions, more species enter and the process continues.

The various stages in a succession are called **seres**.

As successive producers colonize the area, they create more and different habitats and niches for other organisms to occupy. The first organisms that invade the area are called **colonizers**. As a consequence, succession usually involves an increase in the complexity of food webs. The final, most complex, state of a succession is the **climax community**.

The following trends occur in any succession:

- ✓ The total biomass of the community increases
- ✓ The species diversity increases
- ✓ The number of ecological niches increase
- ✓ Food webs become more complex
- ✓ The community becomes more stable can accommodate small changes/losses more easily.

Both successions end with the same climax. Because the first takes place from rock it is called a **xerosere**. The second, starting from water, is a **hydrosere**.

Different areas have different climax communities due to:

- Climate

- grazing animals
- temperature
- precipitation (rainfall)
- soil type
- soil depth

Primary succession occurs on the bare land or in an area where there had been volcanic eruption. The first community that occupies a bare land is called the **pioneer community**.

Secondary succession occurs where original community has been destroyed by some factors like fire, earth quake or clearing forest by man. Secondary successions to the original climax are usually much quicker than primary successions because:

- the succession is not starting from bare rock/open water
- there is a seed bank of many of the climax plant types available in remaining undamaged plants
- the soil is already present

10.4. Biomes

Biosphere is the worldwide sum of the ecosystem or parts of the earth where life exists. This biosphere can be grouped into a number of biomes. **Biomes** are large geographical regions in different parts of the world with characteristic climate and particular organisms. A give biome has its typical plant (flora) and animal (fauna), which are adapted to the environmental conditions, a specific climate, and a specific soil type in similar ways to the abiotic conditions within the area.

Temperature and **precipitation** (rainfall) are the most significant climatic factors in determining biome type.

There have been many classifications of the different biomes and scientists are still refining their ideas but we can classify the biomes into two main types:

- **Terrestrial**

A terrestrial biome is defined by temperature, rainfall, soil type, flora and fauna (plants and animals). This biome consists of

Desert (hot

A Deseret is a region with less than 250 mm of rain per year or with no rain. Has hot temperature with poor soil quality.

Desert (cold)

Has cold temperature with poor soil quality.

Thorn forest (scrub)

They have hot summer and cold winter season with poor soil quality. The thorn forests grow in the regions which receive less than 70 cm of rainfall. The trees present in the thorn forest have long roots which penetrate deeper into the soil in search of water. In these trees, the leaves are thick and also small to minimize evaporation.

Tundra

Has very low rain low rain fall less than 250 mm and water is not available for most of the year because of it is frozen.

Boreal forest (Taiga)

Coniferous forests of northern cold winter climates. Slightly warmer temperate and low rain fall (100 to 350 mm) distinguish taiga from tundra. It is dominated by evergreen trees.

Temperate deciduous forest

It is an area with relatively warm summers and cold winters. The annual rainfall ranges from 750 to 2500 mm.

Tropical montane forest and

They are found in hilly areas having a high altitude. The wet temperate forests are found between 1000-2000 meters. More than 3000 meters give the way to alpine vegetation.

Tropical rainforest

Found on and near the equator all around the world. Rainfall is between 2000 to 4500 mm.

Table 2.1 *The characteristics of the major terrestrial biomes*

Biome	Precipitation	Temp.	Soil	Plants	Animals
Desert (hot)	Almost none	Hot	Poor	Sparse – succulents (like cactus), sage brush	Sparse – insects, arachnids, reptiles and birds
Desert (cold)	Almost none	Cold	Poor	Sparse – micro-organisms and some lichens	Sparse – polar bears, seals
Thorn forest (scrub)	Dry summer, rainy winter	Hot summer, cool winter	Poor	Shrubs, some woodland (like scrub oak)	Drought- and fire-adapted animals
Tundra	Dry	Cold	Permafrost (frozen soil)	Lichens and mosses	Migrating animals
Boreal forest (Taiga)	Adequate	Cool year-round	Poor, rocky soil	Conifers	Many mammals, birds, insects, arachnids, etc.
Temperate deciduous forest	Adequate	Cool season and warm season	Fertile soil	Deciduous trees	Many mammals, birds, reptiles, insects, etc.
Tropical montane forest	8–9 wet months, air always humid	Always warm	Fertile soil	Ferns, tree ferns, large deciduous trees, epiphytes	Many animals
Tropical rainforest	Very wet	Always warm	Poor, thin soil	Many plants, epiphytes common	Many animals

❖ **Aquatic**

We can subdivide the aquatic biomes into two main types:

- marine biomes
- freshwater biomes

There are several biomes in each category.

Table 2.2 The main features of the aquatic biomes

Biome	Salt content	Moving or standing	Other feature	Animals and plants
Marine:				
Oceanic, pelagic	High	Moving	The region of the ocean where light penetrates	Many fish, mammals and plankton
Oceanic, abyssal	High	Less movement	The region of the ocean where no light penetrates	Angler fish, sulphur bacteria at vents
Coral reef	High	Moving	Most diverse of all marine habitats. Has many strata like a rainforest.	Corals, many fish, many seaweeds
Estuarine	Intermediate	Extreme movement	Unique habitat due to mixing of saltwater and freshwater	Shore birds, fish, crabs, mangroves, kelps, sea grass
Freshwater:				
Ponds and lakes	Freshwater	Standing	Are stratified as top layer absorbs more heat and light	Large numbers of plankton, plants and animals in top layer
Streams and rivers	Freshwater	Moving	Water is highly oxygenated	Algae, plankton, plants and fish
Wetlands	Freshwater	Standing	Water is very nutrient rich	Many plants and animals – highest of all aquatic biomes

10.5. Conservation and Biodiversity

Biodiversity is the variety of life forms on earth and the essential interdependence of all living things. This is quite simply the number of different species that are present in an ecosystem. A more useful concept is species diversity. This takes into account, not just how many different species are present, but the success of each species in the ecosystem. An **index of diversity** can be calculated and this can be used to give a picture of the ecosystem as a whole. A low value for the index of diversity suggests an area dominated by one or just a few species.

One index of diversity is Simpson's index of diversity and is calculated from the formula:

$$d = \frac{N(N-1)}{\sum n(n-1)}$$

In this formula, d is the index of diversity, N is the total number of organisms in the area and n is the total number of organisms of each species. A higher diversity index suggests a number of successful species and a more stable ecosystem. More ecological niches are available and the environment is likely to be less hostile. Environmental change is likely to be less damaging to the ecosystem as a whole unless it affects all the plants present.

However, biodiversity isn't just about the numbers of different species and how well they are doing. It is also about the diverse ways in which these different species are found. So we must also consider:

- the ecological diversity of each species – how many different ecological niches has it managed to colonize?
- the genetic diversity of each species – is there just one strain of the species with essentially one set of genes (the gene pool) or are there several different (but related) gene pools because there are several different (but related) populations of the species living in different areas?

So, biodiversity is a measure of the overall variability of life on the planet (or a local area) and it includes:

- the **species richness** and species diversity of the planet (or the local area)
- the **ecological variability** of each species
- the **genetic variability** of each species

One of the most important things that concerns scientists around the world at the moment is the loss of **biodiversity** that is taking place very quickly. This means that renewable resources are disappearing from our countries. Biodiversity is a measure of the wealth of species in a given place. It includes everything from the smallest microbe to the largest animal.

Importance of biodiversity

Ecosystems are linked on a large scale across the Earth. If biodiversity is reduced in one area, the natural balance may be destroyed elsewhere. Healthy biodiversity is important for the health of the planet. The air and water of the Earth is purified by a wide range of organisms. Waste is decomposed and removed by many different organisms. Photosynthesis by plants plays an important part in stabilizing the atmosphere and the world climate. Plants absorb water from the soil which evaporates into the atmosphere through transpiration. This helps determine where rain will fall. Plant roots hold the soil together. This reduces the risk of flooding and makes sure that the soil is not blown away and remains fertile. Plant pollination, seed dispersal, soil fertility and the nitrogen cycle are all needed for natural ecosystems and for farming. They rely on good biodiversity to work properly. Biodiversity also gives us the genetic diversity we need to develop crops to grow in different conditions. Biodiversity matters for the appearance of our country. But there are both direct and indirect effects that reduce our biodiversity.

Some of the direct effects are:

- ✓ deforestation – conversion of forests, woodlands and savannas to agricultural lands (for cultivation and grazing) and other land use systems reduce the area available to native species
- ✓ fuelwood collection and illegal logging
- ✓ overgrazing by stock animals – reduces the availability of forage and woody plant species for other animals
- ✓ introduction of improved crop varieties – reduce the genetic diversity of the particular crop
- ✓ overhunting (poaching) – directly reduces the numbers of the species hunted
- ✓ introduction of alien invasive species – these often outcompete native species for the available resources, sometimes making native species locally extinct

some of the indirect effects are:

- → high population growth
- → undervaluation of the biodiversity resources – if biodiversity is not seen as important at all levels of government
- → legal and institutional systems that promote unsustainable exploitation
- → disregard of traditional communal (range) land management systems

Of these factors two important activities have been:

• **deforestation**

Deforestation is usually carried out for one of two main reasons:

- ✓ to clear land for human activities, such as mining, agriculture or house building, or
- ✓ to obtain timber to make products such as paper, charcoal, furniture, or to use as a building material.

- **the impact of agriculture**

There are several reasons bringing biodiversity loss via agriculture. This includes:

- the area is dominated by just one species, drastically reducing the number of niches for other organisms to fill
- organisms that might live there are regarded as pests, as they reduce the crop yield and so they are controlled by the use of pesticides, and

- hedgerows are removed to create bigger and more productive fields; this reduces still further the number of habitats and niches and, therefore, reduces the biodiversity of the area.

With these all problems biodiversity loss contributes to:

- → worsening health
- → increasing insecurity of food supply
- → increasing vulnerability
- → lower material wealth
- → worsening social relations
- → less freedom for choice and action

Now we understand how important biodiversity is, we need to look at ways in which it can be conserved. **Conservation** means keeping and protecting a living environment. There are a number of ways in which we can conserve biodiversity. Individual species may be protected, so that it is illegal to capture, kill or harm them.

People can **reduce pollution** and around the world nations are looking at ways in which they can reduce the levels of carbon dioxide in the atmosphere and reduce climate change if possible.

The **loss of habitats can be reduced** – for example, if deforestation is stopped and more forests are replanted biodiversity may be increased again. One of the most effective ways of conserving biodiversity is to **protect large areas** of habitat so that natural biodiversity is conserved in a very large area.

10.6. Vegetation and wildlife

Vegetation refers to a **plant community** which has grown naturally without human aid & has been left undistributed by humans for a long time. This is termed as a virgin vegetation. Thus, cultivated crops and fruits, orchards from part of vegetation but not natural vegetation.

Plants are of great importance to human beings all around the world. We use them in many different ways. We use them for food, for example, teff, sorghum, anchote and beans. We use them to make drinks such as tella, and coffee (bunna). The coffee plant is not only used in our homes for drinks, it is very important in our economy as coffee is one of our main exports too. Plants are used for building materials – wood is used to build our homes and plants are used to thatch the roofs. But the impact of human on the vegetation should be considered as indicated above.

Endemic species

Ethiopia is a country which is internationally recognized for its rich diversity of plant species. We have around 7000 different species of higher plants alone, with up to 800 endemic species. An endemic species is an organism that is only found in a particular area – so we have around 800 endemic plants which grow wild in parts of Ethiopia. They are very important to both Ethiopian and world biodiversity! Examples of our endemic species include teff (Eragrostis teff), many Euphorbia spps, noug or niger seed (Guizotia abyssinica), enset (Ensete ventricosum), Ficus vasta Forssk, zigba, juniper (tid), kererro and sembo trees and many other species.

Vegetation should be a **sustainable resource** – plants make more plants and grow continuously, so we can harvest them.

Wildlife

Wildlife refers to living organisms (flora and fauna) in their natural habitats. wildlife includes any animal, bees, butterfly, crustacean, fish and moth and aquatic or land vegetation, which form part of any habitat. The wildlife of Ethiopia is some of the richest in the world. We have 242 listed mammalian species, which range from huge elephants to tiny elephant shrews. There are around 862 species of birds as well. Some of the wildlife acts as a genetic bank for our domestic animals and can be used as a source of genetic diversity. However, one of the most important uses of wildlife in Ethiopia is to generate income from tourism.

Endemic species

We have a high number of endemic species of different types of wildlife. For example, there are 28 species of mammals, which include the Gelada Baboon, the Walia ibex, Menelik's Bushbuck, the Mountain Nyala, Swayne's Hartebeest and the Ethiopian wolf you have looked at before. Endemic bird species include the heavy-headed, thick-billed raven, the wattled ibis, the black winged lovebird, the white-collared pigeon and the Prince Ruspolis Turaco. We also have six endemic reptiles and around 33 endemic amphibians. These animals and many others are found only within the boundaries of Ethiopia.

10.7. Global warming and air pollution

Pollution is the contamination of the natural environment by harmful substances as a result of human activities. Pollution can happen on a very small, local scale – every time you drop litter, or a dog fouls the street; the local environment is polluted. On the other hand, pollution happens on a very large scale too, affecting whole countries – acid rain, global warming and the ozone hole are all examples of the effects of large-scale air pollution. **A pollutant** can be defined as something that contaminates the air, soil and water. In this section we will be concentrating on substances which pollute the air.

Air pollution

Air pollution comes in various forms, each of which has serious implications for our health and well-being as well as for the whole environment. One type of air pollution is **smoke** produced by burning fuel for energy. Much of the fuel we use is **fossil fuel** – coal, oil or gas, or electricity produced by burning them. Fossil fuels contain chemicals known as **hydrocarbons**. When these fuels are burnt, tiny particles of unburnt hydrocarbons are released into the air. Diesel smoke is a good example of this. The **particles** are very small pieces of matter. This type of pollution is sometimes referred to as '**black carbon'** pollution. The exhaust from burning fuels in cars, homes and industries is a major source of pollution in the air. Even the burning of wood on our fires can release significant quantities of soot into the air causing local air pollution. Smoke pollution worldwide is thought to be causing **global dimming**, blocking out some of the light from the sun. Another major cause of air pollution is the production of **carbon dioxide**. Carbon dioxide is produced by living organisms as a waste product of respiration. It is used by plants in the process of photosynthesis. Carbon dioxide is also produced as a result of burning wood and fossil fuels.

Global warming

So as a result of human activities the amount of carbon dioxide (and methane) in the air is continuing to increase. This build-up acts like a blanket and traps heat close to the surface of our Earth. This causes the temperature at the surface of the Earth to rise. This in turn may have many effects on our climate and health – and it is also thought to contribute to the increased hurricane activity which has affected some areas of the world in recent times.

Another air pollutant is **carbon monoxide**, also produced by the burning of fossil fuels. It is produced by cars as well as by home water heaters, paraffin lamps and fires if they are not functioning properly. Carbon monoxide is very dangerous because it combines irreversibly with haemoglobin in your blood, reducing the oxygen carrying capacity.

Acid rain

Acid rain is the result of another form of air pollution. When fossil fuels are burned carbon dioxide is released into the atmosphere as a waste product. However, carbon dioxide is not the only waste gas produced. Fossil fuels often contain sulphur impurities. When these burn they react with oxygen to form sulphur dioxide gas. At high temperatures, for example, in car engines, nitrogen oxides are also released into the atmosphere.

Sulphur dioxide and nitrogen oxides pollute the air and can cause serious breathing problems for people if the concentration gets too high. They form a haze of pollution known as smog, which can be a real problem in big cities where there are millions of motor vehicles. They are also involved in the formation of acid rain. This pollutes land and water over a wide area. The sulphur dioxide and nitrogen oxides dissolve in the rain and react with oxygen in the air to form dilute sulphuric acid and nitric acid. This makes the rain more acidic – it is known as acid rain.

Effects of Acid Rain

- Harmful to aquatic life
- Increased acidity in water bodies
- Stops eggs of certain organisms (e.g. fish) to stop hatching
- Changes population ratios
- Affects the ecosystem
- Harmful to vegetation
- Increased acidity in soil
- Leeches nutrients from soil, slowing plant growth
- Leeches toxins from soil, poisoning plants
- Creates brown spots in leaves of trees, impeding photosynthesis
- Allows organisms to infect through broken leaves

Solution to reduce acid rain

- Use cleaner fuels
- Remove oxides of sulphur and oxides of nitrogen before releasing
- Flue gas desulphurization
- Use renewable energy like wind power, solar panels, tidal power
- Limit the number of vehicles on the roads and increase public transport.