TEPI SECONDARYAND PREPARATORY SCHOOL

BIOLOGY SHORT NOTES FOR GRADE ELEVEN STUDENTS 2012 EC

DEPARTMENT OF BIOLOGY

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BIOLOGY GRADE ELEVEN (11) SHORT NOTE FOR STUDENTS 2012EC

UNIT 1 THE SCIENCE OF BIOLOGY

1.1 The Methods of Science

- Biology is the science of life and living organisms .Life is DNA in modern thought
- Biologists engage in all kinds of research to try to find evidence of life
- Astro biologists tried to find evidence of life on other planets in our Solar System and in galaxies elsewhere in the Universe.
- Biomedical researchers help in the development of new drugs and vaccines. Others still
- Microbiologists. Study how micro-organisms of all kinds function. Some cause disease, and understanding how they work makes a treatment more likely.
- Paleobiologists try to find out more about the way in which life began on Earth and how it has evolved from simple life forms into more complex ones.

What is science? Latin *scientia*, 'knowledge', but science isn't just about having knowledge: **Science** is unique system of acquiring knowledge based on scientific method. It is sometimes called experimental science, because it depends on experimentation to obtain the information. This is different from applied science, in which scientific research is used to meet certain human needs. However, it is often difficult to separate the two.

- **Scientific method** the process by which scientists approach their work
- **Experimental science** the use of experiments to obtain information
- **Applied science** the use of scientific research to meet certain human needs

What is the scientific method? What are the main steps of the scientific method?

- ✓ **Spontaneous generation** ;the appearance of living organisms from non-living matter
- ✓ **Hypothesis** an educated guess what a biologist thinks the explanation of an observation will be. But it can be tested by an experiment
- ✓ **Prediction** an educated guess as to how biologist thinks his/ her experiment will turn out
- ✓ **Control group** standard group in an experiment in which the experimental groups are compared with
- ✓ **Experimental group** the group in an experiment which is being experimented on in order to compare with the control group

Table 1. How a Biologist would follow the scientific method

Step of the method	**Step of the method What happens at this step**
Ask a question	Something catches our ***imagination***. We know that tomato seeds germinate when they are planted. But why don't tomato seeds grow inside tomatoes?
Do background research	Before start trying to do the whole investigation, first check scientific magazines and internet to see if anyone else has looked into the problem, or into a similar problem. We find out that there are substances in plants control growth, or growth regulators.
Construct hypothesis '	There are chemicals in tomatoes that stop the seeds from growing still in tomatoes.' This hypothesis is testable by an experiment. We think that it is ***a chemical that responsible***. So how do we prove that? We could try covering some seeds with tomato juice and others with water and see if any germinate. Based on hypothesis we make a prediction: 'Seeds covered in tomato juice will not germinate as well as seeds covered in water'.
Design and carry out an experiment to test the hypothesis	1. Put several tomatoes in a blender. 2. Filter (strain) the blended material through some muslin. 3. Collect the tomato seeds and wash them in distilled water. 4. Place 20 in a Petri dish on filter paper and cover with tomato juice obtained from filtering. 5. Place 20 in a Petri dish on filter paper and cover with same volume distilled water. 6. Place them in a growth cabinet keep temperature and lighting conditions constant. 7. Leave them for four days. 8. Check the numbers that have germinated in each condition. 9. Repeat the experiment 50 times to confirm your results.
Analyze results and draw conclusions	Out of 1000 seeds sown in each condition, 668 germinated in the distilled water (13.36 per dish) and 265 germinated in the tomato juice (5.3 per dish). It seems like something in tomato juice is affecting the germination of the seeds. It can't be the cells themselves, because they were filtered off. It must be a chemical in the juice.
Accept or reject the hypothesis	***Hypothesis*** is along the right lines; the tomato juice will only contain chemicals, not cells, and it does reduce the amount of germination. So we accept the hypothesis. But inside the tomatoes themselves, none of the seeds germinate.
Report results	Report results; decide whether or not to report the results to other biologists. decide to take the work further and try to isolate a particular chemical from the many in the juice to find exactly what is stopping them from growing inside the tomato

What do we mean by cause and effect?

- ***Scientific experiments*** try to establish cause and effect. This means that they try to prove that a change in one factor brings about a change in another factor.
- ***Independent variable*** (IV) ;the factor that the scientist changes, or manipulates, the independent variable was the presence or absence of tomato juice.
- ***Dependent variable*** (DV) ;the factor that scientist measures to see if it changes when the IV is changed. The DV was the number of tomato seeds germinating
- The scientist will want to find out if changes in the IV produce changes in the DV

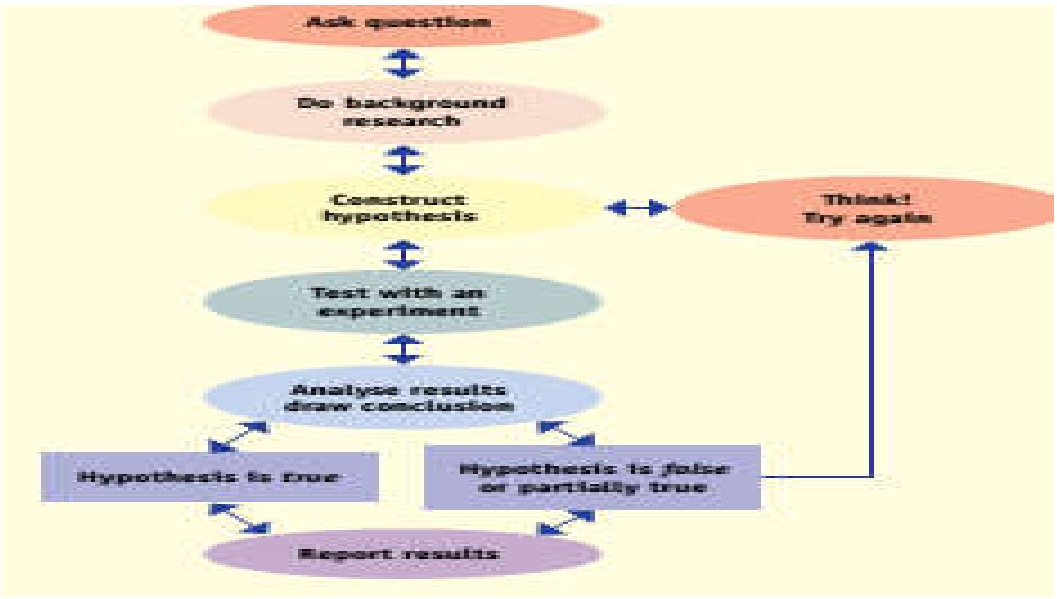


Figure 1. The main steps of scientific methods

Table 2. How do we write reports on scientific experiments?

Steps	Section How it would be written
Title	Title An investigation into the effect of tomato juice on the germination of tomato seeds.
Procedure	30 tomatoes were blended for five minutes. The blended material was then filtered and liquid (juice) was collected. The seeds were extracted from the cellular material which was then discarded. The juice was diluted with distilled water to give a total volume of 550 cm3. The tomato seeds were washed in distilled water for 30 seconds 20 seeds were placed in each Petri dish on the intersections of the lines of the grid (to ensure even spacing in all dishes). 10 cm3 tomato juices were added to half of the Petri dishes and 10 cm3 distilled water was added to the other half. All the dishes were placed in an incubator at a temp. of 20 °C for four days. At the end the number of successful germinations in each dish was recorded and means for each condition calculated. If radical (root) 0.5 cm or more present, the seed was said to have germinated.
Results	Out of 1000 seeds sown in each condition 668 germinated in the distilled water (13.36 per dish) and 265 germinated in the tomato juice (5.3 per dish).
Conclusion	Hypothesis is accepted. Germination of seeds in tomato juice is much less successful than in distilled water. Chemical in tomato juice must inhibiting germination. In tomato fruits no seeds germinate
Evaluation	No anomalous results. Germination of seeds in all of dishes in experimental (tomato juice) was less successful than in dishes in control (distilled water). Experiment was not without limitations. • It was only carried out for four days (to limit the development of fungal growth that might have interfered with germination). Had it been carried out for longer the pattern may have been different. • It was only carried out at one temperature; this may have influenced the experimental and control conditions differently. Repeating investigation at a range of temperatures would help to clarify this. • The judgment of germination (a radical of 0.5 cm length) was arbitrary but it did overcome problem of including in the count seeds that had merely swollen with water but not produced any growth.
Acknowledgement	Acknowledgements Biology – Martin Row lands – information on plant growth regulators.

1.2 The tools of a biologist;

What do biologists use in the laboratory? There are some basic tools. These include:

- Microscopes
- Dissecting equipment
- Petri dishes
- Pipettes and syringes
- Centrifuges
- Measuring cylinders
- Balances

What do biologists use in the field? Biologists outside laboratory study to find out how Animals, Plants and Microorganisms interact with each other and with environment. All this involves:

- ✓ Taking measurements of the abundance of organisms in the field
- ✓ Taking samples of the environment (for example, soil, rocks,
- ✓ Water for analysis in laboratory collecting specimens for identification and analysis

Some other instruments that biologists use in the field are;

- **Data logger** – this is used to record information,
- **pH kit** – this is used to measure the pH of soil or water,
- **Flow meter** – this is used to measure the rate of flow of water,
- **Field microscope** –used to investigate structure of specimens in field, whilst still fresh,
- **Theodolite** –used to measure the height of trees or slopes in the area mostly,
- **Clinometers** –used to measure heights of trees for determining forest structure
- **GPS (Global Positioning System) receiver**; record positions quickly, extremely and accurately. By taking several readings at different points on the perimeter of the area, an accurate map of the area can be drawn.

1.3 The relevance and promise of biological science

Biology seeks to understand how all life functions including life on other planets, should it exist, to give scientific answers to questions of most people think. Some of these are listed below:

- ✓ Where did humans come from? How is disease caused?

- ✓ Where did I come from? How did all life begin?
- ✓ How is AIDS caused? (How is covid 19(SARS cov-2) caused?)
- ✓ How can vaccines be developed against diseases like malaria and AIDS?
- ✓ What makes cancer cells different from ordinary cells?
- ✓ Will it ever be possible to grow a new kidney just for me?
- ✓ What causes global warming? How can we solve problems of food shortage?

Biology has relevance in almost every aspect of life. Some undoubtedly of great importance are;

BIOLOGY AND AGRICULTURE

- World's population is growing at alarming rate, this poses challenges to all governments.
- Extra people all need ***Homes***, ***Food*** and ***other services***. Global warming alter crops grow.
- Many crops produce high yields in some countries not do so if current trends continue.
- Some countries benefit, as their agricultural output will increase with global warming.
- There are many different estimates as to which countries will 'win' and which will 'lose'.

Biologists carrying out research how to produce crop plants that adapted to the new conditions;

- ✓ Are capable of producing their crop quickly so that more yield
- ✓ ***Are disease resistant? Are weed resistant? Are drought resistant?***
- ✓ This work involves genetic modification of existing crop plants to give new characteristics that will enable them to be productive in the changed environment.

Biology and Medicine

Biologists' advice on ways of reducing rate of population growth. Individuals and governments on effective methods of contraception and ways of educating people about need to limit population growth. Doctors and Nurses have specialized biological knowledge and help sick people and advice ways of staying healthy. Their work is supported by other biologists, such as:

- Medical laboratory technicians test blood samples and other provide reports for doctors
- Medical researchers find more ways in disease-causing organisms function and spread
- Radiographers, who produce X-rays and other images to help in
- Specialized researchers who look into why and how cancer is caused

- Drug development researchers, work and develop new drugs to treat diseases

BIOLOGY AND THE ENVIRONMENT

Biologists involved in monitoring impact of global warming. The abundance and distribution of species in many areas are changing. Biologists advice governments on ***how best to conserve environments***, introducing new species that maintain best balance of species in area. The promise of research in these like *biotechnology* fields is huge. Among the goals are:

- ✓ Cures for genetic diseases
- ✓ Treatments for degenerative diseases, such as Parkinson's and Alzheimer's disease
- ✓ Establishing industrial processes to manufacture more biological products like insulin.
- ✓ Producing drugs that are 'tailor-made' to suit an individual's needs genetically modifying plants to meet a specific need; for example
  - plants that can produce a good yield of a crop in dry conditions
  - plants that produce their own insecticide will not need chemical insecticides
- ✓ Cloning of productive animals and plants
- ✓ Production of monoclonal antibodies that can deliver a drug to only those cells that need treatment (example, cancer cells)
- ✓ Using stem cells to repair damaged organs and ultimately, to grow whole new organs

The Relevance of Biology in Ethiopia

Biology is very relevant in Ethiopia considering issues ***overpopulation, food security, environmental well-being, health care, Natural resource conservation, Biodiversity***, others, Practical biological knowledge is special relevance and education in biology needs attention.

- ✓ As citizens of Ethiopia must have biological literacy to understand and assist in preservation, development and proper use biological resources b/c our heritage.
- ✓ Systematically combine indigenous knowledge with modern science by training.
- ✓ Control of land degradation, Biodiversity loss, disease and
- ✓ Develop biological and agricultural potential contribute transforming country's economy.

1.4 Biology and HIV/AIDS

AIDS (Acquired Immune Deficiency Syndrome) is caused by Human Immunodeficiency Virus (HIV). HIV infects immune systems cells called T-helper cells that enable us to fight off diseases. For a time body keeps replacing HIV infected cells, and this can last for many years. However, the body eventually cannot keep pace and AIDS develops. People suffer from '***opportunistic***' infections that normally have able to fight off. Also develop some forms of cancer. AIDS is usually fatal and epidemic. There are:

- ✓ 33 million people living with AIDS (2.2 million in Ethiopia)
- ✓ 2 million children living with AIDS
- ✓ 11.6 million AIDS orphans in Africa alone (650 000 in Ethiopia)
- ✓ Over 17 million women living with AIDS worldwide

AIDS is largely a sexually transmitted disease (STD), although there are four main ways in which HIV can be transmitted. These are:

1. Homosexual or heterosexual intercourse with an infected person
2. Transfusion of infected blood or blood products
3. Sharing infected needles
4. Mother to child during pregnancy, Breast feeding.

How can biology help in the fight against AIDS?

There are several methods of combating the spread of a disease. These are described below.

- ✓ HIV cross barrier and find its way to blood so can infect T-helper cells and multiply.
- ✓ Break transmission pathway, if cannot spread it will eventually disappear.
- ✓ Produce drugs that kill virus or stop reproducing. Antibiotics cannot act on viruses.
- ✓ Produce vaccine against virus used to build 'herd immunity' to break transmission.

HIV viruses are two sub types these are HIV-1 and HIV-2. **HIV-1** is more virulent and globally distributed. HIV-2 sub type is less distributed and restricted to West Africa. HIV viruses are spherically enveloped, Retroviruses and composed two copies of +ssRNA enclosed by capsid , all have a similar life cycle, shown in the diagram below:

1 – The entry phase
2 – Viral genetic material is converted to DNA
3 – The new DNA enters the host cell DNA
4 – The new DNA 'instructs' the cell to make more HIV

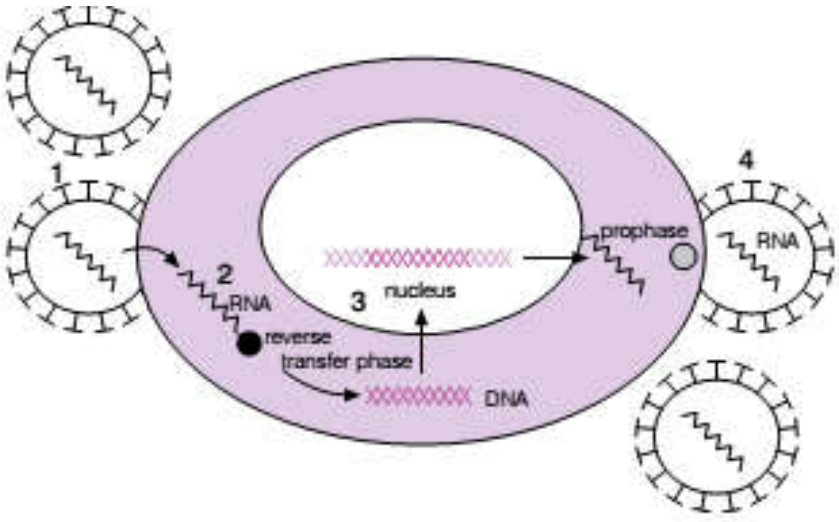


Figure 2 Retro virus life cycle

- Drugs that target and aim to break this life cycle. They are called **anti-retroviral drugs**.
- Different ***antiretroviral drugs*** target different stages in the life cycle.
- More effective when taken in combination than taken singly, although there can be side effects.
- The combination treatment is called **highly active anti-retroviral therapy**, or **HAART**.
- These drugs only treat the HIV that is currently present in the body.
- They do not provide any lasting immunity and a person could be re infected.
- Other biologists have been working for years to try to produce a vaccine against HIV.
- A vaccine *would* provide lasting immunity against re infection by HIV.
- The problem is HIV mutates (changes) and any infected person have several types of HIV.
- Most experimental AIDS vaccines based on a weakened HIV itself and were potentially dangerous because the virus could always revert to its infective form.
- People of Kenya who repeatedly exposed to HIV but never developed AIDS. Their immune responses to HIV may hold **the key to a vaccine**.
- Human antibodies produced against HIV completely protect some monkeys against a very similar disease caused by a very similar virus. A vaccine could well be possible.

What can we do in the fight against AIDS?

The first is to recognize that people with AIDS are simply sick people who need medical care as well as the support and love of their families and friends. AIDS victims have been stigmatized all over the world. This makes the problem worse in a number of ways:

- ✓ It makes it harder for victims to come to terms with their illness,
- ✓ It may prevent them from seeking early advice for fear of stigmatization; this in turn may lead to further infection before the condition is diagnosed.
- ✓ It can make governments reluctant to take decisive action for fear of offending powerful pressure groups. We must show tolerance and support.

Communities, individuals agree to control spread of AIDS by breaking transmission pathway. These are;

- ✓ Restricting the number of sexual partners. If sex with many people, increase risk of contracting HIV and passing it on. Sex within a loving, monogamous relationship limits the spread of AIDS.
- ✓ Men can elect to be circumcised, this significantly reduces risk of men acquiring and passing HIV
- ✓ Not sharing infected needles. Drug users who do this spread from one to another and then into other members of the community through intercourse.

UNIT 2 BIOCHEMICAL MOLECULES

2.1 Inorganic and organic molecule

Classification of inorganic and organic molecules

Biological molecules can be classified into two main types: inorganic molecules and organic molecules

- ➢ Organic molecules are molecules that always contain both carbon and hydrogen.
- ➢ Inorganic molecules may contain one or the other (or neither), but not both.

Which chemical elements are found most frequently in living organisms? Elements are used to build biological molecules, for example in humans;

- ✓ Calcium (Ca) for bones, teeth and muscles, Chlorine (Cl) for digesting food,
- ✓ Fluorine (F) for tooth enamel and iron (Fe) to help blood carry oxygen.

Atoms of elements;

- ➢ Can join together to form molecules with forming a chemical bond.

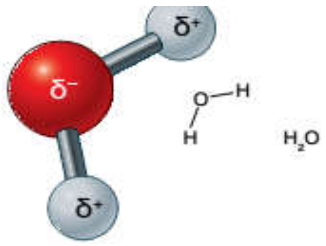
- Two atoms of same element join to form a molecule of that element example, oxygen gas is O_2.
- Atoms of one element can join with atoms of another element to make a molecule of a compound.
- The atoms are always present in the same ratio in all the molecules of the compound.
- Each atom can make a certain number of bonds with other atoms; this is called its valency

Water, water everywhere?

- Water covers three-quarters of the planet and remaining one-quarter, is land;
- Water is not very far away. It may be in streams, rivers, ponds, lakes or in underground aquifers.
- It is in all living things. Most cells are about 70% water and some are as high as 90%.

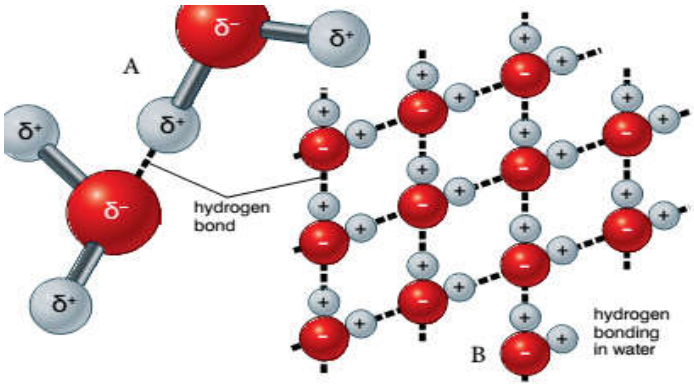
What is water?

- ✓ The chemical formula for water is **H_2O.**
- ✓ Water is made of molecules, contains two hydrogen atoms bonded to one oxygen atom.
- ✓ Notice that the molecule is not 'straight' it is bent into a 'v' shape.
- ✓ The molecule forms a '**dipole'.** Part of the molecule has a slight negative charge (δ–) and other parts have a slight positive charge (δ+).
- ✓ All water molecules are interlinked! the bonds joining the hydrogen atoms to the oxygen atom, there are very weak bonds called **hydrogen bonds** that join oxygen in one water molecule (slightly negative part) to hydrogen in another water molecule (slightly positive part).



***gure 2.5** A molecule of water*

- ✓ Water is the name of a substance. It is the only substance that exists in three states
- ✓ Solid, Liquid and Gas – at temperatures commonly found on Earth.
- ✓ Solid water is ice, liquid water we call water and gaseous water is steam



Figjre 4 Hydrogen bonding between water molecules

- ✓ The hydrogen bonds in water keep breaking and reforming as the molecules move around, but there is always some bonding between the molecules in a mass of water.
- ✓ One water molecule can possibly make bonding with four other molecules.

Why is water so important to living things?

The very first cells on Earth evolved in water about 3.5 billion years ago. Water has many properties that make it important to living things, such as:

- ➢ a transport medium
- ➢ a reactant in many chemical reactions
- ➢ a place for other reactions to take place• water is a vital chemical constituent of living cells
- ➢ water is a vital chemical constituent of living cells
- ➢ a place to live in. Many organisms live in water. Plants, algae and different animals

Water is Transparent.

- – Means light can pass through the water and allow the plants and algae to photosynthesize.
- – So animals can see where they are going.
- – However, water does not allow all light to pass through it, as we go deeper less light penetrates.
- – Different wavelengths of light penetrate to different depths. Red and indigo are soon lost.
- – Blue and green wavelengths penetrate deeper than others.

Water has a high specific heat capacity.

- ♣ Specific heat capacity the amount of energy needed to raise temperature of 1 g substance by 1 ^{o}C
- ♣ It takes quite a lot of energy to heat water up. Water also loses heat quite slowly.

- ♣ The overall effect that water stays more or less the same temperature particularly large masses of water, such as oceans and lakes.
- ♣ This is important as the functioning of enzymes in living cells is affected by temperature.
- ♣ Too hot or too cold and the enzymes do not function efficiently and the reactions in the cells controlled by the enzymes are not carried out efficiently.

Ice is less dense than liquid water.

- ♣ It is unusual for solid form of a substance to float on liquid form of same sub., but ice floats on water. Because water expands when it freezes. So, in cold weather, water freezes from top down.
- ♣ The ice on the surface acts as an insulator and slows down heat loss from liquid water underneath. ***So life can continue in relatively warm water underneath the ice all through the cold weather.***

Water has a high latent heat of vaporization.

- ♣ latent heat of vaporization the energy used in converting a liquid to a gas at the same temperature
- ♣ This means that it takes a lot of energy to turn liquid water into water vapour (or steam).
- ♣ Means water doesn't vaporize too easily and that ponds don't dry up too quickly in hot weather – and the organisms in the pond have a better chance of survival.
- ♣ Important in temperature control. When we sweat, the energy needed to vaporize the sweat comes from our bodies. This heat is then lost from our bodies and so we cool down.
- ♣ If water vaporized easily, sweating wouldn't be as effective in controlling our body temperature.
- ♣ Different wavelengths of light penetrate to different depths. Red and Indigo soon lost.
- ♣ But Blue and green wavelengths penetrate deeper than others.

Water has a high surface tension.

- ➢ Water molecules in main body of a mass of water H bonded to other water molecules on all sides.
- ➢ But at the surface, there is no H bonding above. So the 'pull' from the sides is stronger than it would otherwise be and the molecules at the surface are held together more strongly.
- ➢ This is why some animals can 'walk on water' and others attach themselves to surface of water.
- ➢ Water strider one example of an insect is light that force of surface tension support insect weight.
- ➢ The mosquito larvae in figure 2.11 hang from the surface of the water by their breathing tubes.
- ➢ The surface tension is sufficiently strong to hold their weight.

Water is a good solvent for many substances

- Many organic and inorganic substances important to life dissolve in water, but don't dissolve either at all or as well in other liquids.
- Water is very versatile. Substances dissolve in water, transported in a water-based medium.
- Biological mechanisms such as Active transport, Diffusion and Facilitated diffusion move substances in and out of the water (transport medium).
- In mammals, the plasma of blood is 90% water.
- In plants water carries dissolved minerals upwards from roots to other parts of plants in xylem.
- Water in the phloem tubes carries dissolved organic substances all over the plant.

Water has the ideal viscosity for a transport medium.

- ♣ Viscosity is a measure of how fluid a liquid is, how easily it flows.
- ♣ If water more viscous (less fluid) than think of tar! Heart not moves it through blood vessels.
- ♣ If it were more viscous, it would damage the delicate organelles in the cells.
- ♣ If water were less viscous (more fluid) than it is, it would flow too easily and, inside cells, the organelles would not be supported.
- ♣ Plant cells absorb a lot of water, they swell until cellulose cell wall won't let them swell any more. In this condition, we say they are turgid.
- ♣ Turgid cells press against each other and this pressure helps to support the plant.

Water as a reactant;

- ✓ Many reactions in living things need water as a raw material.
- ✓ Photosynthesis is process of energy transfer requires water as reactants.
- ✓ Water is also involved in digesting large food molecules into smaller ones.
- ✓ Reactions use water to split large molecules called **hydrolysis**. Hydro = water; lysis = splitting.
- ✓ Water molecules are used to split large food molecules into smaller
- ✓ Water involved in reactions CO_2 in RBCs transport CO_2 around body as hydrogen carbonate ions.

Water as a medium for chemical reactions.

- ❖ Cell function many chemical reactions that are continually taking place in them.
- ❖ Take place on membrane systems of the cell, but others in e liquid 'cytosol' of cytoplasm.
- ❖ Photosynthesis and respiration take place in liquid inner of chloroplasts and mitochondria.

Water is an ideal medium for these reactions, for some of the reasons already discussed:

- ❖ It can dissolve many substances; the reactions will only take place effectively in solution.
- ❖ It has a low viscosity; particles can move around and come easily into contact with each other.

2.2 Organic molecules

What are carbohydrates and why do we need them? Carbohydrates;

- ➢ All carbohydrates contain carbon, hydrogen and oxygen. The ratio of H to O atoms is 2:1.
- ➢ Range from very small molecules containing 12 atoms, to very large thousands of atoms.

Carbohydrates have a range of functions:

- Used to release energy in respiration glucose is the main respiratory substrate of most organisms.
- Carbohydrates are a convenient form to store chemical energy; storage carbohydrates include:
  – Starch in plants
  – Glycogen in animals

Some carbohydrates are used to build structures; structural carbohydrates include:

- – **Cellulose**, is the main constituent of the primary cell wall of plants
- – **Chitin**, occurs in the cell walls of fungi and in the exoskeletons of insects
- – **Peptidoglycan** occurs in bacterial cell walls

What different types of carbohydrates are there?

- Based on the number of sugar molecules carbohydrates are grouped in tothree groups.
- These are Simple, Double and Complex carbohydrates

1. MONOSACCHARIDES

- ✓ Are the simplest carbohydrates.
- ✓ Monosaccharides are carbohydrates with atoms that are arranged in a single ring-like structure.
- ✓ A monosaccharide molecule can be thought of as a single sugar unit.

Monosaccharides can be classified according to how many carbon atoms are present in the molecule.

- ➢ Triose monosaccharide has 3C atoms, $C_3H_6O_3$. Glycerate phosphate important in photosynthesis.
- ➢ Pentose monosaccharide has five C atoms, $C_5H_{10}O_5$. Ribose is found in RNA nucleotides.
- ➢ Hexose monosaccharide has six carbon atoms – formula $C_6H_{12}O_6$. Glucose is the hexose

- There are several different Trioses, Pentoses and Hexoses. Isomers; the same number of each kind of atom but atoms are put together in a different way. Example pentoses and hexoses.

Monosaccharide; classified based on functional group they possess. Aldehyde and Ketone groups

- Aldehyde with CHO(carbonyl group) at end of carbon chain (monosaccharide are Aldoses),
- Ketone; with C=O (carbonyl group) in middle of carbon chain (monosaccharide are ketoses).

The main significance is difference in the ability to polymerize.

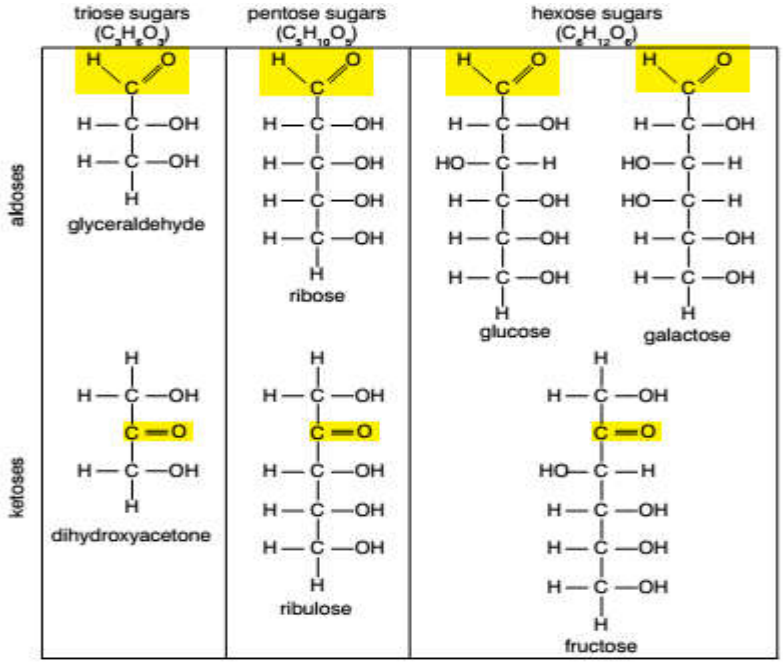


Figure 2.16 *Aldose and ketose monosaccharides*

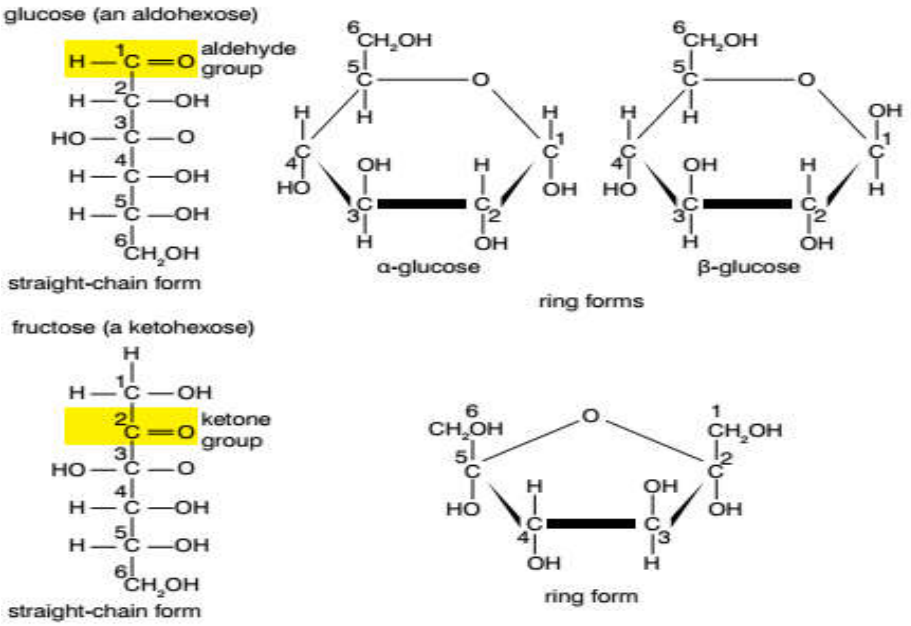


***Figure 2.17** Straight chain forms and ring forms of glucose and*

- ✓ Straight chain form of glucose can produce two different ring forms – α-glucose and β-glucose.
- ✓ There is only one difference between these two. Can you see it?
- ✓ The straight chain form of fructose produces only one ring form.
- ✓ The carbon atoms in the molecules are numbered according to their positions in the molecule.
- ✓ You do not have to know the position of every C, H and O atom in these molecules.
- ✓ Diagrams show shape of molecule, position C, H and O atoms attached to carbon atoms 1 and 4.

2. DISACCHARIDE

- ➢ Carbohydrate molecules that are made by two monosaccharide molecules joining together.
- ➢ **Maltose**(malt sugar) is derived from two α-glucose molecules
- ➢ **Sucrose** is derived from an α-glucose molecule and a fructose molecule
- ➢ **Lactose** (milk sugar) is derived from a β-glucose molecule and an α-galactose molecule.

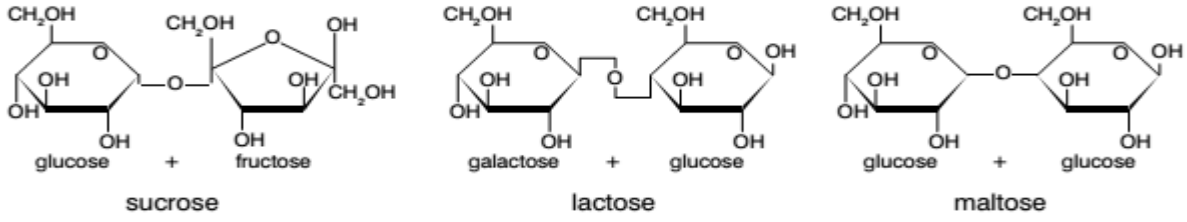


***Figure 2.20** The structures of three disaccharides*

- ❖ The formula of the disaccharides to be $C_{12}H_{24}O_{12}$.

- H_2O is formed from a hydroxyl group from one monosaccharide and a \H atom from the other
- The two monosaccharide units bonded to make a disaccharide is condensation.
- The bond that holds the two monosaccharide units together is a glycosidic bond.
- It is formed b/n C atom 1 of one α-glucose and C atom 4 of the other α-glucose molecule.
- The full name of the bond is, therefore, a α-1, 4-glycosidic bond.

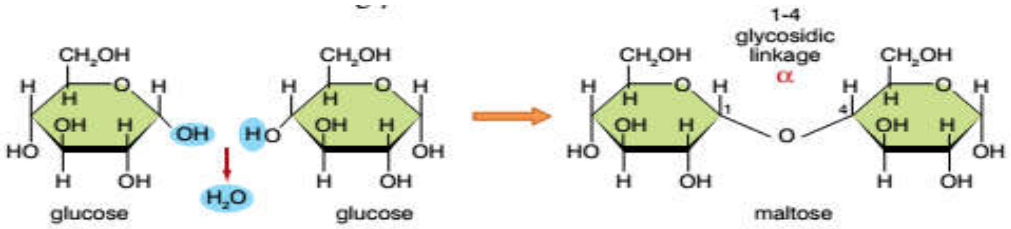


Figure 2.21 *Two molecules of α-glucose are joined to form a molecule of maltose (a disaccharide).* KEY

3. POLYSACCHARIDES;

- Are complex carbohydrates. Built as many monosaccharide join together by condensation links.
- Some polysaccharides are storage molecules that will not interfere with the metabolism of cells
- Structural carbohydrates. build structures – like plant cell walls and insect exoskeletons.
- Examples include, starch, cellulose, glycogen, chitin, pectin, lignin
- A polymer molecule is made from many smaller, usually identical, molecules called monomers.
- ***Chitin*** is the main structural components of exo skeletons of invertebrate like insects and in fungi
- ***Pectin*** extracted from plants and serve as gelling agent in food industries for preserving
- ***Lignin*** is a polymer of conferral alcohol

Starch

- Starches are plant storage form of carbohydrates and polymers of **α-glucose**,
- Starch is not a single compound but a mixture of Amylose (linear) and Amylopectin (branched).
- Both are polymers of α-glucose, but the arrangement of the α-glucose monomers is different.
- **Amylose** is a linear molecule containing many hundreds of α-glucose molecules joined by α-1, 4-glycosidic bonds. As it is being formed, this long chain winds itself into a helix.

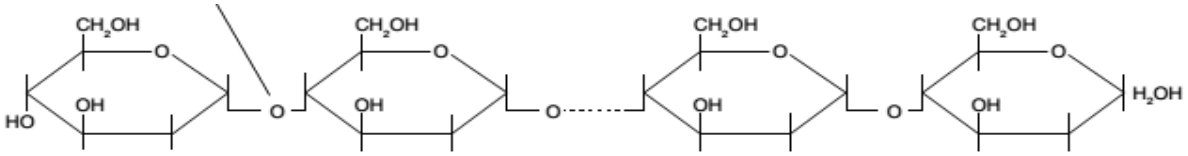


Figure 2.23 *Linkages in amylose*

- **Amylopectin** is a linear 'backbone' of α-glucose joined by α-1, 4-glycosidic bonds and side branches bonded with α-1, 6-glycosidic bonds.
- An α-1, 6-glycosidic bond with another glucose as well as the usual α-1, 4-glycosidic bond.
- The branched nature of amylopectin means that there are many 'ends' to the molecule.
- This allows it quickly hydrolyzed by enzymes at ends of chains to release glucose for respiration.

Why starch stains blue or black or blue-black with iodine

- Amylose molecule winds itself into a helix when in contact with water.
- This allows a reaction to occur between the starch and the iodine solution.
- Rows of iodine atoms sit inside the amylose helix.
- This changes light-absorbing properties of both, so that the amylose iodine complex appears blue.
- Starches in different plants have different proportions of amylose and amylopectin.
- This results in different shades of blue-black iodine test, because only amylose reacts with iodine.

How the structure of starch is suited to its function

Starch is a plant storage carbohydrate. Both Amylose and Amylopectin are;

- ❖ Compact molecules, so many α-glucose stored in small space, without affecting cell metabolism.
- ❖ Insoluble. If soluble glucose stored (instead of converted to starch), it draw water, by osmosis, from neighboring cells and organelles within cell. Insoluble starch produces none of these effects.
- ❖ Insoluble, the molecules cannot move out of cells – they remain in storage organs.

Glycogen

- Glycogen is a storage carbohydrate in animal liver and muscles cells and polymers of **α-glucose**
- Similar structure with amylopectin but more α-1, 6 links, making it more highly branched.
- Because of this, it can be hydrolyzed even more quickly to release glucose for respiration.
- This is important because animals have a higher metabolic rate than plants and need to release energy more quickly to 'drive' their metabolic processes.
- Glycogen is more branched and a protein at the heart of every glycogen called glycogenin

Cellulose

- ➢ Cellulose is a polymer of β-glucose.and most abundant organic molecule in the biosphere
- ➢ Polymer of β-glucose joined by β-1,4glycosidic bonds, formed by condensation reactions.
- ➢ However, different position of H and OH groups on carbon atom 1 compared to α-glucose, every

- Other glucose unit in the chain is upside down, as figure 2.26. Also, the chain is unbranched.

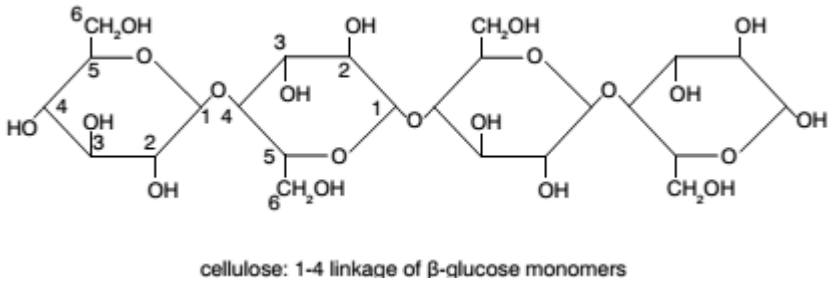


Figure 10. The cellulose structure

Many cellulose molecules lay side by side and hydrogen-bond to each other results formation of cellulose micro fibrils. Micro fibrils bond together to form bigger fibers or fibrils make up of cell walls structure.

How the structure of cellulose is suited to its function, The cellulose molecule is;

- Un branched this allows hydrogen bonding and the formation of micro fibrils.
- If it were branched, micro fibrils could not form.
- The fibrous nature gives the cell walls their strength, but also gives them some flexibility.

What are Lipids?

Lipids contain C, H and O, but much less oxygen than carbohydrates. Varied lipids group that include:

- Triglycerides formed from; Glycerol and three fatty acids
- Phospholipids formed from, Glycerol, two fatty acids and a phosphate group
- waxes formed from Fatty acids and long-chain alcohols

Whilst some lipids have quite large molecules, they are not polymers and, in many cases, their molecules are relatively small. 'The feature that they all share is that are all made from fatty acids and alcohols. Because of their varied nature, lipids have a range of functions.

- ✓ Waxes are so insoluble in water that they make excellent water repellents, for example,
- ✓ In coating birds' feathers and the epidermis of the leaves of plants (the waxy cuticle).
- ✓ Phospholipids are one of the basic components of all cell membranes.

Triglycerides have functions including: respiratory substrate a molecule of triglyceride yields over

- **Respiratory substrate** – a molecule of triglyceride yields over twice as many molecules of ATP (twice as much energy) as a molecule of glucose

- **Thermal insulation** – the cells of adipose tissue found under the skin of many animals contain large amounts of triglycerides, which give good thermal insulation
- **Buoyancy** – lipids are less dense than water (oil floats on water),so the presence of large amounts of lipid reduces the density of an animal, making it more buoyant
- **Waterproofing**–the oils secreted by some animals onto their skin are triglycerides

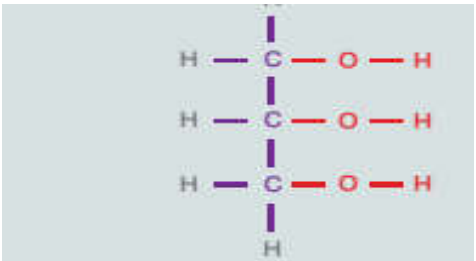


***Figure 2.28** The structure of glycerol*

Triglycerides

- A triglyceride is an ester formed from one molecule of glycerol and three fatty acid molecules.
- A fatty acid molecule consists of a covalently bonded hydrocarbon chain, at the end of which is a carboxyl group, which has acidic properties.
- The hydrocarbon chain is non-polar (this means that it has no charge).
- Carboxyl (functional group of fatty ac.) is ionic and dissociates in solution to form COO^- and H^+.
- The hydrogen ions released make the solution acidic.
- When triglyceride formed, condensation reactions join 3 fatty acid molecules to glycerol.
- The bonds formed are **ester bonds**. broken by hydrolysis to give glycerol and fatty acids once .

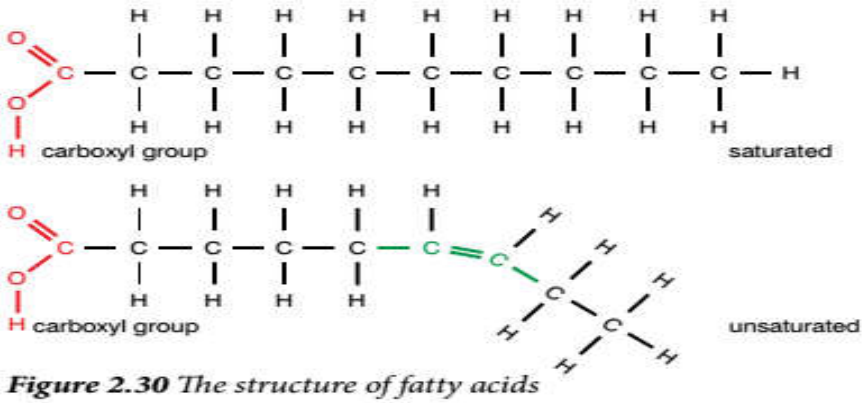


***Figure 2.30** The structure of fatty acids*

The nature of the hydrocarbon chains in fatty acids can differ in two main ways: These are;

- The number of carbon atoms in the chains can vary.
- Hydrocarbon chains with same number of C atoms can have different numbers of H atoms.

This is because of the nature of the bonding between the carbon atoms in the chain.

- If all the C–C bonds in hydrocarbon chain are single bonds, the fatty acid is a saturated fatty acid.
- If one of the carbon–carbon bonds is a double bond, then it is a monounsaturated fatty acid.
- If more than one C–C bond is a double bond, then the fatty acid is a polyunsaturated fatty acid.

Phospholipids

Phospholipids are formed when two fatty acid molecules are bonded to the glycerol and the place of the third is taken by a phosphate group. Since the phosphate group is ionic and the hydrocarbon chains of the two fatty acids are covalently bonded, there are two distinct regions to a phospholipids molecule:

- Hydrophilic (water-loving) region, consisting of the phosphate 'head'
- Hydrophobic (water-hating) region, consisting of the hydrocarbon 'tails'

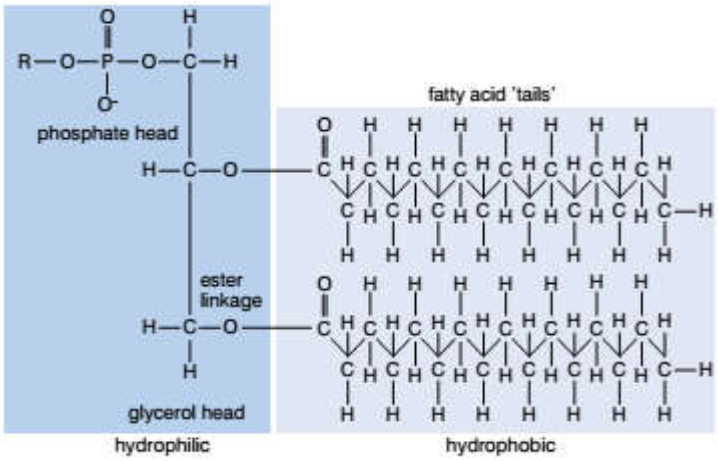


Figure 13. Phospholipids structure

- In water, phospholipids become organized into a bilayer (two layers sandwiched together).
- In this configuration, the hydrophilic heads face outwards into the water and t
- The hydrophobic tails face inwards, away from the water.
- Phospholipids bi layers are the basis of plasma membranes.
- The phosphate head is shown as a ball and the fatty acids as two tails.
- The glycerol 'backbone' somehow gets lost in the simplification!

Why do we need proteins? Proteins

- ♣ Are extremely important substances that are needed to form all living cells?
- ♣ Contain elements C, H and O (like carbohydrates and lipids), also contain N and most contain S
- ♣ Protein molecules are polymers of amino acids and so are macromolecules also.
- ♣ But they vary enormously in size; the smallest protein molecules contain fewer than 100 amino acids, whilst the largest contain several thousand.

Proteins have a range of functions; they are important in:

- ➢ The structure of **plasma membranes**, protein molecules form ion channels, transport proteins and surface receptors for hormones, Neurotransmitters and other molecules
- ➢ The **Immune system** – antigen and antibody molecules are protein
- ➢ The control of **metabolism by enzymes** ,all enzymes are proteins
- ➢ The structure of **Chromosomes**, DNA is wound around protein histone to form a chromosome

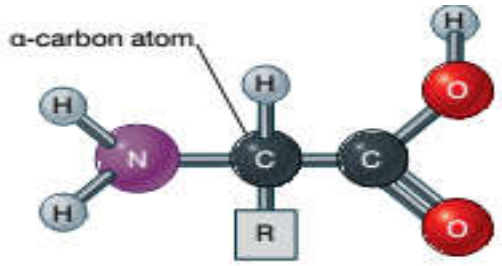


***Figure 2.34** The general structure of an amino acid*

All amino acid molecules are built around a carbon atom (the α-carbon) to which is attached:

- ❖ Hydrogen atom
- ❖ An amino group ($–NH_2$)
- ❖ A carboxyl group (–COOH)
- ❖ An 'R' group, which represents the other atoms in the molecule, such as a single hydrogen atom, a hydrocarbon chain or a more complex structure

Two amino acids can be joined together by condensation to form a dipeptide bond.

- H and OH are lost to create a molecule of water.
- 'H' lost from amino group amino acid and 'OH' lost from carboxyl group on other amino acid.
- 'Spare bonds' created on each molecule, form a peptide bond, holds two amino acids together.

A dipeptide can be enlarged into a polypeptide by condensation with more amino acid molecules.

- ❖ Many amino acids joined by peptide bonds form polypeptide sequence is **primary structure**.
- ❖ Formed, polypeptide chain folds itself into secondary structure, either α-helix or β-pleated sheet
- ❖ Structures held in place by H bonds b/n peptide bonds in adjacent parts of the amino acid chain.
- ❖ Both types of secondary structure can exist in different regions of the same polypeptide chain.
- ❖ Protein also tertiary structure by folding of secondary structure and formation new bonds to hold.

These new bonds include:

- ➢ More hydrogen bonds – between the R-groups of some amino acids
- ➢ Disulphide bridges – between amino acids that contain sulphur
- ➢ Ionic bonds; amino acids with positively charged R-groups with negatively charged R-groups

Each protein has a unique tertiary structure and so has a unique configuration (shape) because:

- ✓ The primary structure of each protein is coded for by DNA, which determines the type and position of each amino acid in the polypeptide chain
- ✓ The secondary structure of the molecule is the consequence of its primary structure; some sections of the primary structures form α-helices, others form β-pleated sheets, and
- ✓ The secondary structure determines where ionic and hydrogen bonds and disulphide bridges form, so it determines the tertiary structure and shape of the protein molecule.

The tertiary structure of a protein is unique and this gives each protein a specific function. For example

- ♣ Active site shape of an enzyme lets it bind with only one substrate and catalyze only one reaction
- ♣ The shape of a hormone receptor in the plasma membrane of some cells allows the hormone to bind with this receptor and to target only cells that have this receptor
- ♣ The shape of an antibody means it can bind with and destroy just one antigen

Quaternary structure. Proteins are two, or more, polypeptide chains folded into a tertiary structure of protein. Examples haemoglobin (oxygen-carrying molecule in RBCs) and collagen (fibrous protein in tissues in mammals). Proteins are classified into two main groups, according to their molecular shapes:

- ➢ **Fibrous proteins**- a tertiary structure that resembles a long string or fiber (collagen and keratin)
- ➢ **Globular proteins** tertiary structure resembles a globule or ball (enzymes and receptor proteins).

What are Nucleic Acids?

Biologists discovered two different types of nucleic acid at the end of the nineteenth century:

- DNA (Deoxyribo Nucleic Acid) is nucleic acid found in chromosomes. Gene is a short section of DNA codes for specific protein and, determines particular feature. DNA is the genetic material.
- RNA or Ribonucleic Acid is a nucleic acid found both in nucleus and cytoplasm. Different types of RNA are involved in allowing a specific gene (DNA) to produce protein it codes for.

DNA was isolated from animal cells and RNA from yeast cells. DNA is made up of two strands of nucleotides wound into double helix. RNA is much smaller and is single-stranded. Both nucleic acids are made from nucleotides. All nucleotides have the same basic structure with three components. These are;

- ✓ Phosphate group
- ✓ Pentose sugar (deoxyribose in DNA nucleotides and ribose in RNA nucleotides), and
- ✓ One of four nitrogenous bases; Adenine, Cytosine, Guanine and Thymine (DNA) Uracil (RNA).

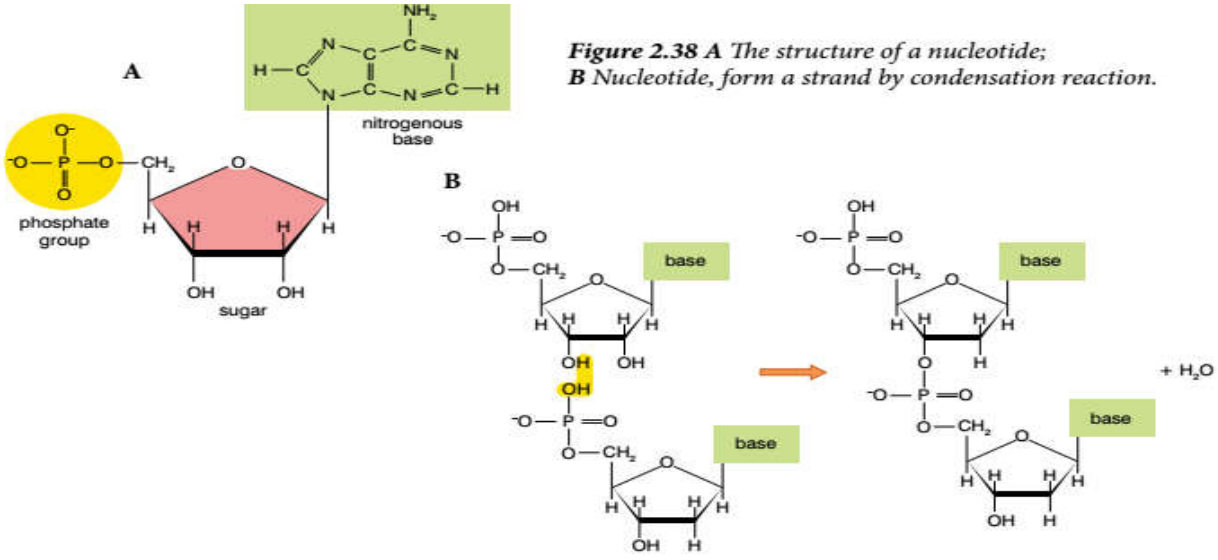


***Figure 2.38 A** The structure of a nucleotide;*
***B** Nucleotide, form a strand by condensation reaction.*

Table 2.3 How the structure of nucleic acids relates to their functions

Feature	DNA	RNA
Size	Huge – allows the molecule to carry the code for many different proteins in the genes.	Much smaller – need only code for one protein; small size allows RNA to move out of the nucleus.
Stability	Very stable – ensures that the genes remain the same over generations.	Less stable – is degraded quite quickly so does not carry on coding for a protein.
Number of strands	Two strands – allows coding of genes and replication during cell division.	Single stranded – does not replicate.

UNIT 3 ENZYMES

3.1 Nature of Enzymes

What are enzyme molecules like?

Enzymes are globular proteins. Having a unique tertiary structure, a unique shape? Lipase that hydrolyses lipids into fatty acids and glycerol. You should be able to identify regions where there is:

- An α-helix
- A β-pleated sheet
- No folding into a secondary structure

Second, **Active site** is a region within complex structure where a molecule binds with its substrate so the enzyme can catalyze reaction. The active site of an enzyme is shaped to allow:

- ✓ Binding with a particular substrate and that substrate only, and
- ✓ The reaction can take place requiring less energy than if the enzyme was not present.

Example Enzyme sucrase catalyzing the hydrolysis of sucrose into glucose and fructose. The substrate for the enzyme is sucrose. This binds with the active site to form ***Enzyme–substrate complex.*** A molecule of water then reacts with sucrose to hydrolyze the molecule into glucose and fructose. These are then released from the active site, which can then accept another molecule of sucrose. It is important to note that the enzyme is unaltered by the reaction.

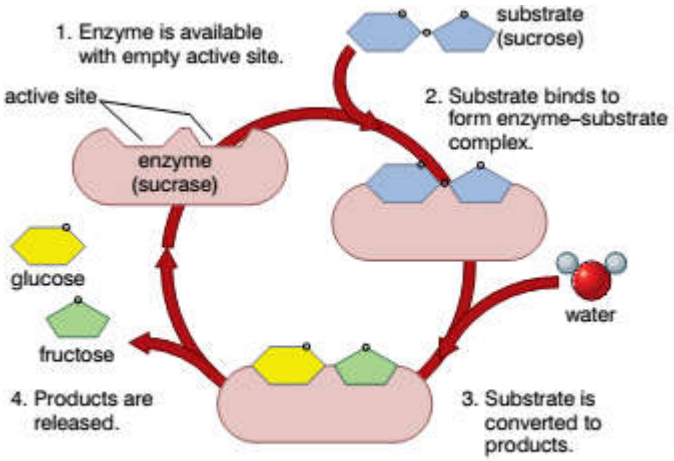


Figure 3.2 *The hydrolysis of sucrose by sucrase*

An enzyme is a globular protein with a uniquely shaped active site; it acts as a biological catalyst for a specific reaction, but remains unaltered by the reaction

What are the properties of enzymes?

- They are all proteins. They are biological catalysts:
- They speed up a reaction without being used up, can used over and over again.
- They are specific: they catalyze one reaction only.
- A small amount of enzyme can bring about a change in a large amount of its substrate.
- Enzymes are affected by PH, temperature. heat, concentration of substrate and inhibitors.

What are catalysts?

Catalyst is a substance that speeds up a reaction .The reaction is unaltered. There is no overall change to:

- The nature of the products
- The energy change that takes place during the reaction
- The catalyst itself

Why are enzymes specific?

This is also a function of ***active site***. The conformation of active site (the way in which it is shaped), only a certain substrate or combination of substrates can bind with it. Because only one substrate (or substrate

combination) can bind, there is only one possible reaction that can be catalyzed. This is illustrated in fig/.

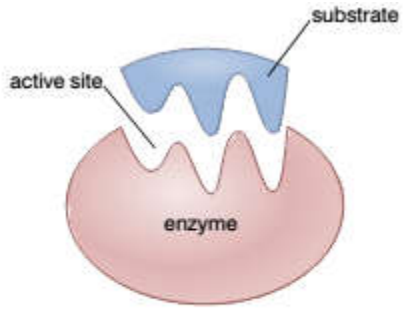


***Figure 3.3** An enzyme can only bind with one substrate because of the shape of its active site.*

How are enzymes affected by pH and by temperature? Temperature affects enzyme in two ways:

- A higher temperature gives the enzyme molecules (and their substrate molecules) more kinetic energy; they move around faster and form more enzyme–substrate complexes
- A higher temperature affects the chemical bonds holding the tertiary structure of the enzyme in place (particularly those in the active site); as these bonds break, shape of the active site changes and it can no longer bind with its substrate pH affects the enzyme molecule in a similar way
- A pH too low (too acid) or too high (too alkaline) cause changes on active site and cause active site to lose its conformation. The substrate cannot bind and so the reaction is no longer catalyzed.

How do we name and classify enzymes? Common enzyme nomenclature (naming of enzymes)

***Table 3.1** Examples of enzymes and the reactions they catalyse*

Name of enzyme	Reaction catalysed
Lipase	Hydrolysis of lipids
ATPase	Hydrolysis of ATP
Succinate dehydrogenase	Removal of hydrogen ions from succinate (during respiration)
DNA polymerase	Joining of nucleotides to form DNA
Pepsin	Digestion of proteins in the stomachs of mammals

Different enzymes are named in different ways.

- Most enzymes are named by adding ‘ase’ to part of the name of the substrate. For example, lipase (lipid hydrolyzing enzyme), sucrase (sucrose hydrolyzing enzyme).

- Some named on the basis of reaction they catalyze. Example, polymerase (in polymerization, joining similar units together), Dehydrogenase (removal of H atoms or ions).
- Some named based on the source were first identified. Example, Papayin from papaya.
- Others according to where they act. example, intestinal protease acts on proteins in intestine.
- Enzymes end with 'in', indicating they are basically proteins. Example pepsin, trypsin, etc.
- Enzymes usually have alternative names that tell more about them. Example, the alternative name for pepsin is gastric protease. Tells that it acts on proteins and it does so in the stomach.

Enzyme classification and the systematic nomenclature are generally classified on the basis of the type of reactions that they catalyze. Six groups of enzymes can be recognized on this basis. Table 3.2.

***Table 3.2** Classification of enzymes*

Class	Reaction catalysed	Examples
1. Oxidoreductases	Transfer of hydrogen and oxygen atoms or electrons from one substrate to another	Dehydrogenases Oxidases
2. Transferases	Transfer of a specific group (a phosphate or methyl, etc.) from one substrate to another	Transaminase Kinases
3. Hydrolases	Hydrolysis of a substrate	Esterases Digestive enzymes
4. Isomerases	Change of the molecular form of the substrate	Phosphohexoisomerase Fumerase
5. Lyases	Nonhydrolytic removal of a group or addition of a group to a substrate	Decarboxylases Aldolases
6. Ligases (Synthetases)	Joining of two molecules by the formation of new bonds	Citric acid synthetase

Each class of enzymes contains several different, but related, subclasses. Each subclass is further divided into sub-subclasses. Within the sub-subclasses, each enzyme has a number. So, in the systematic naming of enzymes; an enzyme will have a 'name' such as EC 3.4.11.1. Each part of the description tells us something about the enzyme:

- EC stands for Enzyme Commission
- The first number shows to which of the six main classes the enzyme belongs
- The second figure indicates a subclass
- The third figure gives a sub-subclass
- The fourth figure is the serial number of the enzyme in its sub subclass

Enzyme EC 3.4.11.1 is:

- ♣ Hydrolase – all the enzymes in class 3 hydrolyze some kind of bond
- ♣ Peptidase – all the enzymes in subclass 4 of class 3 are peptidases and hydrolyze peptide bonds
- ♣ Amino-peptidase – all the enzymes in sub-subclass 11 of sub class 4 are amino-peptidases; they hydrolyze peptide bonds at the amino end of a polypeptide chain
- ♣ Leucyl-amino-peptidase – this particular amino-peptidase is number 1 of this sub-subclass

What do enzymes do for you?

- ❖ Yeast is a unicellular fungus that ferments carbohydrates to produce carbon dioxide and alcohol.
- ❖ The enzymes in yeast control the reactions of fermentation.
- ❖ We still use yeast to brew alcoholic drinks, such as Tella, and to bake breads, such as Injera.
- ❖ Both these Ethiopian products are often made at home, as well as professionally.
- ❖ To produce bread, tiny alcohol formed lost and CO_2 expands dough 'rise' to form loaf of bread.
- ❖ When beer is brewed, it is the carbon dioxide that is lost and the alcohol remains!
- ❖ However, enzyme technology is now very big business. used to produce washing powders,
- ❖ Enzymes in washing powders digest stains in clothes.
- ❖ 'Stone-washed' denim jeans are now given their stonewashed look by the action of enzymes.

Enzymes are used in many industries to produce the following products needed by human; these are;

- ➢ Dairy
- ➢ Detergents
- ➢ Textiles
- ➢ Food processing
- ➢ Pulp and paper
- ➢ Medicine
- ➢ Pharmaceutical

3.2 Functions of Enzymes

How do enzymes act as catalysts?

- ✓ Catalysts speed up chemical reactions. Molecules to react, they must have sufficient energy.
- ✓ This energy to start off the reaction is called *Activation energy* (or Ea).
- ✓ reaction in substance A reacts with B to form substance AB. an equation as: $A + B \rightarrow AB$
- ✓ The equation gives only the reactants (starting materials) and the products.
- ✓ It does not show how the energy changes as the reaction takes place.

- ✓ The reactant must 'climb an activation energy hill' before anything happens.
- ✓ Under normal conditions, very few molecules of A and B have sufficient kinetic energy to 'climb the activation energy hill', so the reaction proceeds slowly.
- ✓ A catalyst lowers the activation energy required for the reaction.
- ✓ More reactant molecules meet this lower energy requirement and reaction proceeds more quickly.
- ✓ Because the enzyme molecule is unaltered by the reaction, it can be used over and over, and so a small amount of enzyme can affect a large amount of substrate. This is shown in figure 3.8.

How do enzymes lower activation energy? There are two models of enzyme action;

- ➢ The lock-and-key model, first proposed in 1894 by a German biochemist named Fischer and
- ➢ The induced-fit model, proposed in 1958 by Koshland.

Both of these models suggest that the enzyme catalyses the reaction by lowering the activation energy.

- ♣ However, they differ in the way that they explain how this happens.
- ♣ In particular, they differ in explaining how the substrate binds to the active site of the enzyme.

1. The lock-and-key model; this model proposes that

- ❖ The shapes of the substrate molecules are complementary to that of the active site,
- ❖ Rather like the shape of a key is complementary to that of the lock it fits.
- ❖ A useful way of thinking of complementary shapes is to think of an egg sitting in an egg cup.
- ❖ The egg can sit inside the egg cup because the shapes are complementary.
- ❖ One egg cannot sit inside another egg because the shapes are the same.

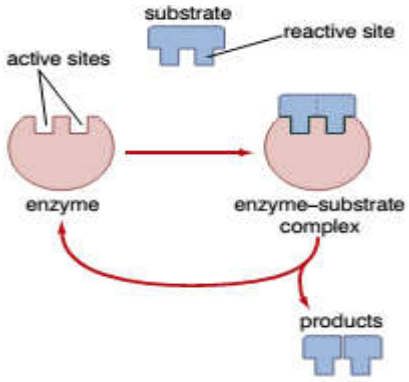


Figure 3.10 *The lock-and-key model of enzyme action*

- ❖ Complementary substrate binds with active site of enzyme to form enzyme–substrate complex.

- The complex causes reactants to enter a transition state, activation energy of reaction is lowered.
- The reaction takes place and the products formed are released.
- The lock-and-key model of enzyme action suggests that the enzyme lowers the activation energy by providing an alternative pathway for the reaction. For example:
- Non-catalyzed pathway: Reactant A + Reactant B ⟶ Product AB
- Enzyme-catalyzed : Reactant A + Reactant B + enzyme ⟶ Intermediate ⟶ Product AB + enzyme
- Model sees enzyme–substrate complex as the intermediate, which is part of a pathway that requires less energy than the normal pathway.
- Weakness of this model is it does not explain how the intermediate reduces activation energy.

2. The induced-fit model

- This model suggests that the active site and substrate aren't naturally complementary in shape,
- But binding of substrate produces a conformational change (change in shape) in the active site.
- This allows the substrate and active site to bind fully.
- The conformational change also puts the substrate molecules under tension,
- So they enter a 'transition state' and are able to react because of the lowered activation energy.
- In the transition state, bonds in the reactants are put under strain and break more easily and rejoin with other bonds to form the products. The products formed leave the active site.
- Most biologists now prefer the induced-fit model over the lock and-key model
- As it explains properties of enzymes, such as enzyme inhibition, in complete than lock-and key
- The rate of a chemical reaction is the rate at which reactants are converted into products.
- Enzyme-controlled reaction is determined by how many molecules of substrate bind with enzyme molecules to form enzyme–substrate complexes.
- The number of molecules of reactants that form enzyme–substrate complexes with each molecule of an enzyme, per second, is the turnover rate of the enzyme.

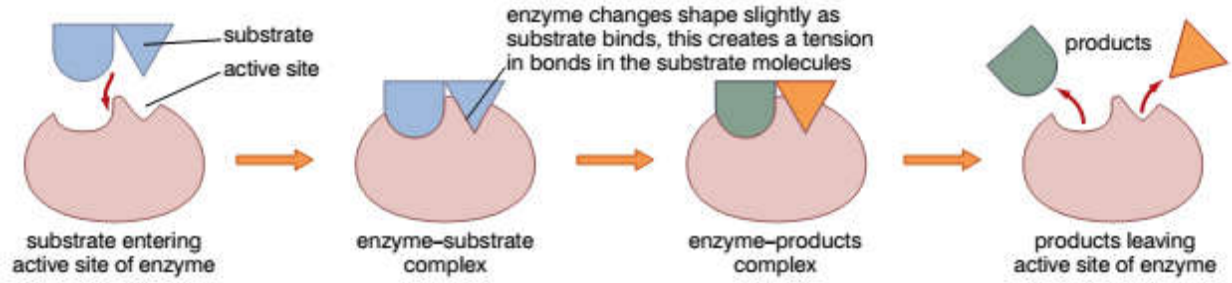


Figure 3.11 *The induced-fit model of enzyme action*

Why do some enzymes need cofactors?

Sometimes an active enzyme isn't just a single molecule, but is made from two molecules, neither of which has enzymic activity without the other; The two parts are the apoenzyme and the cofactor;

- ***Apoenzyme*** – a protein that combines with a cofactor, to form an active enzyme. The protein is inactive on its own.
- ***Cofactor*** – a small non-protein particle essential for the activity of some enzymes. The cofactor combines with the apoenzyme to produce an active enzyme.
- An active enzyme comprises an apoenzyme and a cofactor, referred to as the Holo enzyme..

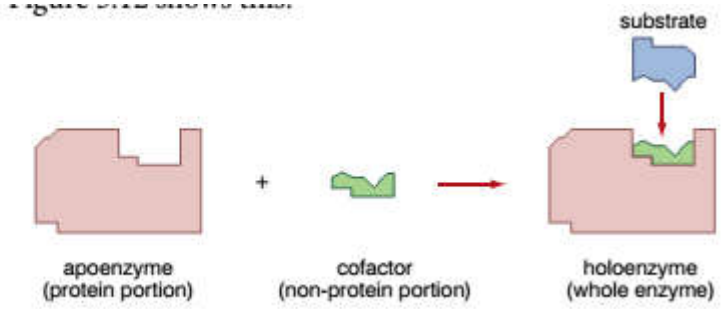


Figure 3.12 *The apoenzyme and the cofactor make the holoenzyme.*

Cofactors include:

- Coenzymes
- Mineral ions

Coenzymes ; organic molecules and derived from vitamins. Bind with enzyme to give catalytic activity.

Table 3.5 shows some common co enzymes, the vitamins they are derived from, the enzyme with which they bind, and their functions.

Table 3.5 *Common coenzymes and their functions*

Coenzyme	Vitamin	Enzyme	Function
Nicotinamide adenine dinucleotide (NAD)	Niacin	Oxidoreductase in respiration	Oxidation or hydrogen transfer in respiration
Flavin adenine dinucleotide (FAD)	Riboflavin	Oxidoreductase in respiration	Oxidation or hydrogen transfer in respiration

Some enzymes can only function in the presence of certain mineral ions. These bind loosely with the enzyme to give it its catalytic activity. Table 3.6 shows some examples of enzymes that require mineral ions as cofactors.

Table 3.6 *Enzymes that require mineral ions as cofactors*

Enzyme	Mineral ion	Function
Carbonic anhydrase	Zinc ions (Zn^{++})	Causes CO_2 to react with water to form hydrogen carbonate
Alcohol dehydrogenase	Zinc ions (Zn^{++})	Oxidises alcohol
Cytochrome oxidase	Copper ions (Cu^{++} or Cu^{+})	Transfers electrons to oxygen during respiration

3.3 Factors affecting the functions of enzymes

The turnover rate and activity of enzyme are influenced by a number of external factors, including:

- Temperature
- Ph
- Substrate concentration
- The presence of Inhibitors

How hot must it be?

When the temperature is raised, particles are given more kinetic energy. This has two main effects:

- ‘Free’ particles move around more quickly. This increases the probability that a substrate particle will collide with an enzyme molecule.
- Particles in molecule vibrate more energetically puts strain on bonds hold atoms. Bonds begin to break, enzyme shape and active site change. Enzyme loses its tertiary structure and denatured.

Enzyme activity at a given temperature is a balance b/n these two effects. If raised temperature results

- In little denaturation but a greatly increased number of collisions, enzyme activity will increase.
- Causes significant denaturation , despite extra collisions, activity of enzyme probably decrease.
- Further temperature increase cause increased denaturation outweigh effects of extra collisions.
- Above optimum temperature, the enzyme denatures quickly at which shape of the active site has changed that an enzyme–substrate complex cannot form. At this point the reaction rate is zero.
- A decrease in temperature means that fewer collisions will occur.

How acidic must it be?

- The pH scale is a measure of the hydrogen ion concentration of a solution or other liquid system.
- The pH scale ranges from 0 to 14.
- Solutions with a pH of less than 7 are acidic, those with a pH of more than 7 are alkaline and
- A solution with a pH of exactly 7 is neutral.
- The majority of enzymes in most mammals function most efficiently within the pH range 6.0–8.0,
- PH of pepsin (an enzyme found in the stomach) is between pH 1.0 and pH 3.0.

Significant changes in pH can affect an enzyme molecule by:

- Breaking ionic bonds that hold the tertiary structure; this leads to denaturation of enzyme
- Altering the charge on some of the amino acids that form the active site; this makes it more difficult for substrate molecules to bind

These effects occur if the pH becomes either more acidic or more alkaline

Does the concentration of the substrate matter?

- Activity of enzyme depends on number of substrate per second that bind to form enzyme–substrate complexes.
- So the number of substrate molecules present must have an effect.
- Small number of substrate mean, few collisions, and few enzyme–substrate complexes form.

- Increasing concentration of substrate means more collisions and more enzyme–substrate complexes. So, the overall rate of reaction is increased.
- Because of high substrate concentration, each enzyme molecule working at maximum turnover
- Each active site is binding with substrate all time and there is no 'spare capacity' in the system.
- Increasing the substrate concentration beyond this point will have no effect on the activity of the enzyme because all the active sites are occupied all the time.

How much enzyme should there be?

The reaction rate will be directly proportional to the number of enzyme molecules – the concentration of the enzyme. Increasing the concentration will increase the reaction rate. However, increasing the concentration of the enzyme will not increase the activity of the enzyme. Each enzyme molecule will be working at maximum turnover, so the activity of the enzyme is likely to remain constant.

How do other substances affect enzyme activity?

Inhibitors are substances that bind to enzymes and prevent them from forming enzyme–substrate complexes and, as a result, stop, or slow down, the reaction. There are two main types of inhibitors:

- Irreversible inhibitors, and
- Reversible inhibitors.

Irreversible inhibitors bind strongly to enzymes, usually by a covalent bond, permanently altering the structure of the enzyme molecule and inactivating it. The painkiller aspirin is an example of an irreversible inhibitor. It binds with the enzyme cyclo-oxidase-2, which is an important enzyme in producing prostaglandins which give the sensation of pain.

Reversible inhibitors bind to enzymes only weakly and the bond that holds them breaks easily releasing the inhibitor. This allows the enzyme to become active again. There are two kinds of reversible inhibitors:

- Competitive inhibitors and
- Non-competitive inhibitors .

Competitive inhibitors;

- Have molecules with shapes that are complementary to all, or part, of active site of an enzyme.
- They are often similar in shape to the substrate molecules.
- They can bind with the active site and prevent substrate molecules from binding.
- The binding is only temporary and the competitive inhibitor is quickly released.

- A competitive inhibitor blocks the active site so substrate molecules cannot bind.
- The overall effect on rate of reaction depends on concentrations of substrate and inhibitor.
- Each molecule of competitive inhibitor can inhibit (temporarily) one enzyme molecule – but only if it can collide with the enzyme molecule and bind with the active site.
- To do this, it must compete with substrate molecules for active site, hence the name, competitive
- If 99 substrate molecules for every inhibitor molecule, then 99% of the collisions would be between enzyme and substrate and the reaction would proceed at 99% of the maximum rate.
- If the ratio were 90 substrate molecules to ten inhibitor molecules, there would be 10% inhibition and the reaction rate would fall to 90% of maximum.
- The painkiller ibuprofen acts as a competitive inhibitor of the enzyme cyclo-oxidase-2, competing with the precursors of prostaglandins, which are the substrate of cyclo-oxidase-2.
- The metabolic poison cyanide acts as a competitive inhibitor of the enzyme cytochrome oxidase, an important enzyme in the release of energy in respiration.

Non-competitive;

- ✓ Inhibitors do not compete for the active site.
- ✓ Instead, they bind to another part of the enzyme called the allosteric site.
- ✓ This produces a conformational change in part of enzyme molecule that includes the active site.
- ✓ So active site is a different shape and can no longer bind with substrate to catalyze the reaction.
- ✓ Effectiveness of a non-competitive inhibitor is in no way affected by concentration of substrate.
- ✓ If inhibitor bind allosteric sites of 80% of enzyme. 80% of enzyme inhibited irrespective of the number of substrate molecules (as the two are not competing for the same site) and the reaction rate will drop to 20% of maximum.
- ✓ Non-competitive inhibitors are particularly important in regulating metabolic pathways in cells.

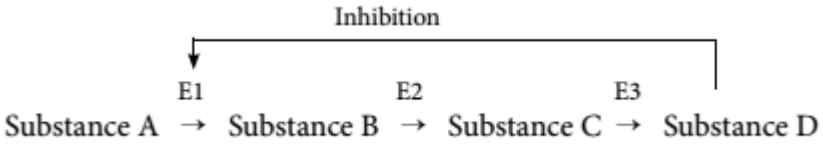
How do inhibitors control enzyme activity in living cells? Many substances produced in cells as a metabolic (a series of reactions), which can be represented as

$$\text{Substance A} \xrightarrow{E1} \text{Substance B} \xrightarrow{E2} \text{Substance C} \xrightarrow{E3} \text{Substance D}$$

E1, E2 and E3 are enzymes catalysing the reactions.

All the reactions in this sequence are enzyme controlled. Therefore, inhibition of any of these enzymes will interrupt the process. However, the main function of this pathway is to produce substance D for use by the cell. If the requirement for substance D in the cell decreases, then the concentration of D will increase. This is at least inefficient (producing something that is not being used) and may be potentially

harmful because high concentrations could be toxic. Such reaction sequences are often controlled by end-product inhibition. The end product (D) inhibits the enzyme controlling the first stage of the reaction sequence, as shown in the diagram.



Substance D normally acts as a non competitive inhibitor, which prevents the enzyme E1 from catalyzing the reaction that converts A to B. As a result, the entire reaction sequence is halted. When the inhibition is removed, the metabolic pathway can start again. Sometimes, a decrease in the concentration of D is sufficient to remove the inhibition. In other cases, the inhibitor must be removed by a substance known as **an activator**. Enzymes are often kept inactive in a cell by an inhibitor and activated by a specific activator only when they are required.

End-product inhibition; In the pathway, the amino acid threonine is converted to another amino acid, isoleucine. Isoleucine acts as a non-competitive (allosteric) inhibitor. High concentrations of isoleucine inhibit more and more of the enzyme catalyzing the first reaction in the pathway, until the pathway is completely inhibited.

UNIT 4 CELL BIOLOGY

4.1 Cell Theory

How did the modern cell theory develop?

- Today we take it for granted that living things are made of cells.
- Billions of cells in the human beings, one cell in the case of organisms like amoeba.

A timeline for the development of the cell theory

1665 ***Robert Hooke***, with earliest compound microscopes, makes drawings of cork and sees tiny structures that he calls 'cells'. His microscope lenses are not very good and magnifications of more than 30× are very blurred and do not show much detail. Hooke saw only ***dead cells***.

1674 ***Anton van Leeuwenhoek*** sees living, moving unicellular organisms (protoctistans) in a drop of water. He is using a simple microscope with one lens. van Leeuwenhoek is very skilled

at grinding lenses and his microscope can achieve magnifications of **300×.** He calls the moving organisms '***animalcules***'. He sees bacteria (from his teeth), he also calls '***tiny animalcules'***

1824 ***Rene Dutrochet*** French biologist concludes that all organisms are composed of cells. This follows many years work in which he also discovers:

- The stomata in the epidermis of leaves
- The process of osmosis
- Chlorophyll is needed for photosynthesis to occur
- Respiration occurs in both animals and plants
- He states cell theory that all organisms are made of cells and that 'all growth occurs because of the increase in volume of cells or by the addition of more little cells'.

1839 ***Matthias Schleiden and Theodor Schwann*** the first clearly stated cell theory. It states that:

- The cell is the unit of structure, physiology and organization in living things
- The cell retains a dual existence as:
  - a distinct entity, and
  - a 'building block' in the formation of organisms
- Cells form by free-cell formation (spontaneous generation) accept the first two ideas, the final idea of spontaneous generation has now been proved false.

1858 ***Rudolf Virchow***, German doctor develops many surgical techniques and promotes modern medicine, declares: '***Omnis cellulae cellula'***, which means ***cell can only arise from another cell like it.*** He completes the first accepted version of the cell theory:

- All organisms are made up of one or more cells
- All cells come from pre-existing cells
- The cell is the unit of structure, physiology and organization in living things
- Cell retains dual existence as distinct entity and building in construction of organisms

Today modified and extended; increased knowledge of genetics and cell biology and now reads:

- ✓ All known living things are made up of cells
- ✓ The cell is a structural and functional unit of all living things

- ✓ All cells come from pre-existing cells by division (no spontaneous generation of cells)
- ✓ Cells contain hereditary information which is passed from cell to cell during cell division
- ✓ All cells have basically the same chemical composition
- ✓ All energy flow (the metabolism and biochemistry of life) occurs within cells

How big are cells? It all depends on kind of cell. The contents of a chicken's egg are just one huge cell packed with food it's a pretty big cell, up to 5 cm (0.05 m) in length. On the other hand, the smallest bacterial cells are only just over 100 nm in length. This is approximately one hundred-thousandth of the size of the chicken's egg. That's quite a range of sizes

What units shall we measure cells in?

Depends on which cells, which units available and which is convenient to use. We could measure cells in meters, but the size of a RBC in meters approximately 0.000007 m. All those 0's are very confusing and we don't easily work with such small numbers. So we use other, smaller units to measure the size of cells and molecules. These smaller units give us numbers that are more convenient to work with. There are three smaller units commonly used:

- ✓ Millimeters (mm) – 1/1000 of a meter
- ✓ Micrometers (μm) – 1/1000 of a millimeter, and 1/1 000 000 of a meter
- ✓ Nanometers (nm) – 1/1000 of a μm; 1/1 000 000 of a mm, and 1/1000 000 000 of a meter

We can convert the units from one to another as shown below:

$$\text{m} \underset{\div 1000}{\overset{\times 1000}{\rightleftharpoons}} \text{mm} \underset{\div 1000}{\overset{\times 1000}{\rightleftharpoons}} \mu\text{m} \underset{\div 1000}{\overset{\times 1000}{\rightleftharpoons}} \text{nm}$$

To convert a larger unit to the next smaller unit, multiply by 1000: For example,

- ♣ To convert 3.5 mm to μm. 3.5 mm = 3.5 × 1000 = 3500 μm

To convert a smaller unit to the next larger unit, divide by 1000:

- ♣ For example, convert 87 nm to μm 87 ÷ 1000 = 0.087 μm
- ♣ RBC 0.000007 m in diameter is 0.007 mm or 7 μm this is more comprehensible number.
- ♣ Most cells fall within narrower range of sizes than chicken's egg and smallest bacterium.

- ♣ Most bacteria are about one-tenth of this length.
- ♣ The relative sizes of an animal cell, a bacterium and a virus in a slightly different way.
- ♣ This diagram makes it clear just how much bigger an animal cell is than a bacterium.
- ♣ Animal cell may be 10X as long, as wide and as deep. So 1000X bigger than bacterium!

What are the consequences of the different sizes of cells?

When a cell gets bigger, all its dimensions change. It is easy to be tricked into thinking that when a cell doubles all its dimensions it is twice as big. But, in fact, there is now eight times more cell as a result! This is most easily explained if we pretend that our cell is a cube, but the same principles hold true for other shapes also. Look at figure 4.13. It shows three cubic 'cells' of different sizes. The linear dimensions double from the first cell to the second and double again from the second cell to the third. But the surface area and volume of the cell doesn't double. There are six sides to a cube. To calculate the area of each side by multiplying length by breadth. In the case of the first cell, this is 1 arbitrary unit (a.u.) × 1 a.u., so the area of one side is 1 a.u.2. The volume of a cube is length × breadth × height. In this case 1 a.u. × 1 a.u. × 1 a.u. So the volume of the first cell is 1 a.u.3. The ratio of the surface area to the volume is 6:1.

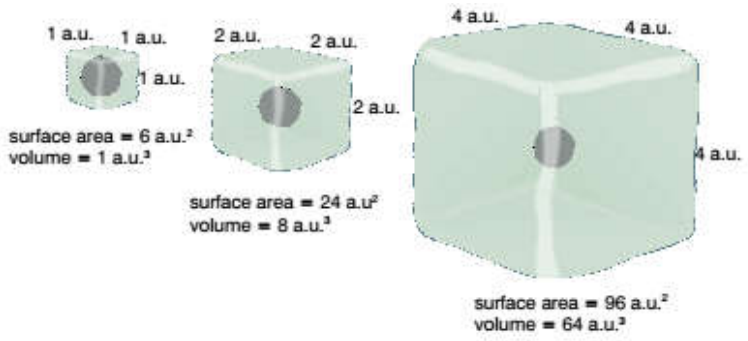


Figure 4.13 *How increasing size affects surface area and volume. The measurements are in arbitrary units (a.u.).*

What about the second cell? The linear dimensions have doubled, but surface area is 24 a.u.2 and the volume is 8 a.u.3. The ratio of the surface area to volume is now 24 ÷ 8 = 3:1. It is half that of the smaller 'cell'. The ratio of surface area to volume of the third cell is in fact 1.5:1. Smaller again and half the value of the ratio of the cell with linear dimensions that are half of this one.

So, does it matter if the surface-area-to-volume ratio changes?

The functions of surface area of cell and volume of cell. It is best understood if think function of respiration. A cell respires to release energy to drive the other entire cellular processes take

place. If it can't release enough energy, other processes slow down and the cell may die. In order to respire, the cell needs oxygen, which enters through the surface of the cell.

- The volume determines how much activity in a cell. A; large cell have more processes happening, or at least the same processes happening faster, than a smaller cell. The amount of energy must released in respiration is therefore decided largely by ***volume***.
- The amount of oxygen that can be delivered into the cell is; decided largely by how much 'surface' there is, since it is through the surface of the cell that the oxygen enters.

A large surface-area-to-volume ratio means that it is likely that the surface will be able to supply the oxygen demands of the cell. But as cells increase in size, the volume increases faster than the surface area and the surface-area-to-volume ratio decreases.

4.2 Types of cells;

What are prokaryotic and eukaryotic cells? Prokaryotic cells

- Many biologists believe that the first type of cells to be formed when life first evolved.
- Simple organisms that lack a distinct nuclear membrane and other organelles.
- Much smaller and simpler than eukaryotic cells; even so
- These cells carry out functions that a eukaryotic cell carries out in order to survive
- Representative of prokaryotes are the bacteria and blue-green algae

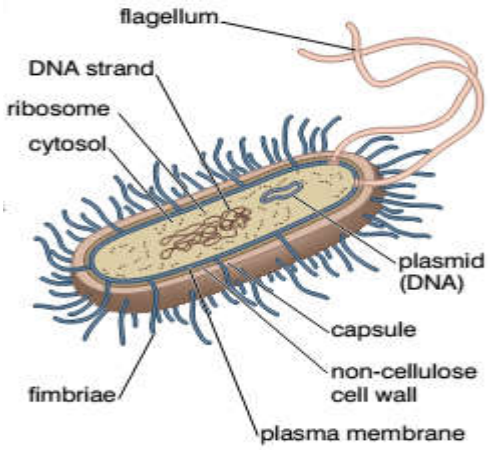


Figure 4.14 *A generalised prokaryotic cell*

Eukaryotic cell

- Possess a distinct membrane-surrounded nucleus containing the DNA

- These are clearly much more complex cells than the prokaryotic cell.
- A cell characterized by compartmentalization (by membranes) internal structures
- Many more different individual structures, called organelles
- However, there is much more division of labour in a eukaryotic cell.
- Different types of eukaryotic cell, but all of them have a number of features in common.

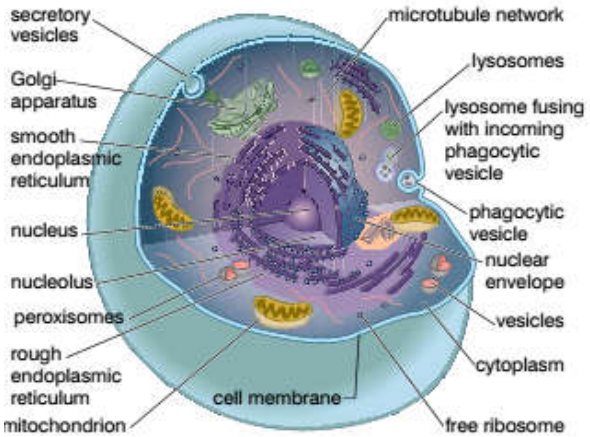


Figure 4.15 *A generalised animal cell*

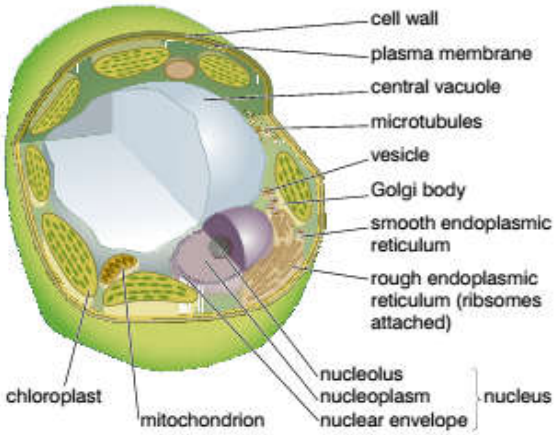


Figure 4.16 *A generalised plant cell*

Eukaryotic have many more membranes that form complex membrane system found throughout cell like Endoplasmic reticulum. There are also several membrane-bound organelles. These are;

- Nucleus
- Mitochondria
- Chloroplasts (if present)
- Lysosomes
- Golgi apparatus

These membranes make the cell able to function more **efficiently**. Example membranes of;

- ✓ Mitochondrion; the reactions take place are not affected by other cellular reactions.
- ✓ Endoplasmic reticulum separate areas of cytoplasm and allow to function independently.

How did eukaryotic cells originate? One theory is '***modern' eukaryotic cell was formed when several more primitive prokaryotic cells 'got together***'. Over myrs ancestral prokaryotic cells became more membranous. The plasma membrane around the cell became more and more

'infolded' until there was an extensive membrane system in the cell. This eventually evolve into (EPR) of eukaryotic cells. The next theory suggests that this membranous cell engulfed other smaller cells that were better at respiring organic molecules to release energy.

These 'engulfed' prokaryotes would evolve into the mitochondria of eukaryotic cells. The cells that contained them were heterotrophic and the forerunners of animal, fungal and protoctistan cells. One further stage suggests that some of these cells with their 'primitive mitochondria' also engulfed other, smaller, prokaryotic cells. These were prokaryotic cells that could photosynthesise and would, in time, evolve into chloroplasts. The cells that contained these would be autotrophic and the forerunners of plant cells. This theory of the origin of eukaryotic cells is called the **Endosymbiont** (theory first proposed by biologist Lynn Margulis).

What are the differences between prokaryotic and eukaryotic cells?

Table 4.2 *A summary of the main differences between prokaryotic and eukaryotic cells*

Feature	Prokaryotic cells	Eukaryotic cells
Size	1–10 µm	10–100 µm
Nucleus	No membrane-bound nucleus	Nucleus surrounded by nuclear envelope
DNA	• In a continuous loop • Not associated with protein to form chromosomes	• Linear DNA • Associated with histone proteins in chromosomes
Mitochondria	Absent	Present
Chloroplasts	Absent (but some prokaryotic cells contain a kind of chlorophyll and can photosynthesise)	Present in some cells (some plant cells and some algal cells)
Ribosomes	Present, but smaller than in eukaryotic cells (**70S**)	Present, but larger than in prokaryotic cells (**80S**)
Cell wall	• Always present • Not made from cellulose (often made from peptidoglycan)	• Present in plant cells, algal cells and fungal cells • Cellulose in plant cells, various materials in other cells

4.3 Parts of the cell and their functions

What is the importance of the cell membrane? The membrane that surrounds and encloses a cell is sometimes called the cell surface membrane, but most now refer as plasma membrane. The plasma membrane plays provide little mechanical strength to support cell and a crucial role in controlling what enters and leaves in and out of the cell by:

- Simple diffusion
- Facilitated diffusion
- Osmosis
- Active transport
- Endocytosis
- Exocytosis

Cell signaling; various molecules in the membrane allow the cell to be recognized by hormones and immune system (in animals) and (in plants) growth regulator substances, such as auxins. The plasma membrane clearly has a vital role in isolating the cell from its environment, whilst allowing necessary exchanges with that environment.

What is the plasma membrane like? The basis of plasma membranes is a ***Phospholipids bilayer***. But a plasma membrane is much more complex than a simple bilayer. Several models of the structure of plasma membrane.

The Davson– Danielli model

- ✓ In 1935, both proteins and phospholipids involved in structure of plasma membranes.
- ✓ Without any direct observational evidence to assist them (first electron microscopes were only just being built and they could not reveal membrane structure)
- ✓ Davson and Danielli suggested a kind of 'sandwich' of protein and phospholipid

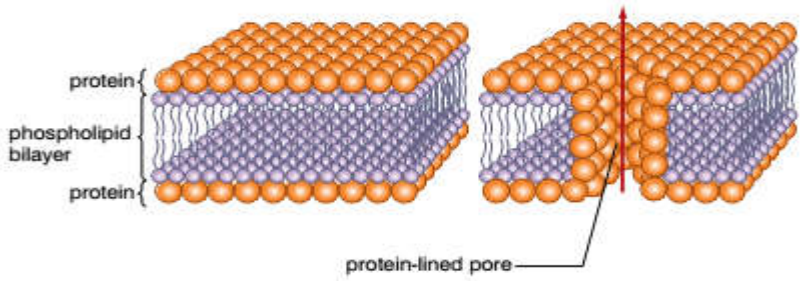


Figure 4.20 *The Davson–Danielli models of 1935 and 1954*

- ✓ Based on what they knew of the proportions of the two substances in the membrane.
- ✓ The protein form 'bread' of sandwich with phospholipids' forming the 'filling'.
- ✓ But in 1954 they proposed a revised model in which they included protein-lined pores.
- ✓ As more evidence accumulated this model not adequately explain all the new evidence.
- ✓ The model therefore had to be rejected.

Fluid mosaic model

- ✓ In1972, Singer and Nicholson
- ✓ Proposed different arrangement of phospholipids and proteins in plasma membrane.
- ✓ They retained the idea of a phospholipid bilayer, but rejected the sandwich arrangement.
- ✓ Instead, they suggested that proteins were 'studded' into the bilayer at different points.
- ✓ Also suggested that arrangement was not static, but was fluid and constantly changing.

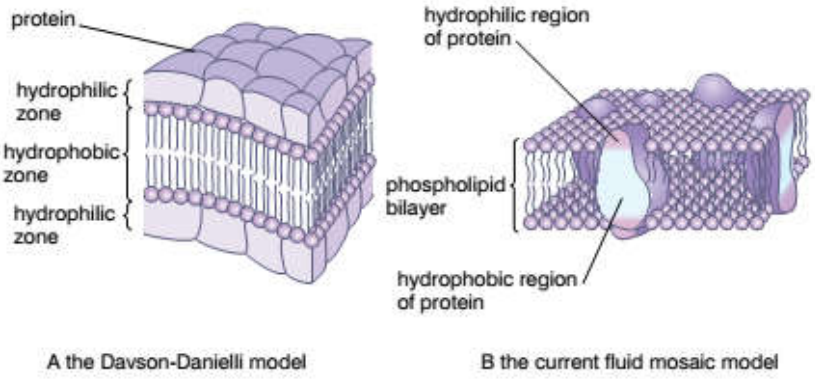


Figure 4.21 *The Davson–Danielli model and the fluid mosaic model*

- ✓ The fluid mosaic model has more sophisticated; Current idea of membrane structure still assumes this fluid-mosaic nature, but there is now much more detail to the model.

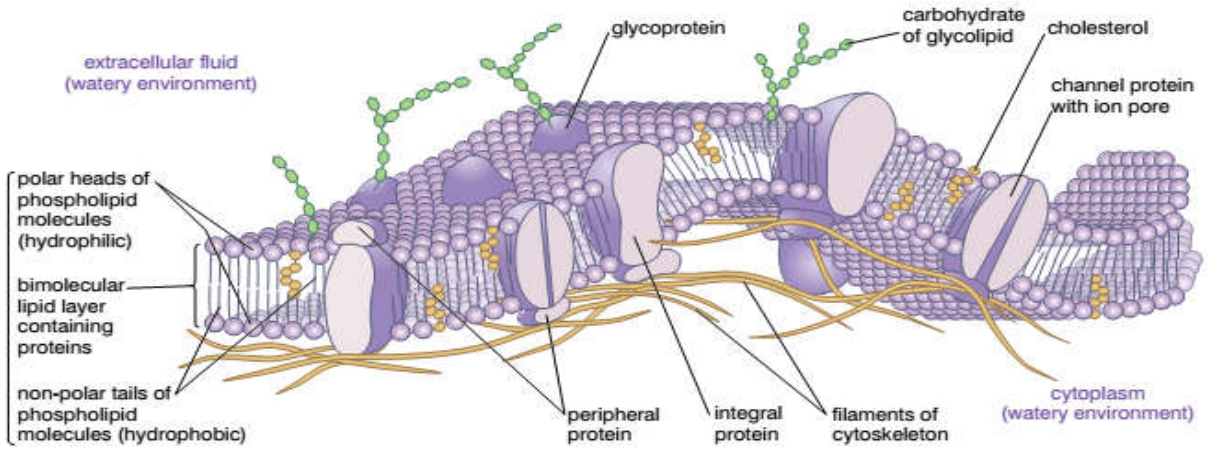


Figure 29. The current fluid mosaic model of membrane structure

The key features of the model as we currently understand it are:

- The phospholipid bilayer as the basis for the membrane
- Integral proteins (Intrinsic and Trans membrane proteins) that span the membrane play important role in moving substances across membrane.

There are three types of transport proteins: these are;

- **Channel proteins** – these proteins have a channel through them along which a specific ion can pass; there are different channel proteins for different ions
- **Carrier proteins** ;more sophisticated to move larger molecules through membrane by facilitated diffusion or active transport; the ones involved in active transport are often referred to as pumps
- **Peripheral proteins** (Extrinsic proteins); span only one layer (sometimes less) of the membrane. Have a range of functions; some are enzymes, others anchor integral proteins to the cytoskeleton

Glycoproteins and Glycolipids – protein and lipids that have carbohydrate chains attached to them and serve as signals to other cells. Also act as receptor sites for hormones and drugs. The carbohydrate component can be cell specific and allow identification of cell by immune system.

Cholesterol – reduces the fluidity of the membrane.

How do substances cross the plasma membrane?

All particles cannot pass through a plasma membrane unaided. Because of the largely lipid nature of membrane. To pass through the membrane by simple diffusion particles must be:

- ❖ Small
- ❖ Lipid soluble
- ❖ Non-charged

This excludes particles such as;

- ✓ Ions (they are charged),
- ✓ Sugars and amino acids (they are not lipid soluble and are not small particles) and
- ✓ Any of really large particles, such as proteins, cross plasma membranes in two types:

Passive processes–rely only on the kinetic energy of the particles of the substances and on concentration gradients; they need no extra energy from the cell's metabolism

Simple diffusion

- ❖ In fluids –liquids and gases – the particles that make up the fluid are free to move around.
- ❖ Kinetic energy drives diffusion. If particles concentrated in a small area, They will move 'spread out' and occupy all space available. This is a result of random particular motion.
- ❖ Diffusion need not involve a membrane.
- ❖ When particles diffuse across membrane, there must be a concentration difference between the two sides of the membrane (a concentration gradient) to drive the process.
- ❖ As diffusion proceeds, high concentration will decrease and low concentration will increase until the two concentrations are the same. there will be no further net diffusion.
- ❖ This means particles will still move across membrane, they will move equally in both directions, so there will be no overall effect. The concentrations are in equilibrium.

The rate at which diffusion across a membrane takes place is influenced by:

- o Concentration gradient a bigger difference in concentration results in faster diffusion than a smaller gradient

- The thickness of the membrane – as all plasma membranes are the same thickness, this is not really an issue when considering diffusion into and out of cells, but particles must cross some kind of barrier, a shorter distance results in faster diffusion
- The surface area of the membrane – clearly if there is more membrane where diffusion can take place, diffusion will happen faster

These features are all related in an equation called Flick's law of diffusion:

$$\text{Rate of diffusion} \propto \frac{\text{Surface area of membrane} \times \text{Concentration difference}}{\text{Diffusion distance}}$$

The rate of diffusion is also influenced by temperature. Diffusion occurs faster at higher temperatures because the particles have more kinetic energy and so move faster.

Facilitated diffusion

- ❖ Essentially the same process as diffusion, it depends on a concentration gradient to allow particles to cross the membrane.
- ❖ However, it differs in particles must be helped to diffuse across the membrane (their diffusion must be 'facilitated') by a carrier protein or a channel protein with an ion pore.
- ❖ The particles are moving from a high concentration to a low (as with simple diffusion).
- ❖ Ions move straight through the ion pore of a channel protein, the carrier protein must undergo a conformational change to move particles through the membrane.
- ❖ The rate of facilitated diffusion is affected by the same factors that affect simple diffusion with the exception that it is not the actual surface area of the membrane that determines the rate, but the number of carrier proteins (channel proteins) present.

Saturation of carrier proteins ; increasing concentration gradient will increase the rate of both simple and facilitated diffusion, a point will come with facilitated diffusion when all the carrier proteins are transferring particles as fast as they can. At this point the carrier proteins are saturated and facilitated diffusion can go no faster.

Osmosis

- ✓ The process by which water moves across a partially permeable membrane.

- ✓ The diffusion of water. Do not refer to concentration of water, but to water potential.
- ✓ Movement of water from a system with a high water potential to a system with a low water potential across a partially permeable membrane.
- ✓ The symbol for water potential is the Greek letter Ψ (psi).
- ✓ Water potential is measured in units of pressure pascals (Pa), kilopascals(kPa) or (MPa).
- ✓ Pure, liquid water has a higher water potential than any other system.
- ✓ It is defined as zero: Ψ (pure water) = 0 Pa All other systems (cells, solutions and suspensions) have a water potential that is lower than that of water.
- ✓ Therefore, water potential values must be negative. So to define osmosis accurately as:
- ✓ Movement of water from a system with a high (less negative) water potential to one with a lower (more negative) water potential, across a partially permeable membrane.

Why water potential values are negative?

- Water potential of a system is due to concentration of free water in that system.
- In pure water, there are only water molecules.
- When a solute is added, some of the water molecules form 'hydration shells' around the solute molecules. This reduces the number of (free) water molecules in the system and so the water potential is reduced. Since pure water is assigned a water potential of zero, the solution must have a negative water potential.
- A more concentrated solution will take more free water molecules out of the system and lower the water potential still further, making it more negative

The rate at which osmosis proceeds is influenced by the same factors as simple diffusion:

- ➢ Surface area of the membrane
- ➢ Difference in water potential
- ➢ Distance the molecules must travel

What happens to cells placed in solutions of different concentrations? Depends on type of cell. Animal cells have no cell wall. The difference in water potential between cell and solution will determine. When comparing the water potential of a solution to cell, we could describe it as:

- ✓ **Isotonic** – having the same water potential as the cell

- ✓ **Hypertonic** – having a lower (more negative) water potential than the cell
- ✓ **Hypotonic** – having a higher (less negative) water potential than the cell

Animal cells; RBCs are placed in different solutions, When In the;

- ♣ Hypertonic solution, the cells lose water by osmosis and shrink. In the
- ♣ Hypotonic solution, the cells gain water by osmosis and swell. The pressure will eventually burst the weak plasma membrane: this is called haemolysis.
- ♣ Isotonic solution there is no change in the.

Plant cells; plant cells are placed in different solutions. When In the;

- ❖ Hypertonic solution, the cytoplasm of cells loses water by osmosis and shrinks. Because of this, no pressure from the cytoplasm on cell wall. The cell is flaccid.
- ❖ If the cytoplasm shrinks too much, it loses contact with cell wall, we say plasmolyzed.
- ❖ Hypotonic solution, the cells gain water by osmosis and swell. However, because of the cell wall, the cell cannot become much larger. Plant cells in this condition are turgid.
- ❖ Isotonic solution there is no change.
- ❖ Turgidity is important in supporting young, non-woody plant stems.
- ❖ If the plant is kept well watered, the cells will remain turgid. The turgid cells will press against each other and this pressure will keep the plant upright.
- ❖ If the plant is not watered, the cells will be plasmolyzed and become flaccid. They will no longer press against each other and the support will be lost. The plant will wilt.

Active processes

- When substances must be moved against a concentration gradient using energy
- From a low concentration to a higher one. This cannot happen by diffusion, since it would tend to concentrate particles rather than spread them out.
- It can only happen if metabolic energy is used to drive the process.
- In living organisms, this energy is released from the ATP produced in respiration.
- When energy is released from ATP, it is broken down into ADP and Pi
- The proteins used to actively transport substances across plasma membranes are pumps.

Endocytosis, In this process;

- Large particles are engulfed by a cell.
- Several ways it can happen, but, essentially, part of plasma membrane surrounds the particles to form a vesicle which is then processed by the cell.

Three different types of Endocytosis. Phagocytosis, Pinocytosis and Receptor-mediated.All of them require ATP to move the membrane around the particles to form the vesicle

- ✓ **Phagocytosis;** involves the creation of pseudopodia (extensions of plasma membrane) to enclose large particles or even whole organisms outside the cell. Once enclosed by the pseudopodia, they form an internal vesicle which is then moved further inside the cell.
- ✓ **Pinocytosis**; differs from phagocytosis only in scale. It involves the ingestion of smaller particles (but particles that are still too large to cross the membrane by other methods) and does not require the formation of large pseudopodia to engulf the particles.
- ✓ **Receptor-mediated Endocytosis**; membrane in folds to form vesicles only in regions where particles have bound to specific receptors. The binding stimulates the infolding.
- ✓ **Exocytosis** process in which substances moved from the inside to the outside of the cell in what is, effectively, the reverse of endocytosis. It is the process by which enzymes and hormones are secreted. Again, ATP is used to alter the configuration of the membrane.

The other cell organelles, what are they like and what do they do? Organelles in outline, their functions, the metabolic processes they carry out.

The Nucleus; typically occupies about 10% of the volume of a cell. It has several components:

- ➢ The nuclear envelope is a double membrane surrounds nucleus. There are many nuclear pores, allow the passage of some molecules between the nucleus and the cytoplasm.
- ➢ The nucleolus is an organelle within the nucleus. It is not membrane-bound. Its function is to synthesize components of ribosomes, pass through nuclear pores into cytoplasm.
- ➢ Chromatin consists of DNA bound with proteins called histones.
- ➢ Most cell cycle, chromatin fibers are loosely dispersed throughout nucleus, before a cell is divided, chromatin condenses into distinct, recognizable structures as chromosomes.

Mitochondria

- Mitochondria are the sites of most of the reactions of aerobic respiration.
- Surrounded by two membranes. The inner is folded into cristae to increase surface area.
- Some of the reactions of aerobic respiration take place in the fluid matrix.
- The folded inner membrane provides a large surface area for the electron-transport system, which produces most of the ATP.

Ribosomes

- Ribosome's are the sites of protein synthesis.
- Found in cytoplasm, also bound to membrane of EPR, forming rough EPR
- Each ribosome comprises two subunits that are made from RNA and protein.
- The subunits are manufactured in the nucleolus.
- They leave the nucleus through nuclear pores and combine in the cytoplasm.

Endoplasmic reticulum (EPR)

- Membrane system found in cytoplasm of eukaryotic cells. There are two types of EPR:
- These are Rough EPR and Smooth EPR
- **Rough EPR** has ribosome responsible for the manufacture and transport of proteins.
- Protein molecules manufactured by the ribosome pass through small pores into the lumen (inner space) of the EPR Then moved in a vesicle to the Golgi body.
- Rough EPR is extensive in cells that manufacture a lot of protein, such as cells that manufacture enzymes to be secreted into the lumen of the intestine.
- **Smooth EPR** has no ribosome on its surface. It is concerned with the synthesis of lipids and steroids. It is also associated with carbohydrate metabolism and detoxification.

Golgi apparatus (or Golgi body)

- ✓ Consists of a number of flattened membrane bound sacs in which proteins are modified.
- ✓ Proteins may be converted into glycol proteins, for example.
- ✓ Modifications act as a 'tag', which determine the final destination of the molecule.
- ✓ Think of Golgi apparatus as a cellular post office that labels and distributes molecules!

- ✓ Modified molecules are released from Golgi apparatus in vesicles to be carried to parts of cell or to plasma membrane to pass out of cell by exocytosis to be used elsewhere.
- ✓ Some vesicles form the lysosomes

Lysosomes

- Have no specialized internal structure and are surrounded by a single membrane.
- Formed in Golgi apparatus
- Contain digestive enzymes that break down cellular waste and debris.
- Abundant in phagocytic WBCs. enzymes digest foreign cells that have been engulfed.
- The organelles we have described so far are found in all eukaryotic cells.

Organelles found in plant cells

Cell wall

- The criss-cross arrangement of cellulose fibers gives it both strength and elasticity.
- There are large 'gaps' (on a molecular scale) between fibers cell wall is freely permeable.

Vacuole

- The vacuole in a plant cell is a fluid-filled sac that stores a range of solutes.
- It is also important in maintaining the turgidity, or turgor, of a cell.
- When full of liquid (water), it exerts pressure on cytoplasm and, in turn, on the cell wall.
- If loses water by osmosis, the pressure reduces and turgor is lost. cell becomes flaccid.

Chloroplast

Chloroplasts are surrounded by two membranes, but, unlike mitochondria, inner membrane is not folded. There are two main regions in chloroplasts that are linked to the stages of photosynthesis:

- ***Grana*** is membranous regions (stack of thylakoids) light-dependent reactions occur, and
- ***Stroma*** is a fluid where the light-independent reactions occur.

Thylakoids are flattened sacs inside a chloroplast where photosynthesis takes place

How have biologists been able to study the different organelles?

- Possible because of a technique called **cell fractionation**.
- The technique is based the masses of organelles vary and depend on their size.
- When a mixture of organelles is spun in a centrifuge, the various types settle out at different speeds of spinning.
- The large nucleus requires a relatively low centrifuge speed to make it settle out;
- The much smaller ribosome requires a much higher speed.

The technique is carried out as follows: The cell sample is stored in a suspension that is

- **Buffered** neutral pH prevents damage to the structure of proteins, including enzymes
- **Isotonic** (equal water potential) – this prevents osmotic water gain or loss
- **Cool** – this reduces the overall activity of enzymes released later in the procedure

- The cells are homogenized in a blender and filtered to remove debris.
- The homogenized sample is placed in an ultracentrifuge and spun at low speed.
- The nuclei settle out, forming a pellet.
- The supernatant (the suspension containing the remaining organelles) is spun at a higher speed – chloroplasts settle out (if plant tissue is used).
- The supernatant is spun at a higher speed still – mitochondria settle out.
- The process is repeated at ever higher speeds until all the organelles have been separated.

UNIT 5 ENERGY TRANSFORMATION

5.1 Respiration

What is the ATP molecule like? The full name for ATP is Adenosine Tri-Phosphate. Nucleic acids are built from nucleotides; all nucleotides contain three sub molecules:

- Nitrogenous base (this one contains adenine)
- Pentose sugar
- Phosphate group

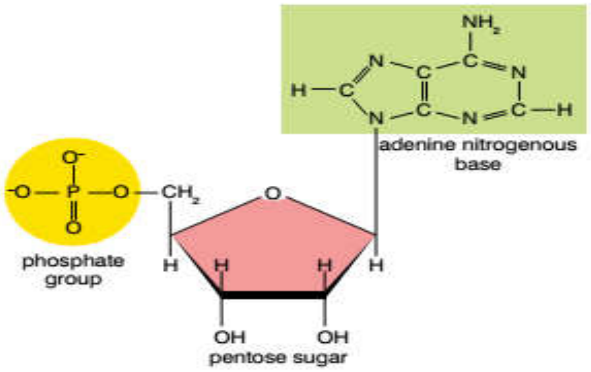


Figure 30. Nucleotide molecule with adenine nitrogenous bases

- ✓ ATP molecule is based on nucleotide molecule.
- ✓ ATP is sometimes described as a phosphorylated nucleotide.
- ✓ 'Phosphorylate' a molecule, mean you add one or more phosphate groups to it.
- ✓ ATP is adenine nucleotide with two phosphate groups added on making three in all.
- ✓ Adding extra phosphates requires energy, particularly when the third phosphate is added.
- ✓ As a result, energy is stored in the ATP molecule and when the bonds that hold this third phosphate in place are broken, the energy is released again.
- ✓ When the third phosphate is removed from ATP, we left phosphorylated nucleotide, but has two Phosphate. It is Adenosine Di-Phosphate or ADP.
- ✓ The phosphate group split off is usually written as Pi to save writing full formula.
- ✓ The inter-conversion of ADP and ATP is formed both photosynthesis and in respiration.

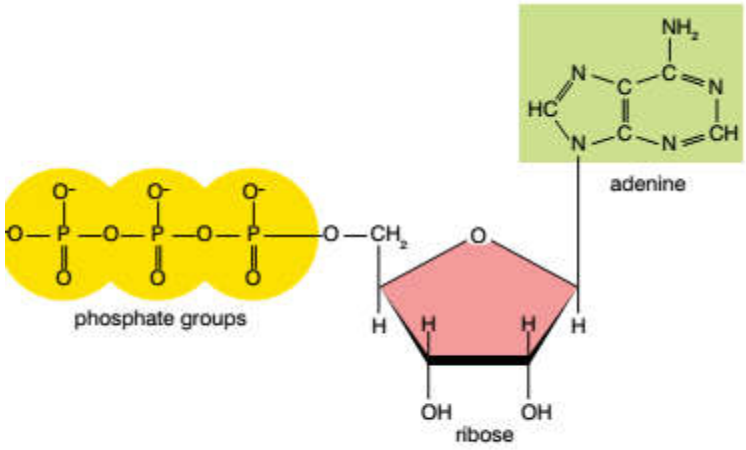


***Figure 5.2** The structure of the ATP molecule*

How is ATP adapted to its role as an energy transfer molecule in cells?

ATP is an energy transfer molecule. Sunlight energy cannot be used directly by plants 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, used to transfer energy to the relevant cellular process. ATP is adapted to this role because it:

- Releases energy matched to energy required in biological processes occurring inside cells
- Releases energy in a single-step hydrolysis reaction, so 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 (see unit 4 for • details)
- Muscle contraction
- Conduction of nerve impulses
- Initial reactions of respiration (later release energy from glucose to form more ATP)

How is ATP produced in a cell?

- Almost all the ATP produced in cells is formed in the same way.
- Involves ADP and Pi joining to form ATP and this requires an input of energy.
- The formation of ATP involves an enzyme called ATP synthase.
- The ATP synthase in membranes of a mitochondrion, in a membrane in a chloroplast.
- In both photosynthesis and aerobic respiration, many of the reactions generate hydrogen ions that will pass through the ATP synthase to produce ATP.

How is ATP produced in respiration? There are two pathways of respiration produce ATP:

- The aerobic pathway (aerobic respiration) – this requires the presence of oxygen, and
- The anaerobic pathway (anaerobic and fermentation) take place in the absence of oxygen.

How is ATP produced in aerobic respiration?

- ✓ Small amount ATP produced not involve ATP synthase; substrate level phosphorylation.

- ✓ Another molecule phosphoenol pyruvate (substrate) transfer a phosphate group to ADP. No ATP synthase and Pi involved. The process catalyzed by enzyme not ATP synthase.
- ✓ Small amount of ATP in fact about 10% of total ATP produced in aerobic respiration.
- ✓ 90% of ATP produced by ATP synthase, many of the reactions of this process are geared to producing H ions that will spin the rotor of the ATP synthase molecule.
- ✓ Many different organic molecules can be respired – they are called respiratory substrates
- ✓ Glucose is the most commonly respired substrate and begin how this molecule respired.

H ions transferred from glucose to ATP synthase? Two molecules important in transfer process:

- ✓ Nicotinamide Adenine Dinucleotide (NAD) and Flavine Adenine Di nucleotide (FAD)
- ✓ Both are coenzymes accepting H ions. When this happens, molecules have been reduced.
- ✓ Write reduced forms as NADH and FADH or NAD(reduced) and FAD(reduced).
- ✓ These molecules can release their hydrogen ions and become oxidised again.
- ✓ The hydrogen ions can then be used to turn the rotor of ATP synthase.

There are four stages in the aerobic respiration of glucose. These are:

1. Glycolysis
2. The link reaction
3. Krebs cycle
4. Electron transport and chemiosmosis

1. ***Glycolysis*** is first stage, takes place in cytoplasm. Do not take place in mitochondria because:

- ❖ The glucose molecule cannot diffuse through the mitochondrial membranes (it is a medium-sized molecule and is not lipid soluble), and
- ❖ There are no carrier proteins to transport the glucose molecule across the membranes.

Glycolysis ('glucose splitting') glucose converted into a smaller molecule containing 3C atoms pyruvate. Pyruvate enters mitochondria and all other stages take place inside Glycolysis can take place in the absence of oxygen and is the only energy-releasing process in anaerobic respiration.

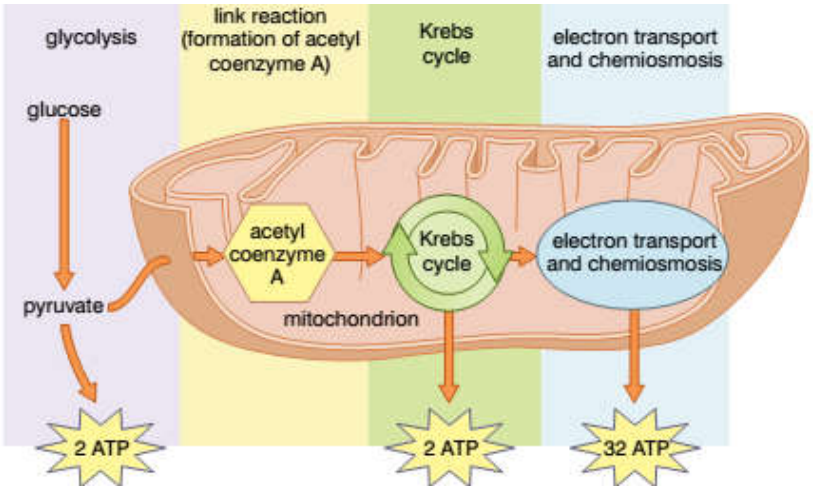


Figure 5.8 *The stages of aerobic respiration*

What happens in Glycolysis? Glycolysis takes place in cytoplasm. Reactions in glycolosis are;

- ♣ 2 ATP used to 'phosphorylate' molecule of glucose. This makes glucose more reactive
- ♣ In the phosphorylation process, it is converted to 6 C sugar (fructose 1,6-bisphosphate)
- ♣ Fructose 1,6-bisphosphate split into two 3 C sugar glyceraldehyde-3 phosphate (GP)
- ♣ Each molecule of GP converted into pyruvate, with the production of two molecules of ATP (by substrate level phosphorylation) and one molecule of reduced NAD
- ♣ Two molecules of pyruvate are produced from one molecule of glucose

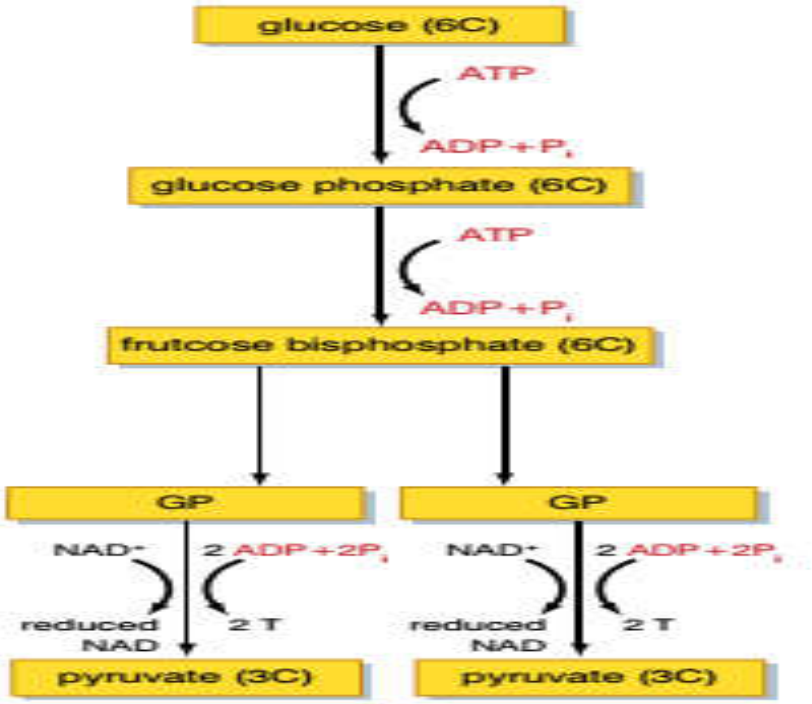


***Figure 5.9** The main stages of glycolysis*

At the end of glycolysis, there is a net gain of 2 ATP molecules per molecule of glucose (2 ATP and then 4 ATP produced). Two molecules of reduced NAD are also produced (per molecule of glucose). Pyruvate pass into mitochondria through carrier molecules.

A summary of the overall reaction of glycolosis:

$$C_6H_{12}0_6 + 2ATP + 4ADP + 2P_i + 2NAD \rightarrow 2C_3H_60_3 + 2ADP + 4ATP + 2NAD \text{ reduced} + 2H^+ + 2H_20$$

Two ideas to keep in mind

1. The idea of net gain of ATP is like profit a business makes. It invests money in materials, advertising and staff. It sells its product and extra money is profit net gain. Glycolysis 'invests' 2 ATP to make glucose reactive, then, later, produces 4 ATP a net gain of 2 molecules of ATP.

2. There are 2 molecules of pyruvate made from each molecule of glucose. So all the gains of ATP and reduced NAD and reduced FAD that accrue from each pyruvate must be doubled to give the gain from each molecule of glucose.

2. The link reaction;

In the link reaction the pyruvate converted into a 2C compound that enters a cycle of reactions Both of these stages of respiration take place in the fluid matrix of the mitochondrion. In the link reaction, a molecule of pyruvate reacts with a molecule of coenzyme A (CoA) to form a molecule of acetyl coenzyme A (acetyl CoA). In the reaction:

- ♣ H is lost and reduced NAD is formed; removing H from a molecule is dehydrogenation
- ♣ A carbon atom is lost to form CO_2; removing carbon from a molecule is decarboxylation.
- ♣ Acetyl coenzyme A then reacts with C_4 (a molecule containing 4C) called oxaloacetate.

In the reaction, acetyl CoA breaks down into:

- ♣ A 2C 'acetyl' group, reacts with C4 compound oxaloacetate to form a C6 compound, and
- ♣ The original coenzyme A molecule, which is reused in further reactions with other molecules of pyruvate. This is the first reaction of the Krebs cycle.

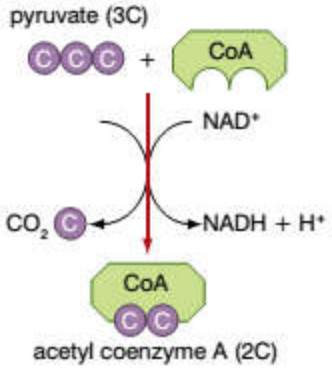


Figure 5.10 *The link reaction*

3. The Krebs cycle

- o Named after Sir Hans Krebs who discovered the reactions involved
- o Both these stages take place in the fluid matrix of a mitochondrion.
- o In all three stages (glycolysis, the link reaction and Krebs cycle), hydrogen atoms are transferred to NAD to produce reduced NAD.
- o Produces reduced FAD. These molecules later release their hydrogen atoms as protons (hydrogen ions) and electrons in the final stage of aerobic respiration.

- The electrons pass along a series of molecules called an ***Electron Transport Chain***.
- The protons are used in the chemiosmotic synthesis of ATP as they spin the rotor of the ATP synthase enzyme located in the inner membrane of the mitochondrion.
- the protons (H ions) and electrons will combine with oxygen to form water. at the end of the electron transport chain to **accept the electrons**.
- The electron transport chain grinds to a halt and production of ATP by ATP synthase. Because it is oxygen-dependent, this production of ATP is oxidative phosphorylation.
- Link reaction, Krebs cycle and electron transport chain depend on presence of oxygen.

What happens in the Krebs cycle?

- The two-carbon group from acetyl coenzyme A reacts with the four-carbon compound oxaloacetate to form a six-carbon compound called **citrate**
- Citrate loses carbon atom (decarboxylated) to form a 5C compound and CO2 is produced
- The 4C compound is then further decarboxylated to form a 4C compound and CO2 is again produced; a molecule of ATP is also produced by substrate level phosphorylation
- The 4C compound undergoes several molecular transformations to regenerate the original 4C compound (oxaloacetate) and cycle is complete and begin again with oxaloacetate reacting with another molecule of acetyl CoA
- In several reactions in cycle, reduced NAD produced and, in one reaction, reduced FAD is produced

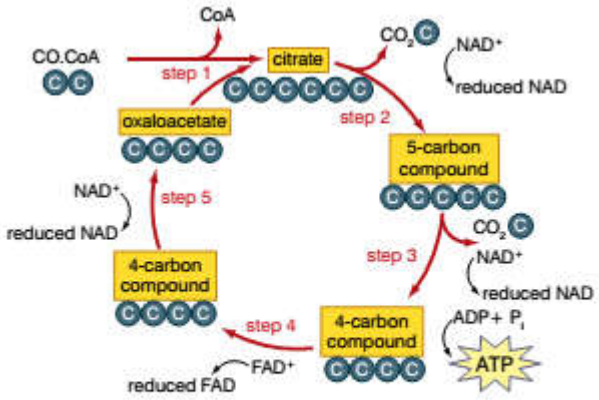


Figure 5.12 *The main stages of the Krebs cycle*

A summary of the overall reaction of the Krebs cycle:

$CH_3CO.CoA + 3NAD + FAD + C_4H_2O_5^{2-} \rightarrow 2CO_2 + 3NAD$ reduced + FAD reduced + $CoA + C_4H_2O_5^{2-}$

4. What happens in the electron transport chain (ETC) and chemiosmosis?

- ***ETC*** and chemiosmosis together make process of oxidative phosphorylation.
- The link reaction and Krebs cycle take place in ***fluid matrix of the mitochondrion*****,**
- ***ETC*** and chemiosmosis reactions take place on ***inner mitochondrial membrane*** cristae,

The following events take place: these are;

- ✓ The hydrogen atoms carried by reduced NAD and reduced FAD are released and split into protons (hydrogen ions) and electrons
- ✓ The electrons pass along a series of electron carriers that form the transport chain; they lose energy as they pass from one carrier to the next
- ✓ Three of the electron carriers are proton pumps that move protons from the matrix of the mitochondrion to the inter-membrane space
- ✓ As the electrons are transferred through these three proton pumps, the energy they lose powers the pumps which move the protons into the inter-membrane space
- ✓ Electrons from reduced NAD make this happen at all three pumps

The molecules that act as electron carriers in the electron transport chain are:

- ❖ Reduced NAD dehydrogenase (also a proton pump)
- ❖ Ubiquinone (proton pump), and
- ❖ A number of carriers called cytochromes (proteins contain iron); two of them form a complex that acts as the third proton pump.

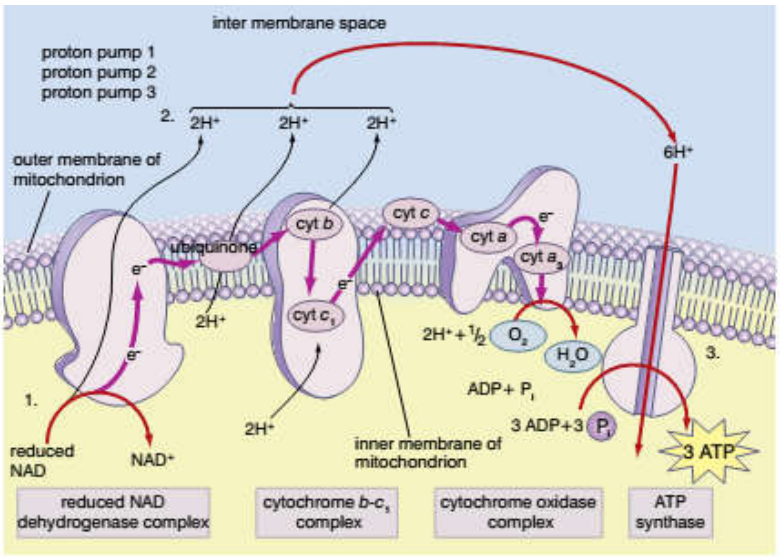


Figure 5.14 *The carrier molecules in the electron transport chain on the inner membrane of a mitochondrion*

- At the end of electron transport chain, the electrons combine with protons and oxygen to form water. Because of this, oxygen is known as the ***terminal electron acceptor***
- Reduced NAD dehydrogenated by NAD dehydrogenase complex,
- Reduced FAD is dehydrogenated by ubiquinone. Electrons from reduced FAD operate two of 3 proton pumps.
- Proton pumps action, protons accumulate in the inter-membrane space creating a higher concentration there than in the matrix (on other side of membrane).
- This proton gradient results in protons diffusing through ATP synthase molecule (down concentration gradient) making synthase rotor 'spin' and produce ATP from ADP and Pi.
- The diffusion of hydrogen ions through the ATP synthase is chemiosmosis.
- The oxidation of one molecule of reduced NAD results in six protons passing through ATP synthase and so leads to the synthesis of three molecules of ATP.
- Oxidation of one molecule of reduced FAD results in 4 protons passing through ATP synthase and leads to synthesis of two ATP. By adding molecules of ATP produced,
- The model of aerobic respiration we have discussed predicts that there will be a net yield of 38 molecules of ATP per molecule of glucose.
- In practice, this is not achieved because some energy (over two ATP) is used to drive the proton pumps. The actual yield is about 36 molecules of ATP per molecule of glucose

A summary of the overall reaction of the electron transport system:

6 reduced NAD (from Krebs' cycle) + 2 reduced NAD (from glycolysis) + 2 reduced FAD (from Krebs' cycle) + 30 ADP + 30 Pi – 2ATP (used in proton pumps) → 36 ATP + 8 NAD + 2FAD

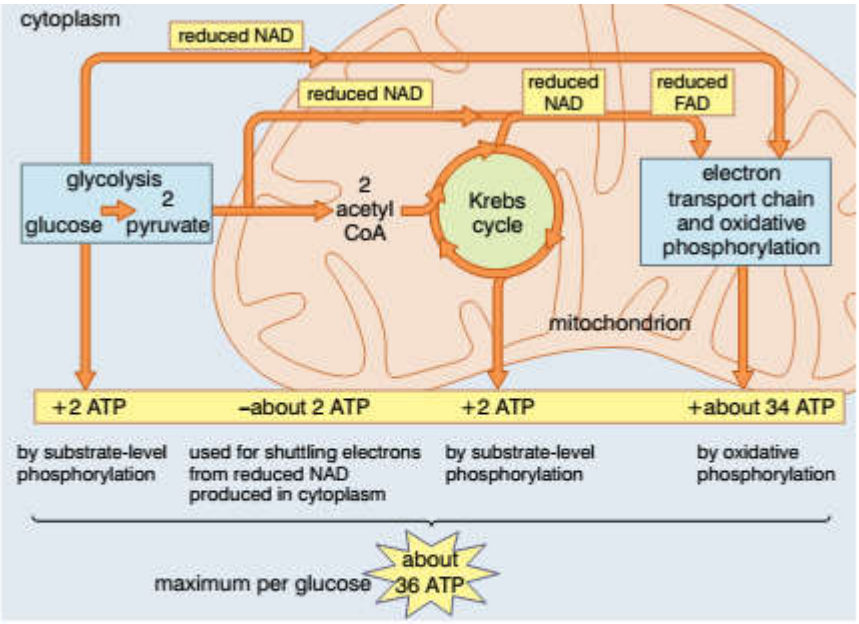


Figure 5.15 *The production of ATP during the aerobic respiration of glucose*

The summary equation for aerobic respiration is:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$ + energy released

Respirometers; in aerobic respiration oxygen and CO_2 produced, are equal in volume of ($6CO_2$ and $6O_2$. This is the basis of how respirometers work. For every molecule of oxygen the organism uses, a molecule of CO_2 produced, but, CO_2 absorbed by KOH. So, over time, a reduction in volume inside respirometer. Respirometer is placed under water. As volume inside respirometer decreases, water will enter pipette. The volume of water entering is equal to volume of oxygen being used up. We can use this to measure rate of respiration by measuring how much oxygen is used in a set period of time (say 10 minutes) then working out a rate per minute

What happens in the anaerobic pathway? If there is no oxygen present,

- The final reaction of oxidative phosphorylation, where electrons and protons react with oxygen to form water, cannot take place.
- As a result, the electron transport chain comes to a halt. No protons are pumped and the action of ATP synthase also stops. There is a further 'knock-on' effect

- If the electron transport chain does not function, NAD is not regenerated from reduced NAD and FAD is not regenerated from reduced FAD. Very quickly,
- The Krebs cycle and the link reaction come to a halt as both NAD and FAD are required in their oxidized forms for the Krebs cycle to function.
- NAD is also required in link reaction and so this comes to a halt also. Glycolysis can continue even though it also requires NAD.
- This is because reduced NAD formed during glycolysis regenerated under anaerobic conditions by converting the pyruvate into another product in a reduction reaction.
- Reduced NAD supplies the hydrogen for this reduction and becomes oxidized itself. It is therefore regenerated and can be used again in glycolysis.

Different organisms produce different fermentation end products.

- ✓ Animal cells produce lactate (lactic acid) when they ferment glucose.
- ✓ Yeast cells produce ethanol (ethyl alcohol). But both only produce two molecules of ATP per molecule of glucose.

A summary of anaerobic respiration in yeast cells

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \longrightarrow \underset{\text{Ethanol (alcohol)}}{2C_2H_5OH} + \underset{\text{carbon dioxide}}{2CO_2} + 2ATP$$

A summary of anaerobic respiration in animal cells

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \longrightarrow \underset{\text{Lactate (lactic acid)}}{2C_3H_6O_3} + 2ATP$$

Lactate formation during exercise

During exercise, the energy demand of muscle cells increases greatly. More glucose is respired to meet the demand. However, sometimes, aerobic respiration is insufficient to meet this energy demand. Fermentation of glucose supplies the extra energy. But it also forms lactate and as this accumulates, it leads to muscle fatigue. Also, fermentation only yields 2 molecules of ATP per molecule of glucose whereas aerobic respiration yields 38. However, fermentation is a much faster process and can produce a lot of ATP quickly, over a short period of time. The ATP used in sprints and short-distance runs is nearly all generated anaerobically.

But, due to muscle fatigue, this cannot be sustained. Longer races must be run slower to allow aerobic respiration to produce the ATP at its slower rate.

Lactate, once formed, can be used to regenerate glucose or be metabolised as an energy source by the liver. Figure 5.23 shows how the Cori cycle makes this happen.

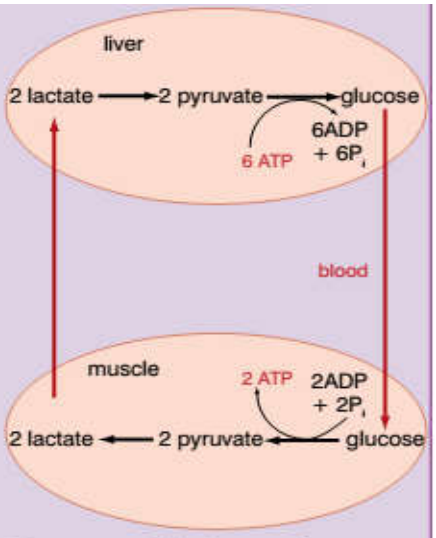


Figure 5.23 The Cori cycle

What substances can be used as energy sources?

Respiration and fermentation of glucose are energy sources. But lipids and proteins also used as respiratory substrates converted to enter aerobic respiration at some. The metabolism of proteins, lipids and carbohydrates 'converges' on the Krebs cycle.

5.2 How do plants harness light energy in photosynthesis?

- In photosynthesis light energy used in series of reactions to synthesis organic molecules.
- Energy entered system as light held in organic molecules produced. is chemical energy.
- When energy is changed from one form to another, we say **transduced**. This takes place in a series of reactions called light-dependent reactions.
- Light energy is absorbed by photosensitive pigments such as chlorophyll in chloroplasts.
- The light-dependent reactions take place in membranes the thylakoids in the chloroplasts.
- The liquid stroma is the site of the light-independent reactions, carbohydrates are synthesized. Chemical reactions take effectively in solution, than fixed in membranes.

How is the structure of a chloroplast suited to its function?

- Chlorophyll and other photosensitive pigment molecules are arranged in special photo systems that are linked to electron transport chains (ETCs).

- The molecules of photo systems and ETCs are fixed in the membranes of thylakoids. This makes the process much more efficient than if they just floating around in a solution.
- Two different photo systems, each sensitive to light of a different wavelength and linked to a different electron transport chain. These are called photosystem I and photosystem II.

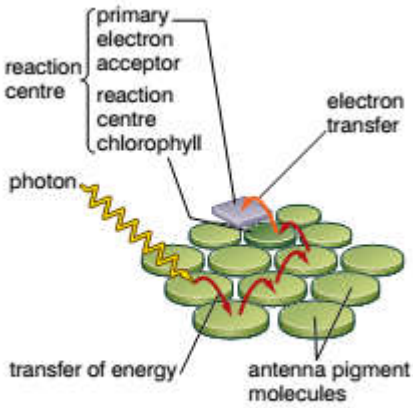


***Figure 5.30** The structure of a photosystem*

What is the structure of a photo system?

- A photo system consists of a number of pigment molecules all clustered around chlorophyll molecule called the reaction centre molecule.
- This cluster of pigment molecules is called an antenna complex.
- Only the reaction centre molecule is positioned next to the electron transport chain.
- Energy absorbed by other molecules in the photosystem is transferred to the reaction centre molecule, where the light-dependent reactions begin.
- Different pigment molecules in the antenna complex can absorb different wavelengths of light, making the whole system more efficient.
- The pigments in the antenna complex include chlorophyll a, chlorophyll b and carotenoids. The reaction centre molecule is always chlorophyll a.
- The range of wavelengths each molecule absorbs is its absorption spectrum.

What happens in the light-dependent reactions?

The light-dependent reactions use light energy to 'drive' the synthesis of two molecules that will, in turn, drive the light independent reactions. These two molecules are:

- ✓ ATP – this provides the energy for the reactions, and
- ✓ Reduced NADP – this provides the hydrogen ions for a key reduction reaction.

NADP is similar to NAD used in respiration and it has the same function transporting H ions.

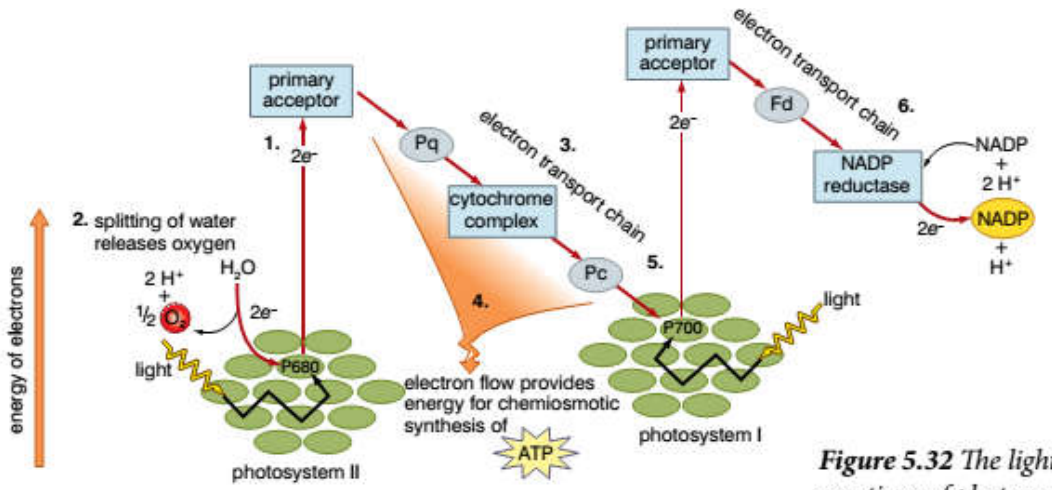


***Figure 5.32** The light-dependent reactions of photosynthesis*

Photo system I and photo system II

1. Electrons (e–) in chlorophyll molecules in photo system II are excited by the energy in photons of light they become more energetic. Because of the extra energy, they escape from the chlorophyll and pass to an electron acceptor (the primary electron acceptor).

2. The conditions created in the chloroplast cause the following reaction to occur:

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ Light-dependent splitting of water is called photolysis. The electrons replace those lost from the chlorophyll molecule.

3. The primary electron acceptor passes (e–) to next molecule in an electron transport chain (plastoquinone or 'Pq'). The (e–) then pass along a series of cytochromes (similar to those in the mitochondrial electron transport chain) and finally to plastocyanin (Pc) the last carrier in the chain. The (e–) lose energy as they are passed from one carrier to the next.

4. One of the molecules in the cytochromes complex is a proton (H ion) pump. As (e–) are transferred to and then transferred from this molecule, the energy they lose powers the pump which moves protons from the stroma of the chloroplast to the space inside the thylakoid. This leads to accumulation of protons inside thylakoid, which drives chemiosmotic synthesis of ATP.

5. Electrons in chlorophyll molecules in photosystem I are excited (as this photosystem absorbs photons of light) and escape from the molecule. They are replaced by the electrons that have passed down the electron transport chain from photosystem II.

6. The electrons then pass along a second electron transport chain involving ferredoxin (Fd) and NADP reductase. At the end of this electron transport chain, they can react with protons (H ions) and NADP in the stroma of the chloroplast to form reduced NADP.

A photosynthetic unit is a unit of pigments, electron carriers and ATP synthase that is capable of carrying out all the reactions in the light-dependent stage of photosynthesis. The formation of ATP in the way called non-cyclic photophosphorylation. This is because:

- The phosphorylation (formation of ATP) is light-dependent
- The electrons lost from the chlorophyll are not recycled in any way

Plants sometimes generate ATP by cyclic photophosphorylation. In cyclic photophosphorylation, only photosystem I is used. No oxygen and no reduced NADP are formed. Electrons lost from the chlorophyll molecule are returned to it, hence the name 'cyclic'. This process usually only happens when sugars cannot be synthesized for some reason such as lack of carbon dioxide.

In cyclic and non-cyclic photophosphorylation, ATP is produced because:

- There is an accumulation of protons (hydrogen ions) in the interior of a thylakoid
- This creates a concentration gradient b/n thylakoid interior and stroma of the chloroplast
- Protons move down this concentration gradient, through ATP synthase, causing the rotor to spin, just as in mitochondria during respiration

How is carbohydrate synthesized in the light-independent reactions?

- The light-independent reactions of photosynthesis occur in the stroma of the chloroplasts.
- Complex cycle of reactions involves addition of CO_2 to preexisting 5C in chloroplast.
- The resulting molecules are modified to regenerate the original molecule whilst, at the same time, synthesizing glucose.
- The sequence of reactions was discovered by Melvin Calvin, an American biologist.,
- Because of his work the light-independent reactions also referred to as the Calvin cycle.

In 1950s **Melvin Calvin** experimented algae called Chlorella by exposing to radioactive CO_2 Algae killed and chemicals in algae contained radioactive carbon (must come from CO_2) were identified using two-dimensional chromatography. As time passes more compounds contain the radioactive carbon. By refining the experiment and using shorter and shorter intervals, Calvin identified the first stable compound to be formed as a compound containing 3C atoms called glycerate phosphate (GP). The main stages of the light-independent reactions are:

- ✓ CO_2 reacts with RuBP a 5C compound in stroma; catalyzed by the enzyme Rubisco.
- ✓ Two molecules of 3C compound GP are formed from this reaction as figure 5.36 shows
- ✓ Each molecule of GP is converted to TP (triose phosphate another 3C compound); this is a reduction reaction using hydrogen ions from reduced NADP and energy from ATP
- ✓ Some TP formed is used to regenerate RuBP (ATP is again required) whilst some is used to form glucose and other useful organic compounds

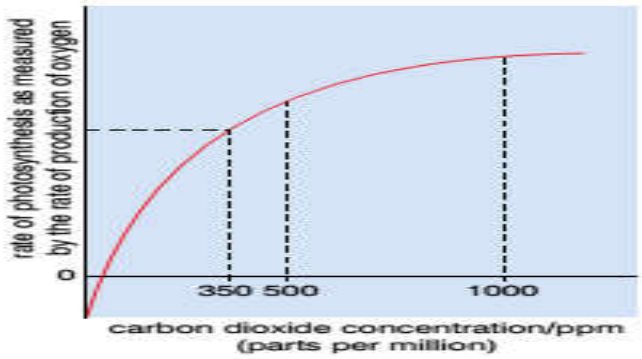
The light-independent reactions shows three 'turns of cycle' result output one molecule TP. Six turns of cycle would give output of two molecules TP enough to make one molecule of glucose.TP also converted to lipids, amino acids ,nucleotides and other organic molecules in plants. TP is the basis for the synthesis of all organic molecules.

What factors affect the rate of photosynthesis?

The rate of photosynthesis is limited by the factor that is present in a limiting quantity. This is known as **the principle of limiting factors**.

What is the effect of light intensity on the rate of photosynthesis?

***Figure 5.39** The effect of light intensity on the rate of photosynthesis (measured by the rate of production of oxygen)*



- Very low light intensities – respiration is still occurring and is taking in oxygen faster than photosynthesis is producing it
- Medium light intensities – photosynthesis is producing more oxygen than respiration uses, the rate of photosynthesis increases with increasing light intensity
- Very high light intensities – the rate of photosynthesis is beginning to level out, even though the light intensity is still increasing; some other factor is probably limiting the rate

What is the effect of the concentration of carbon dioxide on the rate of photosynthesis?

At very low concentrations of CO_2, little photosynthesis takes place; respiration is still using up oxygen. As the CO_2concentration increases, so does the rate of photosynthesis. Again, however, it begins to level off at higher concentrations.

How does temperature affect the rate of photosynthesis?

- Both the light-dependent and light-independent stage are controlled by the enzymes, which are affected by temperature.
- Once the temperature exceeds enzyme denatures and rate of photosynthesis decreases

How can all the factors interact to influence the rate of photosynthesis?

Increasing light intensity should increase the rate at which ATP and reduced NADP are produced in the light-dependent reactions and, as a result, increase the rate at which the Calvin cycle can take place. However, the rate at which the Calvin cycle can 'turn' could be limited by:

- ✓ A low temperature (limiting the rate at which enzymes such as Rubisco can operate)
- ✓ A low concentration of carbon dioxide

This limits rate at which reduced NADP and ATP can be used, which, in turn, limits the amount of NADP and ADP + Pi that reused by light-dependent reactions. The whole process is therefore limited, even though the light intensity continues to increase.

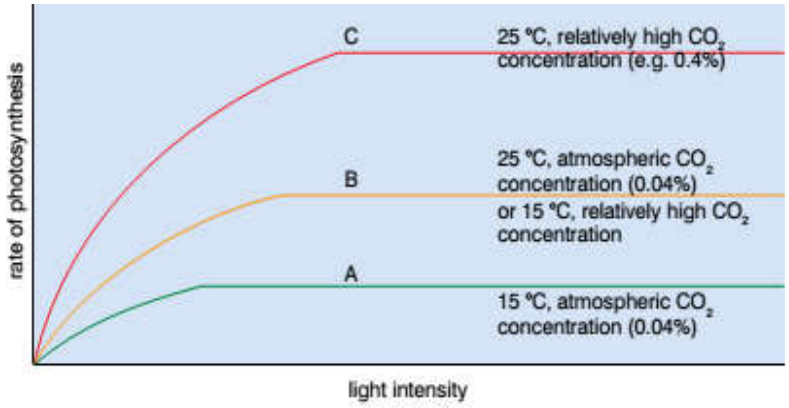


***Figure 5.42** The effect of several factors on the rate of photosynthesis*

In region of graphs where light is non-limiting (horizontal lines), the factors that are limiting are:

- ➢ A; Temperature and CO_2; increasing produces increase rate of photosynthesis to level B
- ➢ B – Temperature or carbon dioxide concentration (the factor that hasn't been increased from A); increasing the temperature increases the rate to level C

As well as major factors above, other factors influence the rate of photosynthesis. These include:

- Wavelength of light; photosynthesis faster in 'red' and 'blue' wavelengths than in other because these wavelengths are absorbed more efficiently; Green are reflected in leaves.
- The amount of chlorophyll present

Are there any other ways of photosynthesizing?

C_3 PHOTOSYNTHESIS AND PHOTORESPIRATION

- ➢ Takes place in plants living in temperate environments, It is called C_3 photosynthesis.
- ➢ The first compound formed in light-independent reactions Calvin cycle is GP (3C atom).
- ➢ C_3 plants have leaves that are adapted to this method of photosynthesis.

- Leaves are generally broad, to catch as much sunlight. The chloroplasts (palisade cells) are nearest the upper surface of the leaf (to absorb as much light as possible).
- The stomata are mainly on the lower surface, to minimize water loss.
- During day time stomata are open to allow CO_2, closed if water loss too great on hot day.
- Spongy mesophyll air spaces allow diffusion of CO_2, O between palisade and stomata.
- However, C3 plants in very hot; the leaves close their stomata to minimize water loss.
- When C3 plants do this, concentration of CO_2, in leaves falls and the enzyme Rubisco starts to behave in an unusual way.
- In the low concentrations of CO_2, Rubisco binds with oxygen, not CO_2,
- This means RuBP is oxidized to one GP and phosphoglycolate., CO_2, is produced
- The process is called photorespiration because it involves oxidation of carbon.

$$\text{Ribulose bisphosphate} + \text{oxygen} \xrightarrow{\text{Rubisco}} \text{GP} + \text{phosphoglycolate}$$

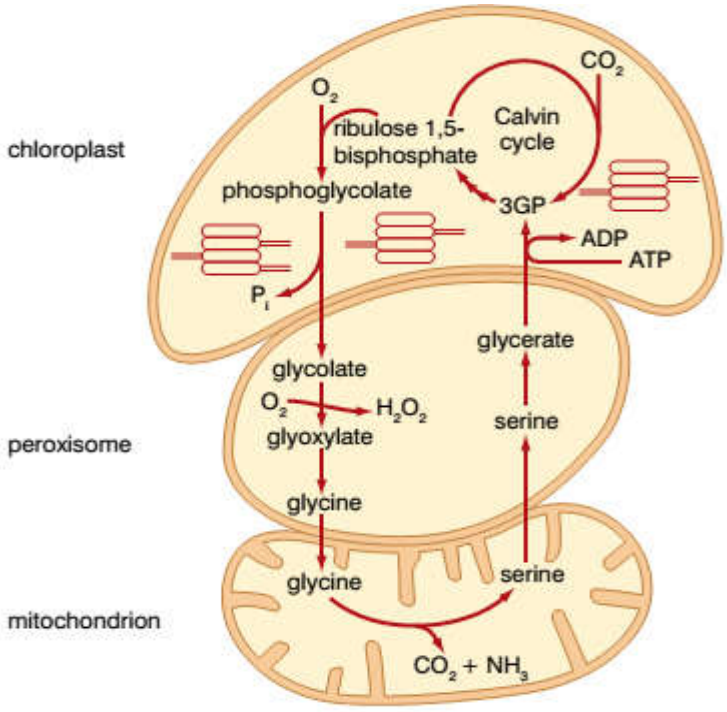


Figure 5.46 *The reactions of photorespiration*

The one molecule of GP formed in photorespiration can re-enter the Calvin cycle, but the phosphoglycolate must be converted into GP for use in the Calvin cycle by a complex series of reactions. These reactions (involving a chloroplast, organelle a peroxisome and a mitochondrion)

Not necessary to remember all these reactions. Instead, think the two phases of photorespiration:

- Rubisco catalyses a reaction between oxygen and RuBP to form one molecule of GP (not two) and one molecule of phosphoglycolate.
- The phosphoglycolate is converted to GP in chloroplast, peroxisome and mitochondrion.

Photorespiration reduces the efficiency of photosynthesis for several reasons, including:

- ✓ The carbon is oxidized, is reverse of photosynthesis, the reduction of C to carbohydrate
- ✓ The ribulose bisphosphate must be re synthesized and the phosphoglycolate removed
- ✓ ATP is used in the re synthesis of RuBP.

C4 PHOTOSYNTHESIS

- ❖ To get round the problem of photorespiration reducing the efficiency of photosynthesis,
- ❖ Tropical plants like (maize, crabgrass, sorghum, sugar cane) are C_4 photosynthesis.
- ❖ The first compound formed in light independent reactions is C4 (4C atoms) not GP (C3)
- ❖ The light-dependent reactions are the same as in the C3 plants, but there is a difference in how glucose is synthesized in the light-independent reactions.

The structure of a C4 is similar to that of a C3 plant, but there is one important difference.

- ➢ The cells of the bundle sheath contain chloroplasts, which they don't in C3 plants.
- ➢ Having no thylakoids means that the light-dependent reactions cannot occur here and so oxygen is not produced in these chloroplasts.
- ➢ This helps to prevent photorespiration and allows Calvin cycle to take in these cells.
- ➢ The light-dependent reactions in C4 also involve a set of reactions not found in C3 plants.
- ➢ These reactions take place in mesophyll cells, which have chloroplasts with thylakoids and so can carry out the light-dependent reactions.

Have no enzymes catalyze reactions of Calvin cycle. Instead, the following reactions take place:

- ✓ CO_2 reacts with a C3 compound called PEP to form the C4 compound oxaloacetate. This is catalysed by the enzyme PEP carboxylase.
- ✓ Oxaloacetate converted to C4 (malate), then passes from mesophyll to a bundle sheath
- ✓ In the bundle sheath cell, malate is converted to pyruvate with the release of a molecule of CO_2, which starts the reactions of the Calvin cycle by binding with RuBP.
- ✓ The pyruvate is converted back to PEP; this reaction requires ATP. the C4 cycle uses two more molecules of ATP to deliver a molecule of CO_2 to Rubisco than does the C3 cycle.
- ✓ During active photosynthesis in the tropics, this is not a problem, as the high light intensity generates much ATP from the light dependent reactions.

C4 photosynthesis is most efficient in conditions of:

- Low carbon dioxide concentration
- High light intensity
- High temperature

***Table 5.2** A comparison of C3 and C4 photosynthesis*

Feature	C3	C4
Bundle sheath cells	Lack chloroplasts	Have chloroplasts with no thylakoids
Enzyme used to fix CO_2	Rubisco	Pepco (PEP carboxylase)
Optimum temperature	15–25 °C	30–40 °C
Optimum CO_2 concentration	700 ppm	400 ppm
Fixation of CO_2	Mesophyll cells	Mesophyll cells
Calvin cycle	Mesophyll cells	Bundle sheath cells

In Ethiopia (such as sorghum and wheat) are all C4 plants and adapted to photosynthesize efficiently in hot, bright days. Crop plants that grown in temperate (peas and carrots) would not photosynthesize as efficiently, because they are C3 plants and not produce high yields.

;;;;;;;;;

THE END