

UNIT ONE
THE SCIENCE OF BIOLOGY

1.1 The method of science

- ❖ **Science** is a systematic body of knowledge developed as a result of observations and practical experience of human beings in their attempt to understand and control nature.
- ❖ **Biology** is concerned in studying all living things from single celled organisms like bacteria, protozoa and unicellular algae to multicellular organisms including plants and animals.
- ❖ Biologists are those who are involved in the study of living organisms under different categories.
- ❖ **Science is an organized way of gathering and analyzing** evidence about the natural world.
- ❖ It is a way of observing, a way of thinking, and a “way of knowing” about the world.
- ❖ In science, **knowledge** is acquired on the basis of scientific method.
- ❖ One goal of science is to provide natural explanations for events in natural world.
- ❖ Scientific methodology involving observing and asking questions, making inferences and forming hypotheses, conducting controlled experiments, collecting and analyzing data, and drawing conclusions.
- ❖ **Scientific method** involves a series of steps followed by scientists to solve problems.
- ❖ The word science also refers to the body of knowledge that scientific studies have gathered over the years.
- ❖ **Scientific method** is a systematic approach to interpreting observations that involve reasoning, predicting, and drawing conclusions which are put into perspective with the existing knowledge:
- ❖ **Thus scientific method is important:**
 - ✓ To solve problems
 - ✓ To discover facts and principles
 - ✓ To formulate laws and theories such as problem has to be identified before processing to the next steps.
- ❖ **Science** is also referred to as experimental study because it involves the use of experiments in obtaining and proving information.

Scientific methods follow the following steps

1. **Observing and asking questions**---scientific investigations begin with observation. Observation is the act of noticing and describing events or processes in a careful, orderly way.
2. **Inferring and forming a Hypothesis**---After posing a questions, scientists use further observations to make inferences.
An **inference** is a logical interpretation based on what scientists already know.
Inference, combined with a creative imagination, can lead to **hypothesis**.
A **hypothesis** is a scientific explanation for a set of observations that can be tested in ways that support or reject it.

3. **Designing controlled experiments**

- Testing a scientific hypothesis often involves designing an experiment that keeps track of various factors that can change, or variables.
- Examples of variables include
 - ☞ temperature,
 - ☞ light,
 - ☞ time and
 - ☞ availability of nutrients.
- Whenever possible, a hypothesis should be **tested** by an experiment in which only one variable is changed. This type of experiment is called a **controlled experiment**.

Controlling Variables---Why is it important to control variables?

- The reason is that if several variables are changed in the experiment, researchers can't easily tell which variable is responsible for any results they observe.
- The variable that deliberately changed is called the **independent variable** (also called the **manipulated variable**).
- The variable that is observed and that changes in response to the independent variable is called **dependent variable** (also called the **responding variable**).

Control and experimental groups----Typically, an experiment is divided into control and experimental groups.

A **control group** is exposed to the same conditions as the experimental group except for one independent variable.

Scientists always try to reproduce or **replicate** their observations.

Therefore they set up **several sets** of control and experimental groups, rather than just a single pair.

4. **Collecting and analyzing data** -----Scientists make detailed records of experimental observations, gathering information, called **data**.

There are two main types of data

1. **Quantitative data**----are numbers obtained by counting or measuring.

2. **Qualitative data**---are descriptive and involve characteristic that cannot usually be counted.

Note: The larger the sample size, the more reliably researchers can analyze that variation and evaluate the differences between experimental and control groups.

5. **Drawing Conclusions**----Scientists use experimental data as an evidence to support, refute, or revise the hypothesis being tested, and to draw a valid conclusion.
- ❖ Hypotheses are often not fully supported or refuted by one set of experiments. Rather, new data may indicate that the researchers have the right general idea but are wrong about a few particulars.
 - ❖ In that case, the original the original hypothesis is reevaluated and revised; new predictions are made, and new experiments are designed.
 - ❖ Those new experiments might suggest changes in the experimental treatment or better control of more variables.

Problem identification or questioning is based on observations that can be made directly or indirectly:

- ❖ **Directly** through seeing, hearing, tasting, smelling and touching
- ❖ **Indirectly** through systematic observations which requires knowledge and skills
 - e.g. Using special equipment like microscope
 - ❖ Facts
 - ❖ Imaginations

Background research –involves carrying faster observations about the problem from:

- ❖ Media broadcasts
- ❖ Magazines
- ❖ Internets
- ❖ Knowledgeable people about the area of the problem
- ❖ Anyone who looked into the problem, etc.
 - ✓ Should consider all the observed facts relevant to the problem.
 - ✓ Should lead to a prediction which is suitable for testing.
- ❖ **There two forms of hypothesis:**
 - 1) **Inductive hypothesis**—is a generalization that processes from specific to general to generate a hypothesis to discover new scientific generalization
 - 2) **Deductive hypothesis**---is a formulated generalization from general to specific conditions.
 - For example a scientist might reason, if organisms are composed of cells then microscope examination of any part of an organism should reveal.
 - We can also say that the scientist has made a **prediction** that the hypothesis can be supported by doing microscope studies.
 - **Making a prediction** helps scientist know what to do next.

Testing a hypothesis through experiments

- ❏ In testing the hypothesis, the hypothesis should be subjected to planned and controlled experimental testing
- ❏ The goal is to control all the variables except the one under the study
- ❏ For valid conclusion many rounds of the same experiments need to be undertaken.
- ❏ This phase of a scientific experimentation is known as **evaluation**.

Peer Review---Scientists share their findings with the scientific community by publishing articles that have undergone peer review, scientific papers are reviewed by anonymous, independent experts.

Publishing peer---reviewed articles in scientific journals allows researchers to share ideas and to test and evaluate each other's work.

Scientific articles contain details about

- ☞ experimental conditions,
- ☞ controls,
- ☞ data analysis, and
- ☞ conclusions.

Researchers read them looking for

- ☞ oversights,
- ☞ unfair influences,
- ☞ fraud, or
- ☞ mistakes in techniques or reasoning.

They provide expert assessment of the work to ensure that the highest standards of quality are met.

Peer review does not guarantee that a piece of work is correct, but it does **certify** that the work meets standards set by the scientific community.

Reporting or publishing of results---Research findings are usually published in **scientific journals**. Communication is an important component of the scientific method.

The Knowledge generated in a field of science has to reach the scientific community.

The Scientific Experiment

Experimental variables

Variables are events or conditions subject to change. Examples include:

- Intensity of light
- Temperature
- Moisture
- Concentration of substances
- Number of organisms, etc.

❏ In most hypotheses there are a number of factors, which may influence the observation. These are called **variables**.

❏ There are **four** general categories of variables:

1, Independent variables

- are variables over which the experimenter can impose control during experimentation.
- They are factors that the scientist changes or manipulates.
- e.g. In an experiment in which seedlings are grown at different temperatures, the temperature is an independent variable.

2, Dependent variable:

- is variable over which the experimenter has **no** control.
- is the factor that the scientist measures to see if it changes when the independent variable changes.
- It is called dependent variable because it is driven by or results from the independent variable.

- E.g. the rate of growth of seedlings at different temperatures.

3, Controlled variable:

- is a condition that could affect the outcome of the experiment but that does not do because it is held **constant. e.g. light and moisture in the experiment on seedling growth.**
- They are factors other than the independent variables such as temperature, intensity of light, number of seeds, volume of liquid added to avoid influencing results.

4, Confounding variable: is a variable that might influence **the** results that we cannot control.

- ❏ For example, If we measure the CO₂ uptake by wheat plants as the light intensity changes over the day, we **cannot** control the effect of change in temperature.

The experimental and control group

The usual way of testing hypothesis is by performing a carefully planned experiment or experiments.

Such a carefully planned experiment consists two components

1. treated or experimental group or
2. untreated or control group.

Steps in conducting an experiment

The following are universally accepted necessary steps that should be followed in initiating and performing a brief and experiment:

1. **Statement of the problem (title)** --this involves specifying the title and giving short elaboration about the problem to be investigated.
2. **Materials required** –a list of all materials needed for the experiment
3. **Method or procedure** –indicates the steps to be followed in the experiment
4. **Results and observations** –May be qualitative or quantitative information and should be presented as clearly as possible in some appropriate form or forms, such as verbal description, tables of data, graphs and so on.
5. **Discussion and conclusion** –should be brief and take the form of the answer (s) to the questions posed by the hypothesis or confirmations of the aim.
 - It should not be a verbal repetition of the results but an attempt to relate the theoretical knowledge of the experimental variables to the results obtained.

The structure of report writing on scientific experiments

A **scientific paper** is a written report describing original research results.

Scientists report the results of their research in **scientific journals** such as **Nature and Science**.

These are read by other scientists working in the same field who can repeat the research and comment on any conclusions that have been drawn.

A scientific report should be made in proper order:

1. **Title**—should be the fewest possible words that accurately describe the content of the paper
2. **Introduction** –should begin by introducing the reader to the pertinent literature and demonstrate the need for the current study.

3. **Materials and method**—the purpose is to provide enough details for a competent researcher to repeat our study and reproduce the results.
4. **Results**--- here we present our findings.
We should present the data, digested and condensed, with important trends extracted and described. Our results must be clearly and simply stated, it is often helpful to summarize these in graphs, charts and tables.
5. **Discussion**—our results should be discussed.
--What biological principles have been established or re-enforced?
--What generalizations can be drawn?
--How do our findings compare to the findings of others or to expectations based on previous work?
6. **Conclusion**--- this can be drawn from the results regarding the significance of the work
7. **References**--- whenever we draw up information contained in another paper, we must acknowledge the source.
 - All references to the literature must be followed immediately by an indication of the source of the information that is referenced

Scientific theory, principle, facts and law

- ❖ When a given hypothesis has been tried many times and found to be acceptable, it is no longer called a hypothesis.
- ❖ It is automatically transformed into a **theory**.
- ❖ **A theory is then a hypothesis that has been tested to be true.**
- ❖ The trend throughout scientific study is to achieve higher levels of predictability.
- ❖ In science, the word **theory** applies to a well-tested explanation that unifies a broad range of observations and hypotheses and that enables scientists to make accurate predictions about new situations.
- ❖ A useful theory that has been thoroughly tested and supported by many lines of evidence may become the dominant view among the majority of scientists, but no theory is considered absolute truth.
- ❖ Science is always changing; as new evidence is uncovered, a theory may be revised or replaced by a more useful explanation.
- ❖ When a theory has proved invariable under all circumstances, or such variations are systematic and predictable, then it may be accepted as **a fact, principle or law**.

Accuracy, reliability and validity in scientific experiments

Accuracy: refers to how precisely something has been measured or counted.

- ❖ The level of accuracy we choose must reflect the magnitude of what we are measuring.
- ❖ To measure **volume**, we could use; a **syringe**, a **pipette** or a **burette**.

Reliability: A measure of how dependable and consistent the results of an experiment are.

To increase the reliability of our experiments, we can:

- ❑ Standardize all our procedures, so as to do exactly the same thing.
- ❑ Repeat it many times ourselves. This allows us to spot any anomalous results and calculate an average result
- ❑ Try not to use personal judgment
- ❑ Have a standard to compare our experiment too
- ❑ Use a special apparatus like a calorimeter

This means, after repeated investigation the results show very close or the same results.

Validity: related to whether an experiment is measuring what it is intended to be measured or not. Thus, all the variables should be controlled for an experiment to be valid.

Some of the areas of study which get involved include:

1. **Taxonomists** — are involved in the methods and study of classification of organisms
2. **Microbiologists** — Study about microorganisms
3. **Astrobiologists** — engaged in research to find evidence of life forms on other planets.
4. **Paleobiologists** — study about how life is originated on the earth and how it is evolved. It is mainly concerned in the study of fossils.
5. **Ecologists** — engaged in the study of relationship between organisms and their environment.
6. **Parasitologists** — involved in the study of the parasites.
7. **Zoologists** — involved in the study of animals
8. **Botanists** — involved in the study of plants
9. **Entomologists** — involved in the study of insects
10. **Neurologists** — engaged in the study of the complex structure of neurons and nervous conditions.
11. **Geneticist** — engaged in the study of heredity variation physiological basis of DNA and the genetic material.

1.2 The tools of a biologist

Biologists need various types of apparatus or equipment to be used in order to carry out biological studies. Some of the major equipment that biologists use include:

- | | |
|------------------------|--------------------------|
| 1. Microscopes | 6. Dissecting equipment |
| 2. Petri dishes | 7. Pipettes and syringes |
| 3. Centrifuges | 8. Bunsen burner |
| 4. Sterilizers | 9. Thermometers |
| 5. Measuring cylinders | 10. Balances, etc. |

Tools for measuring volume of liquids or gases include:

- Measuring cylinders
- Pipettes
- Syringes---some syringes are designed specially as gas syringes to collect oxygen gas.
- ❏ Balances-- are used for measuring mass.
- ❏ Dissecting kit:
 - **Dissection** is the process of cutting tissues of an organism for studying the anatomical structure of an organism.
 - **Dissection** is carried to study internal organs like heart, kidney, lung etc.
 - Biologists can even dissect small specimens by using a microscope.
 - **Dissecting kit** contains:
 - ❖ Scissors
 - ❖ scalpels
 - ❖ forceps
 - ❖ mounting needles
 - ❖ magnifying glass
- ❏ **Petri dish** — is a shallow circular glass or plastic dish used for growing microorganisms or cultured cells in a suitable medium.
 - They are filled with solid nutrient medium called **agar**.

Agar — is a jelly- like substance mainly extracted from red algae used for culturing micro-organisms.

Nutrient medium is a collection of nutrients to grow **microorganisms**.

Micro propagation — is a technique of growing plants from just a few cells on special agars in petri dishes.

Micro propagation allows thousands of plants to be produced from just one ‘parent’ plant. All the plants produced are genetically identical.

Microscopes:

- are one of the most vital tools in a laboratory.
- make very small things look larger than they really are and to show objects that are too small to be seen at all with unaided (naked) eye.
- both **enlarge** the image made by an object and **show its details**.
- The increase of an objects apparent size is called **magnification**.

- The power to show details clearly refers to **resolution**.

There are **two** main types of microscope depending on their complexity:

1. **Optical (light) microscopes:**

2. **Electron microscope**

Optical (light) microscopes:

- ❖ use beams of light to produce magnified images.
 - ❖ have relatively less magnification and resolution capacity.
 - ❖ can be used in the **laboratory** or in **fields**.
 - The magnification capacity of **light (optical)** microscope is 2000 times while the maximum magnification of electron microscope is 2,000,000 times.
 - **Resolution** is the ability to distinguish between two points that are close together.
 - Based on the number of lenses used for observation, optical microscopes are grouped as **simple** and **compound** microscopes.
1. **Simple microscopes**—have magnifying glasses with **only one lens**
 2. **Compound microscope**---This is a microscope in which the magnifying powers of **two convex lenses** called the **eye piece** (ocular) and the **objective lens**.
 - ❖ Since the compound microscope uses light rays coming from a certain source (open light or an electric bulb), it is known as a **light microscope** (fig. 1.17 page 19).
 - ❖ The light microscope is mostly used to investigate **internal** structure of objects.

Electron microscopes: use beams electrons to produce magnified images.

There are two major types of electron microscopes;

1. Transmission electron microscope
2. Scanning electron microscope

Transmission electron microscopes:

- ❖ They make it possible to explore cell structures and large protein molecules.
- ❖ But because of beams of electrons can only pass through thin samples, cells and tissues must be cut into ultrathin slices before they can be examined.
- ❖ This is the reason that such images often appear flat and two dimensional.
- ❖ **Transmission electron microscope (TEM)** ---can magnify image of objects to 1,000,000 times.
- ❖ Transmission electron microscope, so called because electrons used to visualize the specimens are transmitted through the material, are capable of resolving objects only **0.2 nanometer apart** —just twice the diameter of a hydrogen atom!
- ❖ **The limitation of TEM** is that they **cannot** be used to view living specimen.

In scanning electron microscopes:

- ❖ A pencil-like beam of electrons is scanned over a **surface** of a specimen.
- ❖ Beams of electrons onto the surface of the specimen from a fine probe that passes rapidly back and forth.
- ❖ The electrons reflected back from the surface of the specimen, together with other electrons that the specimen itself emits as a result of the bombardment, are amplified and transmitted to a television screen, where the image can be viewed and photographed.
- ❖ Scanning microscopy yields striking three-dimensional images and has improved our understanding of many biological and physical phenomena.
- ❖ Because the image is formed at the specimen's surface, samples do not have to be cut into thin slices to be seen.
- ❖ The scanning electron microscope produces stunning (amazing) three-dimensional images of the specimen's surface.

A **micrograph** is a photo of an object seen through a microscope.

The colors in **light micrographs** come from the cells themselves, or from the stains and dyes used to highlight them.

Electron micrographs, however, are actually **black** and **white**.

Electrons, unlike light, don't come in colors. So scientists often use computers techniques to add “**false color**” to make certain structures stand out.

Table 1:1 **The difference between TEM and SEM**

TEM	SEM
Image is focused onto a fluorescent screen	Image is viewed on a type of “television” screen
Electron beams pass through the specimen and then falls on a photographic plates or a fluorescent screen	The specimen is coated within gold film.
Shows the fine detail of cell structure	Views only the surface of an object

There are two basic types of electron microscopes:

1. **Transmission electron microscope (TEM)**
2. **Scanning electron microscope (SEM)**
- 3.

1. **Transmission EM:**

--transmits a beam of electrons through a very thinly sliced specimen.

--Magnetic lenses enlarge the image and focus it on a screen or photographic plate.

2. Scanning electron microscope (SEM)—provides striking three dimensional images. In this microscope specimen are **not sliced** for viewing, rather, the surface of the specimen is sprayed with a **fine metal coating**.
3. A beam of electrons is passed over the specimen's surface. This causes the metal coating to emit a shower of electrons.
4. These electrons are projected onto a fluorescent screen or photographic plate, producing an image of the surface of the object.
5. Scanning electron microscopes can magnify objects up to 100,000 times and like the TEM, they cannot be used to view living specimens.

Centrifuges--- are used to separate solids from liquids where simple filtration is not adequate for the task.

Ultracentrifuge—is used to spin the tubes at faster speed to separate extremely light particles into the **bottom of the tube**. Thus, it is used to separate plant and animal cells.

What do biologists use in the field?

- For studying an ecosystem a biologist need to go out of the laboratories and study an interaction between organisms and their environment.
- To perform the above activities a biologist is required to:
 - ✓ Take measurements in relation to abundance or distribution of organisms.
 - ✓ Take samples from the environment (soil, water, rock, etc.) to be analyzed in the laboratories.
 - ✓ To collect specimens

- ✓ Identify and analyze the collected specimen.
- ❖ In measuring the abundance or distribution of organisms in an environment biologists are required to use:
 1. **Quadrat**---is a sample area enclosed with frame, usually square within which a plant community or sometimes animal community is analyzed.
 - ♥ It is placed randomly on the ground in order to count organisms.
 - ♥ The number and type of organisms in each quadrat is recorded.
 - ♥ Finally, the abundance of the organisms is estimated based on the recordings from the sample quadrats.
 - ♥ If we have 5 quadrats in which each quadrat has an area of 1m^2 ($1\text{m} \times 1\text{m}$) over an area of 5cm^2 , calculate the total estimate of a given species of a plant, if the number of individuals in each quadrat is as follows.
 - ♥ quadrat 1 == 4
 - ♥ quadrat 2 == 5
 - ♥ quadrat 3 == 3
 - ♥ quadrat 4 == 6
 - ♥ quadrat 5 == 4
 2. **Transect line**---is a line that shows the type and change in distribution of vegetation which exists on a line across a habitat
 - Record the types of plants which touch the rope (transect line) at certain intervals.
 - For example, we can record the type of plants that touch the rope every 1 meter.

Collecting and preserving specimen

- ❖ **Collecting plant specimen**---plants can be easily collected if they are smaller in size and parts of a plant (leaf, flower) can also be collected.
- ❖ **Preserving plant specimen** ---can be preserved temporarily in plastic bags or plastic jars.
 - Their parts can also be preserved in a plant press
- ❖ **Plant press**---is made up of newspapers to separate individual specimen and cupboards that provides support in order to preserve the specimen in shape and form.

Collecting animals

- ❑ Collecting animals is relatively difficult because of their locomotory nature
- ❑ Some of the equipment that are used in collecting animals include:
 1. **Pit fall trap**---is a container that sunk into the ground in order to collect insects that crawl on the ground.
 2. **Sweep nets**---are nets with canvas bags that are used to collect insects and other invertebrates from long grasses.
 3. **Funnel**---for collecting insects from the soil
 4. **Potter (aspirator)**---to collect or suck small organisms on tree trunks or leaf.
 5. **Data logger**---for recording information
 6. **Flow meter**---to measure the rate of flow of water
 7. **Field microscope**---to investigate the structure of specimen in the field while they are fresh
 8. **Theodolite**---to measure the height of trees or slopes in the area
 9. **Global positioning system (GPS)** ---is used for recording positions (or area maps) quickly and accurately.

1.3 The relevance and promise of biological science

- ❑ With the advancement in the instrumentation, biological sciences started a rapid progress in the last two centuries.
- ❑ Study of biology now has moved from the level of organism to the level of the molecule.
- ❑ Since the invention of the first simple microscope by Antony Van Leeuwenhoek, the science of biology has undergone considerable achievements.

- ❏ While the invention of a light microscope resulted in the discovery of the cell, the subsequent invention of the electron microscope enabled scientists to investigate the internal structure of cells in a much better way.

Biology and agriculture

- ❖ The world's population is growing at an alarming rate and this poses challenges to governments all over the world.
- ❖ The extra people all need homes, food and all the other services that are provided.
- ❖ Many biologists are addressing the problem of how to produce the extra food.
- ❖ However, they have another problem to consider, which is that global warming may alter the way in which crops grow.
- ❖ Many crops that produce high yields in some countries will not do so if the current trends continue.
- ❖ Scientists are carrying out research into how to produce crop plants to produce crop plants that:
 - will be adapted to the new conditions
 - are capable of producing their crop quickly so that more than one crop can be obtained per year from a field
 - are disease resistant
 - are drought resistant
- ❖ This work involves the **genetic modification** of existing crop plants to give them the new characteristics that will enable them to be productive in the changed environment.

Biology and medicine

Biological science has a huge relationship with medicine.

Some of the relevance of biological knowledge in medicine are:

- ❖ To advice effective methods of contraception
- ❖ To educate people about the need of controlling population growth
- ❖ To give advice on ways of reducing the rate of population growth.

Medical professionals have specialized biological knowledge and expertise. Some of these are:

- ❖ **Medical laboratory technicians**----They test samples required (blood, urine, faeces, etc.) and provide reports for doctors.
- ❖ **Radiographers**----produce X-rays to help on diagnosing a disease.
- ❖ **Drug development researchers (pharmacologists)** -----work in development of new drugs
- ❖ **Neurologist**---studies about the morphology, physiology and pathology of the previous system.

Biology and the environment

- ❏ Biologists are actively involved in monitoring the impact of global warming on the environment.
- ❏ Many of the field work techniques we discussed earlier are used to find out how the abundance and distribution of species in area are changing.
- ❏ These biologists give advice to governments on how best to conserve environments and to, where necessary, introduce new species that will maintain the best balance species within the area.

Biotechnology—is the use of microorganisms to make things that people want.

Biotechnology--- is an exciting area of biological research that is expanding rapidly.

- ❏ Biotechnology is not just new technology
- ❏ Some biotechnological applications have been around for thousands of years.
- ❏ Using yeasts to ferment sugars have been used for centuries in the manufacture of both bread and alcoholic drinks.
- ❏ Biotechnology involves many different aspects of biology. Some of these can be seen fig. 1.30 page 28.

New application of biotechnology

- Cures for genetic diseases
 - Industrial process like production of insulin
 - Genetic modification of plants to meet specific needs
 - Production of antibiotics
 - Cloning, etc.
- ❏ **Genetic engineering**—is a process which involves altering an organism's genotype by inserting another organism's gene into its DNA.
- ❏ It is a new area in modern biotechnological applications

The relevance of biology in Ethiopia

Biology is very relevant in Ethiopia considering the issue of:

- ❖ overpopulation
- ❖ food security
- ❖ environmental well-being
- ❖ health care
- ❖ natural resource conservation
- ❖ biodiversity and others, which the country needs to address.

As citizens of Ethiopia we must have the biological literacy to understand and assist in the:

- ✓ preservation
- ✓ development and
- ✓ proper use of the abundant biological resources which are our heritage
- ♥ We need to systematically combine the wealth of indigenous knowledge with modern science by training an army of able biologists
- ♥ We need to control
 - ✓ land degradation
 - ✓ biodiversity loss
 - ✓ diseases and other problems as well as
 - ✓ to develop the biological and agricultural potential that will contribute positively to transforming our country's economy.

1.4 Biology and HIV/AIDS

AIDS—is a disease that reduces the body's immune functioning.

- ❖ it is an abbreviation which stands for Acquired-Immuno- Deficiency-Syndrome
- ❖ It is caused by the human immune Virus (HIV)
- ❖ Through time it reduces the T-helper cells which help in fighting diseases.
- ❖ When it reduces the immune capacity of the body the body will be easily affected by opportunistic diseases
- ❖ It is a sexually transmitted disease.
- ❖ The routes of HIV transmission includes:
 - ✓ Unprotected sexual contact with an infected person
 - ✓ During blood transfusion
 - ✓ Sharing sharp objects which are infected
 - ✓ From mother to child during pregnancy, birth or 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:

- ❖ Break the transmission pathway—if the disease cannot spread from one person to another, it will eventually disappear.

- ❖ Produce drugs that kill the virus or at least stop it from reproducing.
- ❖ Antibiotics act in this way on bacteria but cannot act on viruses.
- ❖ Produce a vaccine against the virus.
- ❖ If vaccines are used, one of the arms is to build up a “herd immunity” to break the transmission pathway.
- ❖ If enough people in an area are immune, the microorganisms causing the disease cannot easily spread to an uninfected person and so the disease is eliminated.

Importance of biological knowledge in fighting AIDS

- ❑ Biological knowledge is quite important in controlling the spread of HIV/AIDS.
- ❑ Biology helps in fighting HIV/AIDS through:
 - producing vaccines to control the spread of HIV in the body.
 - Devising ways of reducing or stopping the transmission of HIV from an infected person to a healthy person.
 - Making vaccines for HIV with the aim of breaking the transmission path way by making people immune.
 - Creating awareness in the society about the issues related to responsible sexual behavior.
 - Creating consciousness about the ABC rules especially among the young men and women.
A—abstain from sexual contact
B---be faithful to one sexual partner
C---use condoms

The life cycle of HIV

- ❖ **HIV---** is a retrovirus.
- ❖ Retroviruses are viruses that copy their RNA into DNA by an enzyme called **reverse transcriptase**.
- ❖ The DNA enters the host cell chromosome, where it may continue to the direct production of the virus particle.
- ❖ The steps in the life cycle of HIV are
 - Entry phase
 - Viral genetic material is converted to DNA
 - The new DNA enters the host cell DNA
 - The new DNA ‘instructs’ the cell to make more HIV.

Biologist and the battle against HIV

- ❖ Biologists have been working on ways of breaking the life cycle of HIV.
- ❖ Thus, one of the most important contributions is antiretroviral drugs (ARVDs).
- ❖ ARVDs vary in combination and called **Highly Active Retro viral Therapy (HAART)**
- ❖ In other ways biologists are working to produce long lasting vaccines against HIV.
- ❖ However, the nature of the virus to mutate rapidly made their works difficult.

Fighting HIV/AIDS

- ❖ The major control and prevention mechanisms that people should use in fighting HIV/AIDS include:
 - Avoid having more than one sexual partner
 - Avoid sharing sharp objects like needles
 - Circumcision of males reduce HIV transmission
 - Educating people

Review Questions

1. All of the following are characteristics of science EXCEPT
 - A. The conclusions of science are based on evidence
 - B. Science uses tools to aid investigation
 - C. Science is objectivity

- D. Science is superstitution
2. Which of the following is a recently active area of research in biology today (2005 E.C)?
 - A. Taxonomic study
 - C. Ecological research
 - B. Study about the cell theory
 - D. Stem cell research
3. In the scientific method which one of the following is used to test a hypothesis (2003)?
 - A. Observation
 - B. Theory
 - C. Experiment
 - D. Prediction
4. In the scientific method which one of the following is used to test a hypothesis (2004)?
 - A. Testing hypothesis
 - C. Conducting experiments
 - B. Making observations
 - D. Drawing conclusions
5. Which tool of the biologist is suitable for culturing bacteria in the laboratory(2004)?
 - A. Test tubes
 - B. Petridish
 - C. Microscope
 - D. Beakers
6. Which of the following laboratory equipment is used to separate the organelles of the cell according to their density (2004)?
 - A. Incubator
 - B. Centrifuge
 - C. Measuring cylinder
 - D. Filter paper with fine pores
7. Which of the following is NOT in agreement with the scientific method (2004)?
 - A. Putting forward testable hypothesis
 - C. Putting forward personal value judgment
 - B. Carrying out experiments in duplicates
 - D. Analyzing results and drawing conclusions
8. Which of the following steps in the scientific method comes following observation (2005)?
 - A. Prediction
 - B. Hypothesis
 - C. Experiment
 - D. Theory
9. In the scientific method, which one of the following is used to test hypothesis?
 - A. Theory
 - B. Prediction
 - C. Experiment
 - D. Observation
10. What is a theory in biology (2005)?
 - A. Hypothesis supported by experiments and/ or observation
 - B. A proof that shows the hypothesis is true
 - C. The outcome of the hypothesis is true
 - D. An opinion or educated guess resulting from observation
11. If after dividing plant materials into two groups, an experimenter has applied a fertilizer to group A plants and not to group B plants. What are group B plants (2003)?
 - A. Control group
 - B. Experimental group
 - C. Test group
 - D. Variable group
12. Who coined the term biology for the first time?
 - A. Robert Hooke
 - C. C. Jean Baptiste de Lamarck
 - B. Rudolf Virchow
 - D. Unknown
13. A field biologist who studies the behavior of primates in the forest is most likely expected to frequently use which method data collection (2003 E.C.)
 - A. Experiment
 - C. Comparative biochemistry
 - B. Animal dissection
 - D. Observation
14. Which of the following is based on sufficient supporting data (2003 E.C.)?
 - A. Experimentation
 - C. Theory
 - B. Prediction
 - D. Hypothesis
15. A biologist applied the scientific method repeatedly, gathered a large amount of supporting experimental data and finally described a pattern or relationship between different factors. What is the best term that refers to facts established in this way (2004 E.C.)?
 - A. Theory
 - B. Hypothesis
 - C. Prediction
 - D. Law
16. Data that are quantitative are always
 - A. Described in words
 - C. Represented by numbers
 - B. Recorded on a tape recorder
 - D. Seen through a microscope
17. In an experiment that is testing the effect of temperature on the germination rate of certain seeds, in which one of the following should the experimental and the control groups differ (2004)?
 - A. The amount of water they receive
 - C. The age of the seeds assigned to them
 - B. The number of the seeds assigned to them
 - D. The temperature at which they are kept
18. In an experiment assigned to test the effect of different concentrations of a fertilizer on the growth rate of a plant, which one of the following is the dependent variable (2004)?
 - A. The growth rate of the plant
 - B. Plants assigned to the control group
 - C. Concentrations of the fertilizer applied
 - D. Plants assigned to the experimental group
19. Which of the following field equipment is used to determine an exact location of a plant (2005)?
 - A. Theodolite
 - C. Global positioning system
 - B. Compass
 - D. Altimeter

- B. Field pH kit D. Field microscope
20. What is the specialist in biology called if he/she studies fossils (2005 E.C.)?
A. Geneticist C. Paleontologist
B. Ecologist D. Comparative biochemist
21. Which of the following are all the tools mainly used in the laboratory rather than in field situation (2007 E.C.)?
A. Centrifuges, microscopes, measuring cylinders, petri-dish
B. Flow meter, centrifuges, theodolites, microscopes
C. Centrifuges, plant presses, flow meters, microscopes
D. Theodolites, petri-dishes, GPS receiver, measuring cylinders
22. For which of the following is the theodolite used in biology education (2005 E.C.)?
A. Measuring the height of trees
B. Recording position where the species is found
C. Measuring the rate of the flow of water in a cell
D. Measuring the pH of the water or soil
23. Which unit is the best to use for measuring the smallest cells and organelles (2005 E.C.)?
A. Micrometer B. Milliliter C. Millimeter D. Nanometer
24. In one of his experiments on micro-organisms, Fleming Found green fuzzy spots forming clear area on the plate that was free of microorganisms. This is a good example of
A. Interpretation B. Observation C. Reasoning D. Hypothesis formation
25. Which of the following best defines modern biology (2003 E.C.)?
A. The study of animals C. The biology of plants and animals
B. The study of all living things D. The biology of the transfer of energy
26. What does an ornithologist study (2003 E.C.)?
A. The study of mammals C. The biology of frogs and reptiles
B. The biology of fishes D. The biology of birds
27. While conducting research, which of the following should a biologist do first (2006 E.C.)?
A. Generate hypothesis C. Communicate the results
B. Conducts experiments D. Identify a research question/ problem
28. In scientific method, what is the importance of a background research for a given problem (2007 E.C.)?
A. To formulate a hypothesis C. To make a prediction
B. To prepare report of the result D. To make a conclusion
29. Which of the following is formulated as a possible outcome of an experiment (2007 E.C.)?
A. Hypothesis B. Data analysis C. Prediction D. Recording the data
30. Which of the following is consistent with science (2007 E.C.)?
A. Proof by investigation of the causes of a phenomenon
B. Proof by reference to a respected leader
C. Proof by reference to an unknown object
D. Proof by based on lessons from a person one believes
31. If a hypothesis is not supported a scientist should
A. Give up C. Form a new hypothesis
B. Change the data D. Change the results
32. Suppose in an experiment conducted to test a new drug, 20 people were given the drug and 20 people a placebo, what is the control of the experiment (2006 E.C.)?
A. People who received the placebo C. The new drug itself
B. People who received the new drug D. The new drug and the placebo
33. Which of the following step of the scientific method comes before all the rest (2007 E.C.)?
A. Hypothesis C. Conclusion
B. Experiment D. Reporting the result
34. What do we call a scientist who specializes in studying insects (2007 E.C.)?
A. An ecologist B. A paleontologist C. An entomologist D. A microbiologist
35. A hypothesis is a statement that
A. is always true B. is identical to the theory C. is usually true D. can be tested
36. Choose the steps that comes at the last step in the scientific method
A. Proposing the research hypothesis C. Formulation of a scientific theory
B. Conducting experiments D. Making predictions

37. Which tool of the biologist is more suitable for culturing bacteria (2004 E.C.)?
A. Test tubes B. Petridish C. Microscopes D. Beaker
38. To test the effect of a certain vitamin on dogs, which group gets the vitamins?
A. Experimental B. Neither C. Both D. Control
39. Which tool of the biologist is more frequently used to study cell structures in the laboratory (2007E.C.)?
A. Dissecting kit B. Centrifuge C. Petri-dish D. Microscope
40. Which one of the following parts of the cell can one easily see with the light microscope?
A. Lysosomes B. Nucleus C. Mitochondria D. Golgi apparatus
41. Which of the following units of measurement is more convenient to express the size of cellular organelles (2007 E.C.)?
A. Meter B. Centimeter C. Millimeter D. Micrometer
42. For what purpose do biologists use the GPS receiver (2007 E.C.)?
A. To produce area maps C. To estimate tree ages
B. To measure tree heights D. To count tree rings
43. Which of the following types of microscopes is most suitable for a detailed study of the surface structure of an object (2007E.C.)?
A. Field microscope C. Optical microscope
B. Scanning electron microscope D. Dissecting microscope
44. What is the ultimate source of all scientific knowledge (2007 E.C.)?
A. Observation B. Guessing C. Trial and error D. Observation and experimentation
45. Which of the following corresponds to the beginning steps of scientific work (2004 E.C.)?
A. Testing hypothesis C. Conducting experiments
B. Making observations D. Drawing conclusions
46. In which of the following are all the tools mainly used in the laboratory rather than in the field situation (2007 E. C.)?
A. Centrifuges, microscopes, measuring cylinders, petri dishes
B. Centrifuges, plant presses, flow meters, microscopes
C. Centrifuges, plant presses, flow meters, microscopes
D. Theodolites, petri-dishes, GPS receivers, measuring cylinders
47. Which of the following events happened before all the others (2007 E.C.)?
A. The cell theory was proposed C. The protozoa were discovered
B. The compound microscope was invented D. The structure of DNA was discovered
48. What do you call the reasoning technique in science where general principles are used to analyze specific cases (2007 E.C.)?
A. Induction B. Pseudo-deduction C. Deduction D. Pseudo-induction
49. Which of the following statements is in agreement with the modern cell theory (2004 E.C.)?
A. Cells come from nothing C. Cells come from non-living material
B. Cells come from existing cells D. Cells arise by means of spontaneous generation
50. To which major area of relevance and applications of biology is the production of transgenic organisms related (2004 E.C.)?
A. Agriculture B. Environment C. Biotechnology D. Medicine
51. Which of the following laboratory glassware is used for culturing bacteria (2007 E.C.)?
A. Petri-dish B. Test tube C. Filter paper D. Measuring cylinder
52. The word science comes from the Latin word 'Scientia' means what (2009 E.C.)?
A. Study B. Life C. Experiment D. Knowledge
53. Which of the following laboratory tools is LEAST accurate to measure 1 ml of liquid (2009 E.C.)?
A. Pipette B. Burette C. Measuring cylinder D. Beaker
54. In a report of scientific experiment, description of which of the following comes before all the others (2009 E.C.)?
A. Procedure B. Results C. Hypothesis D. Conclusion
55. Which of the following has the highest risk of HIV transmission (2009 E.C.)?
A. Hand shaking C. Towel sharing
B. Needle sharing D. Toilet sharing
56. Which of the following human cell types is attacked by HIV(2009 E.C.)?
A. Red blood cells C. T-lymphocytes
B. White blood cells D. Leukocytes

57. From among the following, choose the field which is a branch or a part of biotechnology (2009 E.C.)?
A. Parasitology C. Phycology
B. Immunology D. Genetic engineering
58. Who was the person that first observed living cells moving around when he examined drops of water under the microscope (2008 E.C.)?
A. Robert Brown C. Anton Van Leeuwenhoek
B. Robert Hooke D. Theodor Schwann
59. Which of the following types of microscope is the best to show the details of the surface of an object (2003 E.C.)?
A. Optical microscope C. Compound microscope
B. Scanning electron microscope D. Transmission electron microscope
60. A cell was examined under a compound light microscope with an eye piece lens marked 13x and an objective lens marked 40x. How many times larger would the cell appear to the viewer (2004 E.C.)?
A. 40x B. 53x C. 400x D. 520x
61. Which of the following is true about the antiretroviral drugs currently used to treat AIDS patients (2004 E.C.)? A. They cure AIDS C. They serve as anti-HIV vaccines
 B. They stop HIV transmission D. They slow down HIV multiplication
62. Which one of the following cellular forms did Robert Hooke observe under his crude microscope (2006 E.C.)?
A. Bacteria B. . Protozoa C. Yeast D. Empty cell wall
63. Which one of the following is true in relation to scanning electron microscope?
A. Shows fine details of cell structure C. Image is focused on a television screen
B. Image is focused onto a fluorescent screen D. It has less magnification and resolution power
64. Which of the following is true about those bacteria which dwell in hot springs (2003)?
A. They are not metabolically active
B. They use non-protein enzyme
C. They get energy of activation from the spring heat
D. Their enzymes do not denature at that temperature
65. What is the term used to express the ability of a microscope to show details clearly (2003 E.C.)?
A. Enlargement B. Reduction C. Magnification D. Resolution
66. Which of the following is a worthwhile biological problem for scientific investigation (2008 E.C.)
A. Estimation of the amount of carbon in a forest system
B. How a crying dog can tell who among elders of the village is going to die next
C. How witchcrafts inflict bad health by cursing a healthy person
D. How the traditional medicine men/women cure a possessed person

UNIT TWO

Biochemical molecules

Classification of biochemical molecules

Biochemical molecules can be classified into **two categories**:

1. Inorganic molecules
2. Organic molecules

2.1 Inorganic molecules

- ❖ Organic molecules always contain both carbon and hydrogen. Inorganic molecules may contain one or the other (or neither) but **not both**.

Table 2.1 Examples of inorganic and organic molecules

Some inorganic molecules	Some organic molecules
Calcium carbonate (CaCO_3)	Glucose ($\text{C}_6\text{H}_{12}\text{O}_6$)
Carbon dioxide	Glycine (amino acid) ($\text{C}_2\text{H}_5\text{NO}_2$)
Water	Lionic acid (a fatty acid) $\text{C}_{18}\text{H}_{32}\text{O}_2$
Iron III oxide (Fe_3O_4)	Methane (CH_4)

Atoms, molecules, ions and chemical bonds

- ❖ **Atoms**—are the smallest particles of chemical elements.
- ❖ They are minute particles and cannot be seen.
- ❖ Atoms are composed of three basic particles: **protons, electrons** and **neutrons**.
 - **Protons**—are positively charged particles that are found in the nucleus.
 - **Neutrons**—are also found in the nucleus but they have no electrical charge.
 - **Electrons**—are negatively charged particles that are dispersed around the nucleus in layers or orbits.
- ❖ **Elements**—are substances that compose all living and non-living things.
- ❖ Some of the elements that have specified role in our body are **calcium, iron, iodine** and **fluorine**.
- ❖ **Molecules**— are groups of two or more atoms held together by chemical bonds. One of the important biological molecules is **water**.
- ❖ **Atoms** of elements can join together to form molecules.
- ❖ We call this forming a **chemical bond**.
- ❖ Sometimes two atoms of the same element join together to form a molecule of that element (eg. O_2).
- ❖ Atoms of one element can join with atoms of another element to make a molecule of a **compound**.
- ❖ The atoms are 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**. See table 2.2 below.

Table 2.2 The number of bonds (valencies) of atoms of the elements most commonly used to build biological molecules.

Element	Number of bonds formed (Valency)
Carbon (C)	4
Hydrogen (H)	1

Oxygen (O)	2
Nitrogen (N)	3
Sulphur (S)	2 (Sometimes 4 or 6)
Phosphorus (P)	5

- ❑ So, whilst a carbon atom can bond with four hydrogen atoms, each hydrogen atom can only bond with one carbon.
- ❑ Because carbon can bond with four other atoms, it can make large molecules with chains of carbon atoms.
- ❑ These are the organic molecules that are the basis of life. See fig. 2.2 and 2.3 page 45.

Water

- ❑ Water is the **most abundant** inorganic molecule in living things.
- ❑ It covers three-quarters of the planet and on the remaining one-quarter, which is land water, is often not very far away.
- ❑ It may be in streams, rivers, ponds, lakes or in huge underground aquifers.
- ❑ And, of course, it is all living things.
- ❑ Most cells are about 70% water and some are as high as 90%.
- ❑ **Water** is formed when two hydrogen atoms combine with an oxygen atom by sharing electrons.
- ❑ The result is a **stable** molecule and relatively **unreactive**.
- ❑ The shape of the water molecule is triangular rather than linear, it is bent into a 'V' shape
- ❑ It is the only substance that exists in three states—solid, liquid and gas—at temperatures commonly found on Earth.
- ❑ Solid water ice, gaseous water is steam and liquid water is what we normally call water.
- ❖ Also, the molecule forms what we call a **dipole**.
- ❖ Part of the molecule has a slight negative charge and other parts have a slight positive charge.
- ❖ Thus, there is a net **negative** charge (on the oxygen atom) and a **positive** charge on the hydrogen atom.
- ❖ A molecule that carries an unequal distribution of electrical charge is a **polar molecule**.
- ❖ Water molecules form relatively weak bonds called **hydrogen bonds** with other molecules nearby.
- ❖ The hydrogen bonds in water keep **breaking** and **reforming** as the water molecules move around, but there is always some bonding between the molecules in a mass of water.
- ❖ The attractive force between water molecules is known as **cohesion**.
- ❖ This cohesive property keeps water molecules to stay interlinked.

Characteristics and importance of water

1. **It serves as a habitat** or a place to live for many organisms
2. **It is a transport medium.** Thus, water plays a vital role in transporting important substances in the body of organisms.
3. **It is transparent**---this property of water allows light to pass deep into the water bodies in order to assist the photosynthetic process which is carried by aquatic plants and algae.
4. **It serves as a reactant in many chemical reactions.** For example, in hydrolysis processes such as digestion.
5. **It serves as a place for other reactions to take place.**

The most commonly known characteristics of water are

1. **Water has a high specific heat of capacity**
 - ❖ This means that it takes quite a lot of energy to heat water up.
 - ❖ Water also loses heat quite slowly.
 - ❖ This is the overall effect of water stays more or less the same temperature –particularly large masses of water, such as ocean and lakes.
 - ❖ This is important as the functioning of enzymes in living cells is affected by temperature.
 - ❖ When too hot or too cold the enzymes do not function efficiently and the reaction in the cells controlled by enzymes is not carried out efficiently.
2. **Ice is less dense than liquid water**

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

3. **Water has a high latent heat of vaporization**

- This means that it takes a lot of energy to turn liquid water into water vapour (or steam).
- In turn this means that water does not vaporize too easily and that ponds do not dry up too quickly in hot weather—and the organisms in the pond have a better chance of survival.
- This property is also 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 would not be as effective in controlling our body temperature.

4. **Water has a high surface tension**

- The water molecules in the main body of a mass of water are hydrogen-bonded to other water molecules on all sides.
- But at the surface, there is no hydrogen 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 why others can attach themselves to the surface of the water and live just below the surface. (See fig. 2.10 page 48).

5. **Water is a good solvent for many substances**

- ✚ Many organic and inorganic substances important to life dissolve in water, but do not dissolve either at all or as well in other liquids.
- ✚ Water is very versatile (ሁለቱን). Because these substances dissolve in water, they can be transported in water-based transport medium.
- ✚ Biological mechanisms such as active transport, diffusion and facilitated diffusion move the substances into and out of the water (in the transport medium)
- ✚ In mammals, the plasma of blood is 90% water.
- ✚ This is forced through the system of veins, arteries and capillaries by the heart.
- ✚ In plants water carries dissolved minerals upwards from the roots to other parts of the plant in the xylem vessels.
- ✚ Water in the phloem tubes carries dissolved organic substances all over the plant.

6. **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 were more viscous (less fluid) than it is –think of tar! – Then the heart would **not** be able to move it through the blood vessels.
- ❖ Also, the water inside cells transports substances around the cell; 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, inside cells; the organelles would not be supported.
- ❖ Similarly, in the circulatory system, a less viscous liquid would not move the blood cells around the system as efficiently.

7. **Water as a reactant**

- ✚ Many reactions in living things need water as a raw material.
- ✚ **Photosynthesis**---- the process which begins the process of energy transfer between living things—requires water as one of its reactants.
- ✚ No water, no photosynthesis.
- ✚ Water is also involved in digesting large food molecules into smaller ones.
- ✚ Reactions that use water to split large molecules are called **hydrolysis** reactions.
- ✚ Water molecules are used to split large food molecules into smaller ones that can be absorbed into the blood stream.

- Water is also involved in other reactions. For example, it is involved in reactions with carbon dioxide in red blood cells that are important in the transport of carbon dioxide around the body as hydrogen carbonate ion.

8. Water as a medium for chemical reactions

- ❖ Cells function because of the many chemical reactions that are continually taking place in them.
- ❖ Many of these take place on the membrane systems of the cell, but others take place in the liquid 'cytosol' of the cytoplasm.
- ❖ Also, many of the reactions of photosynthesis and respiration take place in the liquid inner regions 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 low viscosity—the particles can move around and come easily into contact with each other.

❑ So, we can see that, without water life as we know it could not possibly exist. Water is just too important.

2.2 Organic molecules

- ❖ Different organic molecules contain different combinations of carbon and hydrogen.
- ❖ They may also contain other chemical elements
- ❖ Most biological organic molecules contain **oxygen** in addition to carbon and hydrogen and some also contain **nitrogen**.
- ❖ Carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus are used to build nearly all biological molecules.
- ❖ Organic molecules are molecules that contain skeletons of covalently bonded carbon atoms.
- ❖ They necessarily contain atoms of carbon and hydrogen.
- ❖ These molecules are known as **organic molecules**, because once it was believed that they were thought to be produced by living things.
- ❖ Organic molecules are **relatively large** and **complex** as they are compared to inorganic molecules.
- ❖ Biologically important groups of organic molecules are:
 1. Carbohydrate
 2. Lipids (Fats and oils)
 3. Proteins and
 4. Nucleic acids (RNA and DNA)

1. Carbohydrates-----organic molecules that contain carbon, hydrogen and oxygen.

- ❖ Their hydrogen and oxygen ratio is **two** hydrogen atoms to **one** oxygen atom (for example, **glucose**, $C_6H_{12}O_6$).
- ❖ The general formula of carbohydrate is **$(CH_2O)_n$** —For $n \geq 3$
- ❖ They range from very small molecules containing only 12 atoms, to very large molecules containing thousands of atoms.
- ❖ Carbohydrates have a range of functions:
 - ♥ Used to release energy in respiration—glucose is the main respiratory substrate of most organisms
 - ♥ Are convenient form to store energy (starch in plants and glycogen in animals)
 - ♥ Some carbohydrates are used to build structures;
 - Structural carbohydrates include;
 - Cellulose**-----constituent of plant cell wall
 - Chitin** -----occurs in cell walls of fungi and in the exoskeleton of insects
 - Peptidoglycan**—occur in bacterial cell wall

Carbohydrate are classified into three based on the number of sugar molecules present

1. Monosaccharides
2. Disaccharides
3. Polysaccharides

Monosaccharides —are simplest and soluble form of carbohydrates.

- ❖ They contain one sugar units.
- ❖ Monosaccharides are classified according to **how many carbon** atoms are present in the molecule.
- 1. Triose (3C) —Glyceraldehyde and dihydroxyacetone
- 2. Pentoses (5C) ---Ribose and deoxyribose are the most common.
- 3. Hexoses(6C) ---glucose, fructose and Galactose

Trioses

1. **Trioses** are monosaccharides with **3** carbon atoms ($C_3H_6O_3$).
 2. **Glycerate phosphate** is a triose, important in photosynthesis
 3. The **two** naturally occurring trioses are **glyceraldehyde** and **dihydroxyacetone**
- ❖ Both these sugars are found in plant and animal cells.
 - ❖ They play important part in carbohydrate metabolism.
 - ❖ They occur combined with a phosphate group as in glyceraldehyde -3-phosphate.

Pentose: A **pentose** monosaccharide has **five** carbon atoms ($C_5H_{10}O_5$)

Pentoses that commonly occur in nature are **ribose and deoxyribose**.

- ❑ Both occur in the furanose ring form (the ring structure contains **four** carbon atoms and **one oxygen** atom)
 - ❖ **Ribose** occurs in RNA, coenzymes and ATP molecules and
 - ❖ **Deoxyribose** occurs in DNA molecule.
- ❑ **Hexose** monosaccharides have **six** carbon atoms ($C_6H_{12}O_6$).
- ❑ They include glucose, galactose and fructose which are all **isomers** of each other.
- ❑ The relative disposition of the –H and –OH groups along the carbon chain in hexose is significant.
- ❑ Only three occur commonly in nature: These are glucose, mannose and galactose.
- ❑ **Fructose** is the only ketohexose to occur in nature.
- ❑ There are different trioses, pentoses and hexoses.
- ❑ Compounds that have the same chemical formula but which differ in the arrangement of atoms are known as **isomers**.

Monosaccharides can be classified according to the functional group that they possess: These are:

1. The **aldehyde group**, with the formula **CHO** (monosaccharides with this group are called **aldoses**) and
2. The **ketone group**, with the formula **C=O** (monosaccharides with this formula are called **ketoses**).
The main significance of this difference is the ability to polymerize.

Nearly **all the polysaccharides** found in living things are polymers of **aldose** monosaccharides.

See fig. 2.16 and 2.17 pages 53 and 54.

- ❖ Monosaccharides appear in linear (straight) and ring form.
- ❖ The straight structure of monosaccharides appears in rings when they are in **solution**.
- ❖ **Glucose** can be written as a **straight** chain structure, but it also exists in a **ring or cyclic** form.
- ❖ The straight form of glucose produces **two** ring forms. namely, **α- glucose** and **β-glucose**.
- ❖ There is only one difference between these two: This is the position of –H and –OH on carbon number 1.
See fig.2.17 pp. 54.
- ❖ The straight chain form of fructose produces **only one ring** form.
- ❖ In these structures the carbon atoms in the molecule are numbered according to their position in the molecule.
- ❖ The ring structure of glucose contains **five carbon** atoms and one oxygen atom--a **pyranose ring**.
- ❖ The ring structure in **fructose** contains **four carbon** atoms and **one** oxygen atom ---a **furanose ring**, but fructose may also occur in pyranose form.
- ❖ **Glucose** ($C_6H_{12}O_6$) --- is the most abundant monosaccharide which is extremely important in life processes.
- ❖ It is synthesized in the process of photosynthesis by plants and algae.

- ❖ Glucose is used mainly as a raw material for the main cellular fuels used in the process of cellular respiration.
- ❖ The main significance of this difference is the ability to polymerize.

Figures 2.16, 2.17, 2.18, 2.19, 2.20, 2.21, 2.22, 2.23, 2.24, 2.25, and 2.26 page 53-58 show different structures of carbohydrate

Disaccharides are made by two monosaccharide molecules

1. Maltose == made from two α -glucose molecules.
 2. Sucrose == α -glucose + fructose molecules
 3. Lactose (milk sugar) == β -glucose + α -Galactose
 $C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$
- ❖ A molecule of water is formed from a hydroxyl group from one monosaccharide and hydrogen atom from the other (fig. 2.21 p55)
 - ❖ This allows the bond to be formed between the monosaccharide units to make a disaccharide.
Condensation –is the process by which two molecules combine to form a large molecule.
 - ❖ Producing a smaller molecule (often water) as a by-product.
The bond that holds the two monosaccharide units together is called a **glycosidic bond**.
 - ❖ Glycosidic bond is formed between carbon atom 1 of one α -glucose molecule and carbon atom 4 of the other α -glucose molecule.
 - ❖ The full name of the bond is, therefore, an **α -1, 4-glycosidic bond**.
 - ❖ The reverse process of condensation is **hydrolysis** (of the disaccharide)
 - ❖ This involves “putting back” the water that was removed during condensation and splitting the molecule into its components, smaller molecules.

Polysaccharides—are complex and stable carbohydrates.

They are composed of repeating units of simple sugars, usually **glucose**.

The monomer units (sugars) that make a polymer (complex sugars) are joined by condensation reaction.

Starch is a polymer of α - glucose.

Some polysaccharides are **storage molecules**. Others are **structural carbohydrates**. As the name suggests, structural carbohydrates are used to **build structures**—like plant cell walls and insect exoskeletons.

Starch and glycogen are storage polysaccharides and **cellulose** is structural polysaccharide

Some biologically important polysaccharides are:

1. Starch
2. Glycogen
3. Cellulose

Starch—is the storage form of carbohydrate in plants.

- ☞ Starch molecule occurs in two forms, namely **amylose** and **amylopectin**.
- ☞ Both are polymers of α -glucose, but the arrangement of the α -glucose monomers in these compounds is different.

Amylose—is a linear molecule containing many hundreds of the α -glucose molecules joined by α -1, 4-glycosidic bonds.

- ❖ It winds into helix when in contact with water which allows the reaction between starch and iodine solution. 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 with the iodine test, **because only the amylose reacts with iodine**.

Amylopectin—also has a linear back bone of α - glucose molecules joined by α -1,4-glycosidic bonds.

- ❖ But in amylopectin, there are also **side branches**.
- ❖ The side branches occur at certain points along the chain when a glucose molecule forms an α -1,6-glycosidic bond with another glucose molecules well as the usual α -1, 4-glycosidic bond.
- ❖ This results in amylopectin having a branching structure as shown in fig. 2.25 page 57.
- ❖ The branched nature of amylopectin means that there are **many 'ends'** to the molecule.
- ❖ This allows it to be quickly hydrolyzed by enzymes acting at the ends of the chains to release glucose for respiration.

How the structure of starch is suited to its function?

- ❖ Both amylose and amylopectin are compact molecules, so many α -glucose molecules can be stored in a small space, without affecting cell metabolism.
- ❖ Both amylose and amylopectin are insoluble. If soluble molecule were stored (instead of first being converted to starch), it would draw water, by osmosis, from neighboring cells and from organelles within the cell. Insoluble starch produces none of these effects.
- ❖ In addition, because amylose and amylopectin are insoluble, the molecules cannot move out of cells—they remain in storage organs.
- ❖ The branched nature of amylopectin means that there are many ends to the molecule. Therefore, starch can be quickly hydrolyzed (by enzymes acting at the ends of the chains) to release glucose for respiration.

Glycogen—is a storage carbohydrate in animal cells.

- ❑ It has similar structure to that of amylopectin — but there are more α -1, 6 links, making it much 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.

Cellulose—is a polymer of β -glucose joined by beta-1, 4-glycosidic bonds, formed by condensation reactions.

- ❑ However, because of the different position of H and OH groups on carbon atom 1 compared to α -glucose, every other glucose unit in the chain upside down, as shown in figure 2.26.
- ❑ Also the chain is unbranched.
- ❑ Many cellulose molecules lie side by side and hydrogen-bond to each other.
- ❑ This results in the formation of cellulose microfibrils bond together to form bigger fibers or fibrils, which make up the structure of cell walls. This is shown in fig. 2.27 page 58.

How the structure of cellulose is suited to its function?

- ❑ The cellulose molecule is unbranched. This allows hydrogen-bonding and the formation of microfibrils.
- ❑ If it were branched, microfibrils could not form. It is the fibrous nature of cellulose that gives the cell walls their strength, but also gives them some flexibility in a particular way.

Aldoses—are monosaccharides with an aldehyde group in the molecule.

Ketoses—are monosaccharides with a ketone group in the molecule.

Condensation ---is the process in which two molecules combine to form a larger molecule, producing smaller molecule (often water) as a bi-product.

Some compounds closely related to polysaccharides are:

- ❖ **Chitin** -- is a polymer similar to cellulose, but each beta-glucose molecule has a nitrogen-containing group attached to the ring.

It occurs in some fungi, in the exoskeleton of insects, arthropods and mollusks

- ❖ **Murein** -- is a polysaccharide that acts as the strengthening material of bacterial cell walls. It is similar in structure to chitin.
- ❖ **Glycolipids** — association of carbohydrates and lipids.
The carbohydrate form a polar head to the molecule, and glycolipids, like phospholipids, are found in membranes.
- ❖ **Glycoproteins** — consist of polysaccharides bound to a protein molecule. These are compounds found on the outer surface of animal cells.

Polysaccharide — is a carbohydrate whose molecules consist of a number of monosaccharide molecules bonded together.

Glycosidic bond --- is the bond that holds two monosaccharide units together.

Isomers — are molecules with the same chemical composition, but a different arrangement of atoms.

Functional group — is a group of atoms within a molecule that behaves in a particular way.

Aldoses — are monosaccharides with an aldehyde group in the molecule.

Ketoses — are monosaccharides with a ketone group in the molecule.

Condensation --- is the process in which two molecules combine to form a larger molecule, producing smaller molecule (often water) as a bi-product.

Lipids

Like carbohydrates, nearly all lipids contain only the elements carbon, hydrogen and oxygen, but they contain much less oxygen than carbohydrates.

Lipids are varied group of compounds that include:

1. **Triglycerides** = formed from glycerol and three fatty acids
2. **Phospholipids** = formed from glycerol, two fatty acids and a phosphate group
3. **Waxes** = formed from glycerol, two fatty acids and a phosphate group
 - ❑ Whilst some lipids have quite large molecules, they are not polymers and, in many cases, their molecules are relatively small.
 - ❑ The feature that all share is that they are all made from **fatty acids** and **alcohols (glycerol)**.
1. **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).
2. **Phospholipids** == are one of the basic components of all membranes.
3. **Triglycerides**== have several functions including:
 - ♥ **Respiratory substrate**—a molecule a 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 n 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 animal, making it more buoyant.
 - ♥ **Water proofing** – the oils secreted by some animals onto their skin are glycerides.

Triglycerides--- a triglyceride molecule is an ester formed from one molecule glycerol 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)
- ❑ The carboxyl group (the functional group of the fatty acid) is ionic and dissociates in solution to form COO^- and H^+ (hydrogen ion).
- ❑ The hydrogen ions released make the solution **acidic**.

Note



- ❖ Some of the lipids found in the myelin sheath that surrounds nerve cells are **sphingolipids**.
- ❖ **Sphingolipids** -- are unusual lipids as they contain nitrogen as well as carbon, hydrogen and oxygen.
- ❖ **Glycerol** -- is a polyhydroxy alcohol.
- ❖ This means it contains more than one hydroxyl group (OH^+).
- ❖ **Covalently bonded hydro carbon**—is a chain of carbon atoms, covalently bonded to each other and to one, or more hydrogen atoms.
- ❖ **Carboxyl group** — is acid radical $-\text{COOH}$. It releases H^+ into aqueous solution to make the solution acidic.
- ❖ **Saturated fatty acid** — all the carbon bonds in the hydro carbon chain are single bonds.
- ❖ **Monounsaturated fatty acid** — one of the carbon-carbon bonds is a double bond,
- ❖ **Polyunsaturated fatty acid** — more than one carbon-carbon bonds is a double bond,
- ❖ **Ester bond** — is the bond that forms between a carboxyl group and a hydroxyl group.
- ❖ **Polyunsaturated fatty acids** -- help to prevent cholesterol being laid down in the linings of arteries (atherosclerosis) and so help to prevent heart disease.

The nature of hydrocarbon chains in fatty acids can differ in two main ways:

1. The **number of carbon atoms** in the chains can vary.
2. Hydro carbon chains with the **same number** of carbon atoms can have different numbers of **hydrogen atoms**.

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

- I. If all the carbon-carbon bonds in the hydro carbon chain are **single bonds**, the fatty acid is a **saturated fatty acid**.
- II. If **one** of the carbon-carbon bonds is a double bond, then it is a **monounsaturated fatty acid**.
- III. If more than one carbon-carbon bond is a double bond, the fatty acid is a **polyunsaturated fatty acid**.

When triglyceride molecules are formed, **condensation** reactions take place to join three fatty acid molecules to a glycerol molecule.

The bonds formed are called **ester bonds**. These ester bonds can be broken by hydrolysis to give **glycerol** and **fatty acids** once again.

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 phospholipid molecule.
- 1. **Hydrophilic** (water-loving) region--- consists the **phosphate head**
- 2. **Hydrophobic** (water-hating) region---consists hydrocarbon 'tails' (fatty acids).
----See figure 2, 32 and 2.33 page 61.
- ❖ In **water**, phospholipids become organized into a bilayer (hydrophilic and hydrophobic layers sandwiched together).
- ❖ In this configuration, the hydrophilic heads face out wards into the water and the hydrophobic tails face inwards, away from the water.
- ❖ Phospholipid bilayers are the basis of **plasma membranes**.

Proteins

Proteins-- are extremely important substances that are needed to form all living cells.

- ♥ Their molecules contain the elements, carbon, hydrogen, oxygen and nitrogen and most contain sulphur.
- ♥ Protein molecules are polymers of amino acids and so are macro molecules also.
- ♥ But they vary enormously in size; the smallest protein molecules contain **fewer than 100 amino acids**, whilst the largest contain **several thousands**.

Proteins 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 proteins.
- ❏ **The control of metabolism by enzymes**---all enzymes are proteins
- ❏ **The structure of chromosomes** –DNA is wound around molecules of the protein (histone) to form a chromosome.

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

- I. A hydrogen atom
 - II. An amino group ($--NH_2$)
 - III. A carboxyl group ($--COOH$)
 - IV. 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**.
 - ✓ This takes place in much the same way when two monosaccharides join to form a disaccharide.
 - ✓ **H and OH** are lost to create a molecule of water.
 - ✓ The H is lost from the amino group on one amino acid and OH is lost from the carboxyl group on the other amino acid.
 - ✓ Spare bonds are created on each molecule, which then join to form a peptide bond, which holds the two amino acids together. This is shown figure 2.35 page 62.
 - ✓ A dipeptide can be enlarged into a polypeptide by condensation with more amino acid molecules.
 - ✓ Many amino acids joined by peptide bonds form a polypeptide chain; this sequence of amino acids is the primary structure of the protein,
 - ✓ Once formed, the peptide chain folds itself into a secondary structure, which is either an alpha-helix-or a beta-pleated sheet (see fig. 2.36 page 63).
 - ✓ The structures are held in place by hydrogen bonds that form between 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.
 - ✓ **A protein molecule can also have a tertiary structure. This involves** further folding of the secondary structure and the formation of new bonds to hold the tertiary structure in place.

These new bonds include:

1. **More hydrogen bonds** ---between the R-groups of some amino acids
2. **Disulphide bridges**---between amino acids that contain sulphur.
3. **Ionic bonds**----between amino acids with positively charged R-groups and those with negatively charged R-groups. See figure 2.36 page 63.

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

1. 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.
2. 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 protein molecule.
- 3. The **tertiary structure** of a protein is unique and this gives each protein a specific function. For example:
 - ❖ The shape of the active site of an enzyme molecule 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.
- 4. Some proteins have yet another level of organization called the **quaternary structure**
 - In these proteins two, or more, polypeptide chains fold into a tertiary structures folded into a tertiary structure become associated in the final structure of the protein.
 - Two important examples are **haemoglobin** (the oxygen-carrying molecule found in red blood cells) and **collagen** things. (the fibrous protein found in many tissues in mammals). See fig. 2.37 page 64.

Proteins are classified into two main groups, according to their molecular shape:

- I. **Fibrous proteins**—that have a tertiary structure that resembles a long string or fiber (for example, collagen and keratin)
- II. **Globular proteins**---that have a tertiary structure that resembles a globule or ball (for example, enzymes and receptor proteins).

Nucleic Acids

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

1. **DNA** (Deoxyribonucleic Acid). 2. **RNA** (Ribonucleic acid)
 - ❑ DNA is found in chromosomes.
 - ❑ Each gene is a short section of DNA that codes for a specific protein and, as a result, determines a particular feature.
 - ❑ DNA is a genetic material.
2. **RNA** (Ribonucleic Acid).
 - ❖ RNA is found in the nucleus and the cytoplasm.
 - ❖ Different types of RNA are involved in allowing a specific gene (DNA) to produce the protein it codes for.
 - **DNA** was isolated from animal cells and **RNA** from yeast cells.
 - Much later biologists realized that both DNA and RNA are present in all living cells.
 - Both types of nucleic acids are made from structures called nucleotides. All nucleotides have the same basic structures (three components):
 1. A phosphate group
 2. A pentose sugar (deoxyribose in DNA and ribose in RNA nucleotides), and
 3. One of four nitrogenous bases (Adenine, Guanine, Cytosine and Either Thymine in DNA or Uracil in RNA).
 - ❑ DNA is a huge molecule made up of two strands of nucleotides wound into a double helix.
 - ❑ RNA is much smaller and is single stranded. See fig. 2.39 pp. 65.

Table 2.3 The difference between DNA and RNA

Feature	DNA	RNA
Size	Huge —allows the molecule to carry the code for many different proteins in the genes	Much smaller ---needs 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
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Food Test

1. **Test for starch**---use iodine solution to give blue black color
2. **Test for reducing sugars** such as glucose, fructose, maltose, but not sucrose.
☞ Use Benedict's solution or Fehling's solution to give a yellow/ orange/red color shows that a reducing sugar is present
☞ **Sucrose** can be tested after it is changed to monosaccharide (by hydrolyzing it using hydrochloric acid).
3. **Test for protein**—Use Million's reagent or Biuret test to give brick red color
4. **Test for fats**---Emulsion test to give milky suspension (emulsion formation)
5. **Test for oil**---Oil spot test to observe transparent spot on the paper.

Review questions

1. Which of the following is different from the other three (2009 E.C.)?
A. Starch B. Cellulose C. Glycogen D. Maltose
2. Which type of fatty acid is healthier when used as a human food source (2009 E.C.)?
A. Saturated fatty acid C. Polyunsaturated fatty acid
B. Mono unsaturated fatty acid D. D. Fatty acids in animal products
3. How are unsaturated fats distinguished?
A. They are made up of glucose and fructose
B. They have only single bonds at the points of attachment
C. They have double bonds in their carbon atoms
D. They are solid at room temperature
4. When a chemical binds to an enzyme and change the shape of the enzyme so that the enzyme can facilitate catalysis, the chemical is said to be
A. A reverse B. An effector C. an activator D. an inhibitor
5. Which of the following elements is the most abundant in living things (2009 E.C.)?
A. Nitrogen B. Hydrogen C. Carbon D. Oxygen
6. Among the following organic molecules, identify the one that that does not contain nitrogen (2009 E.C.).
A, Starch B. Protein C. DNA D. RNA
7. How many hydrogen and oxygen atoms are there in a disaccharide molecule?
A. 24 and 12 B. 12 and 6 C. 22 and 11 D. 6 and 3
8. Which of the following alternatives contains ONLY organic molecules (2009 E.C.)?
A. Calcium carbonate, glucose, methane C. Linoleic acid, glycine, methane
B. Carbon dioxide, sodium chloride, lysine D. Water, carbon dioxide, calcium carbonate
9. Which statement describes all enzymes ?
A. They control the transport of materials C. They affect the rate of chemical reaction
B. They provide energy for chemical D. They absorb oxygen from the environment
10. Which test is suitable for checking the presence of lipids in food staffs (2009 E.C.)?
A. Biuret test B. Bendict's solution C. Emulsion test D. Iodine test
11. Which of the following properties of water makes sweat an effective body cooler ?
A. Its high specific heat C. Its low density when frozen
B. Its high surface tension D. Its high heat of vaporization
12. Which alternative currently matches the polymer with its monomer (2003 E.C.)?
A. Carbohydrate—amino acid C. Nucleic acid---nucleotide
B. Protein—monosaccharide D. Lipid—fat
13. All the following carbohydrates are polysaccharides EXCEPT which (2003 E.C.)?
A. Glucose B. Cellulose C. Starch D. Glycogen
14. Which of the following carbohydrates is highly branched in its structure?
A. Sucrose B. Glycogen C. Starch D. Glucose

15. Which property of water keeps the bottoms of lakes and the life therein from being frozen during cold winters in the temperate regions (2003E.C.)?
 - A. Its high specific heat capacity
 - B. Its high heat of vaporization
 - C. Its high boiling point
 - D. Its high latent heat of fusion
16. The element magnesium is an integral part of an enzyme and is necessary for its activity. In this situation magnesium is a/an
 - A. Coenzyme
 - B. co-factor
 - C. inhibitor
 - D. prosthetic group
17. Which of the following sugars do babies get from the milk of their mother (2003 E.C.)?
 - A. Maltose
 - B. Lactose
 - C. Sucrose
 - D. Fructose
18. If one mixes a sample of a fruit juice and some drops of Benedict's solution and obtain brick-red precipitate upon warming the mixture, what does the juice contain (2004 E.C.)?
 - A. Starch
 - B. Reducing sugar
 - C. Sucrose
 - D. Protein
19. Which of the following is true about the substance represented by the chemical formula " $C_2H_5NO_2$ "?
 - A. Fatty acid
 - B. Simple sugar
 - C. Amino acid
 - D. Inorganic substance
20. Which of the following classes of fatty acids is without carbon—carbon double bond (2007 E.C.)?
 - A. Monounsaturated fatty acids
 - B. Saturated fatty acids
 - C. Unsaturated fatty acids
 - D. Poly unsaturated fatty acids
21. Which of the following helps to keep the biological membranes in a fluid state (2003 E.C.)?
 - A. Waxes
 - B. Cholesterol
 - C. Phospholipids
 - D. Water
22. What is the substance that helps to keep the biological membrane in a fluid state (2007 E.C.)?
 - A. Waxes
 - B. Water
 - C. Cholesterol
 - D. Phospholipids
23. What type of molecules CANNOT pass across the cell membrane by simple diffusion (2004 E.C.)?
 - A. Charged molecules
 - B. Non-polar molecules
 - C. Lipid soluble molecules
 - D. Molecules of very small size
24. Which of the following pairs of elements are found in all carbohydrates in addition to the element carbon (2004 E.C.)?
 - A. Nitrogen and oxygen
 - B. Hydrogen and oxygen
 - C. Hydrogen and nitrogen
 - D. Phosphorus and nitrogen
25. Which one of the following contains phosphate group in its molecule?
 - A. Simple sugar
 - B. Nucleotide
 - C. Cellulose
 - D. Protein
26. Which of the following properties of water makes sweat an effective body cooler (2004 E.C.)?
 - A. Its high specific heat
 - B. Its high surface tension
 - C. Its low density when frozen
 - D. Its high heat of vaporization
27. How many carbon atoms are contained in a single molecule of sucrose (2004 E.C.)?
 - A. 6
 - B. 12
 - C. 24
 - D. 48
28. How many carbon atoms are there in one disaccharide molecule (2005 E.C.)?
 - A. 6
 - B. 12
 - C. 18
 - D. 24
29. Which energy-rich organic compound contains adenine in its molecule (2005 E.C.)?
 - A. Lipids
 - B. Glucose
 - C. Carbohydrates
 - D. ATP
30. Which of the following is NOT one of the four most common elements?
 - A. Sulphur
 - B. Nitrogen
 - C. Hydrogen
 - D. Carbon
31. Which of the following the correct sequence of the steps in scientific research (2007 E.C.)?
 - A. Hypothesis formulation—conclusion—experiment—question
 - B. Question—hypothesis formulation—experiment—conclusion
 - C. Hypothesis formulation—question—experiment—conclusion
 - D. Question—hypothesis formulation—conclusion—experiment
32. All proteins contain carbon, hydrogen, oxygen and what other elements (2005 E.C.)?
 - A. Chlorine
 - B. Nitrogen
 - C. Flourine
 - D. Sulphur
33. What makes unsaturated fatty acids different from saturated fatty acids (2005E.C.)?
 - A. The presence of long chain of carbon
 - B. The presence of one or more double bond
 - C. The presence of large number of hydrogen atoms
 - D. Their occurrence as solid at room temperature
34. Which property of water keeps lake-inhabiting organism from freezing in winter in cold regions?
 - A. High heat of fusion
 - B. High heat of vaporization
 - C. Low density of the solid state
 - D. High specific heat capacity

- B. High surface tension
D. High latent heat of vaporization
35. What is the name of the sugar found in milk (2005 E.)?
A. Glucose B. Maltose C. Lactose D. Sucrose
36. What can one conclude about the contents of the food staff if a mixture of Benedict's solution and a food staff remain blue after heating (2005 E.C.)?
A. It contains proteins C. It contains fats
B. It lacks starch D. It lacks reducing sugar
37. A combination of two or more atoms joined by covalent bonds is called a(an)
A. acid B. Molecule C. solution D. isomer
38. Which of the following is NOT a structural polysaccharide?
A. Cellulose B. Chitin C. Murein D. Ribose
39. Which of the following groups of substances are all inorganic (2005 E.C.)?
A. Water, sugar, calcium, carbonate C. Water, calcium, carbon dioxide
B. Sugar, fatty acids, amino acids D. Carbon dioxide, amino acid, fatty acid
40. In which of the following compounds are both members of the pair are polymers of carbohydrates that naturally occur in plants (2005E.C.)?
A. Starch and chitin C. Starch and cellulose
B. Glycogen and cellulose D. Glycogen and chitin
41. Lipids composed of fatty acids and glycerol are
A. Glycolipids C. Glycoproteins
B. Neutral fats D. Keto acids
42. Which of the following is generally expected to give better health benefit when present in human diet (2005 E.C.)?
A. Animal fat C. Mono unsaturated fatty acid
B. Saturated fatty acid D. Poly unsaturated fatty acid
43. Which of the following pairs of molecules are known to have catalytic activity (2005 E.C.)?
A. Lipids and proteins C. Proteins and RNAs
B. Carbohydrates and proteins D. Proteins and DNAs
44. Pentose does not include
A. Fructose B. Ribulose C. Ribose D. Deoxyribose
45. The main component of the plant cell wall is (2005 E. C.)?
A. Starch B. Protein C. Cellulose D. Chitin
46. Which of the following molecules in living things is NOT an organic molecule (2006E.C.)?
A. Sugar B. Nucleotide C. Amino acid D. Water
47. Which level of a protein structural organization is represented by its amino acids sequence?
A. Quaternary structure C. Tertiary structure
B. Primary structure D. Secondary structure
48. Two monosaccharides are bonded together by
A. Ketone group C. Removal of water
B. Glycosidic bond D. Alcohol group
49. How many carbon and oxygen atoms are there in a molecule of maltose (2006 E.C.)?
A. 6 carbon and 6 oxygen C. 12 carbon and 11 oxygen
B. 11 carbon and a12 oxygen D. 24 carbon and 12 oxygen
50. Which of the following is true about saturated fatty acids (2006 E.C.)?.
A. They have single bonds between carbon atoms
B. They are the same as polyunsaturated fatty acids
C. They are the same as monounsaturated fatty acids
D. They have double bonds between the carbon atoms
51. The protein that makes silk is called
A. Keratin B. Collagen C. Chitin D. Fibrin
52. Which of the following is TRUE about the substance represented by the chemical formula " C_2H_5NO "?
(2006E.C.)?
A. Simple sugar C. Fatty acids
B. Inorganic substances D. Amino acids
53. Unsaturated fatty acids have;
A. One or more double bonds C. Oleic acid

- B. High melting point
D. No bonds
54. Choose the one that represents a chemical formula of an organic compound (2006 E.C.)?
A. $C_{12}H_{22}O_{11}$ B. $Mg(OH)_2$ C. NH_3 D. $NaCl$
55. To which one of the following organic molecules do enzymes belong (2006 E.C.)?
A. Carbohydrates B. Protein C. Amino acids D. Lipids
56. The DNA of an elephant and the DNA of Eucalyptus tree will probably will differ in all of the following respects EXCEPT the
A. number of DNA molecules C. Kinds of molecules utilized in forming DNA
B. kinds of genes for which the DNA codes D. length of DNA molecule
57. How unsaturated fatty acids are distinguished (2006 E.C.)?
A. They are made up of glucose and fructose
B. They are made up of amino acids and glycerol
C. They have double bonds in their carbon chains
D. They have only single bonds at the points of attachment
58. Which of the following is produced when a lipid molecule is hydrolyzed (2006 E.C.)?
A. Amino acid and water C. Fatty acids and glycerol
B. Amino acid and glucose D. Glucose and glycerol
59. Which of the following carbohydrates has structural function (2006 E.C.)?
A. Cellulose B. Glycogen C. Starch D. Sucrose
60. The organic molecule tightly bound to the enzyme and required for the activity of enzyme is grouped as
A. Prosthetic group B. Apoenzyme C. Coenzyme D. Activator
61. Into which of the following organic compounds can lipase, maltase and sucrase be grouped (2006 E.C.)?
A. Hormone B. Carbohydrates C. Nucleic acid D. Enzyme
62. To which one of the following organic molecules do enzymes belong (2007 E.C.)?
A. Carbohydrates B. Amino acids C. Proteins D. Lipids
63. A carbohydrate compound is known to have 12 carbon atoms in the whole molecule. What could this compound be (2007 E.C.)?
A. A polypeptide B. A disaccharide C. A monosaccharide D. A polysaccharide
64. In an enzyme catalyzed reaction, addition of a substrate to the reaction mixture decreases the reaction. The substance added must be
A. Inhibitor B. Co-enzyme C. Substrate D. Enzyme
65. If certain food stuff gave a positive result with Benedict's test only after it was hydrolyzed with hydrochloric acid, which of the following substance could it be (2008 E.C.)?
A. Non-reducing sugar B. Nucleic acid C. Lipid D. Protein
66. Which of the following molecules is NOT a polymer (2007 E.C.)?
A. Protein B. RNA C. Lipid D. Starch
67. If the cofactor is tightly bound to the enzyme permanently, then it is called
A. inorganic ion C. prosthetic group
B. apoenzyme D. coenzyme
68. Which one of the following factors determines the rate at which organelles settle out of cell homogenate if spun in a centrifuge (2007 E.C.)?
A. Mass of the organelle C. Function of the organelle in the cell
B. Location of the organelle in the cell D. Thickness of the membrane covering the organelle
69. Steroids are commonly classified as lipids because their
A. Similarity in composition C. Similarity in solubility
B. Similarity in melting point D. Similarity in structure
70. Which of the following classes of organic molecules is the least important source of energy for cellular respiration (2007 E.C.)?
A. Nucleic acid B. Lipids C. Carbohydrates D. Proteins
71. The most complex structure of protein is called (2007 E.C.)
A. Primary structure C. Tertiary structure
B. Secondary structure D. Quaternary structure
72. A co-enzyme can be
A. Organic molecule B. Inorganic molecule C. Metal D. Conjugated enzyme
73. Which one of the following classes of molecules cannot pass easily across the cell membrane by simple diffusion (2007 E.C.)?

- A. Smaller non-polar molecules C. Lipid soluble molecules
B. Non polar molecules D. Polar molecules
74. At which level of structural organization do proteins have the alpha-helix shape (2007 E.C.)?
A. Primary structure C. Tertiary structure
B. Secondary structure D. Quaternary structure
75. The feedback mechanism means the inhibition by the
A. Substrate B. Intermediate product C. end product D. inhibitor
76. The most complex structure of proteins is called (2007 E.C.)
A. Primary structure C. Tertiary structure
B. Secondary structure D. Quaternary structure
77. The building blocks of nucleic acids are
A. Sugars B. Nucleotide C. Bases D. Phosphates
78. Which level of protein structural organization involves two or more polypeptide (2009 E.C.)?
A. Primary structure C. Tertiary structure
B. Secondary structure D. Quaternary structure
79. Which of the following factors determines the rate at which organelles settle out of cell homogenate if spun in a centrifuge (2007 E.C.)?
A. Mass of the organelle
B. Function of the organelle in the cell
C. Location of the organelle in the cell
D. Thickness of the membrane covering the organelle
80. Which of the following is an inorganic molecule (2007 E.C.)?
A. CaCO_3 B. CH_4 C. $\text{C}_6\text{H}_{12}\text{O}_6$ D. $\text{C}_{18}\text{H}_{36}\text{O}_2$
81. In a formation of macro molecules what type of reaction should join two subunits together (2007 E.C.)?
A. Hydrolysis reaction C. Denaturation reaction
B. Dehydration reaction D. Hydrophobic reaction
82. To which group of organic compounds do the triglycerides and waxes belong (2007 E.C.)?
A. Carbohydrates B. Lipids C. Proteins D. Vitamins
83. Which of the following is true about all proteins (2007 E.C.)?
A. They are twenty amino acids long C. they are globular in shape
B. They perform the same function D. The monomers are held together by peptide bonds
84. Which of the properties of water allows mosquito larvae to protect themselves from sinking down into the water from the water surface (2007 E.C.)?
A. Its high surface heat capacity C. Its high latent heat of vaporization
B. Its high surface tension D. Its low density in solid state
85. Which of the following is a functional group of a fatty acid (2007E.C.)?
A. A ketone group C. An amino group
B. An aldehyde group D. A carboxyl group
86. Which are the four most abundant elements in living cells (2007E.C.)?
A. Carbon, oxygen, sulphur phosphorus C. Carbon, oxygen, hydrogen, nitrogen
B. Carbon, oxygen, nitrogen, sulphur D. Carbon, oxygen, sulphur, magnesium
87. How many fatty acids would a cell need to form a molecule of triglyceride (2008 E.C.)?
A. Two B. Four C. Five D. Three
88. Which of the following food types would most likely give a negative result upon addition iodine solution (2008 E.C.)?
A. Bread B. Biscuit C. butter D. Potato
89. Of the following functions, which one do triglycerides accomplish in cells (2008 E.C.)?
A. Increase density of tissues and cells C. Increase thermal insulation of cells
B. Yield limited amount of ATP for cells D. Facilitate entry of excess water
90. Which of the following molecules can serve as a raw material for industries that produce glucose (2008 E.C.)? A. Nucleic acids B. Proteins C. Lipids D. Starch
91. Which of the following classes of fatty acids contain single bond between each carbon atom (2008 E.C.)?
A. Mono unsaturated fatty acids C. Saturated fatty acids
B. Unsaturated fatty acids D. Poly unsaturated fatty acids
92. Why does sucrose give a negative result when mixed and heated with Benedict's solution (2008E.C.)?
A. Because it is not a sugar molecule C. Because it is non-reducing sugar

- B. Because it is a reducing sugar D. Because it is not a monosaccharide
93. Which one of the following are the main constituents of biological membranes (2005E.C.)?
A. Phospholipids B. Glycoproteins C. Glycolipids D. Cholesterol
94. Which of the following are NOT included in lipids (2003 E.C.)?
A. Nitrogenous bases B. Waxes C. Phospholipids D. Steroids
95. Which of the following is a distinguishing feature of amino acids that is NOT found in carbohydrates (2006 E.C.)? A. Carbon B. Oxygen C. Hydrogen D. Nitrogen
96. Which of the following compounds is important component of the exoskeleton of arthropods such as insects (2003 E. C.)?
A. Oil B. Sugar C. Protein D. Chitin

UNIT Three

Enzymes

Nature of Enzymes?

- ♥ **Almost all enzymes** are globular proteins with uniquely shaped active site.
- ♥ They act as biological catalysts for specific reactions, but remain unchanged by the reaction.
- ♥ **Enzymes** control and regulate chemical reactions within living cells serving as highly efficient catalysts.
- ♥ They have active site on a region where they bind with the substrate.
- ♥ **Active site** is the part of an enzyme molecule that binds with its substrate. This enables the enzyme to catalyze the chemical reaction.
- ♥ **Substrate** is a substance upon which an enzyme acts in a biochemical reaction.
- ♥ An enzyme can only bind with one substrate because of the **shape** of its **active site**.
- ♥ The substrate for an enzyme molecule binds with the active site and forms **enzyme-substrate complex**
 $E + S \longrightarrow ES \longrightarrow P + E$
- ♥ **E == enzyme S == substrate, ES == Enzyme-substrate complex, P == product**
- ♥ **Enzymes** play a vital role in catalyzing metabolic reactions in all cells by reducing the activation energy needed for the reaction)
- ♥ In order for a chemical reaction to take place the reacting molecules must first collide and then have sufficient energy to trigger the formation of new bonds.
- ♥ The energy which is required to produce a collision that is powerful enough to bring about a chemical reaction is called **activation energy**.
- ♥ **Activation energy** is an additional energy that must be supplied to the reactants to assist them to overcome the energy barrier, i.e., to initiate the reaction.
- ♥ Enzymes lower the activation energy for the reaction, i.e. makes the barrier height decrease; that leads to an increase in the number of active molecules and consequently , to an increased reaction rate
- ♥ The lower the activation energy, the more efficient is the action of enzyme /catalyst and the faster is the reaction rate.
- ♥ Under normal conditions, only a very small number of molecules possess the kinetic energy sufficient for overcoming the energy barrier.
- ♥ The process of influencing chemical reactions in a way that lowers activation energy is called **catalysis**, and the substances used to perform the catalysis are called **catalysts**.
- ♥ A catalyst by definition is a substance that speeds up a chemical reaction but remains unchanged itself at the end of the reaction.
- ♥ The enzyme is **not** changed or it is **not** consumed by the reaction.

The major Properties of Enzymes

- ✎ Enzymes are composed of globular proteins that have unique tertiary structure which makes them to have a specific shape.
- ✎ They are biological catalysts. Catalyst is a substance that speeds up the rate of chemical reaction without being used up in the reaction. Because of this reason enzymes can be used again and again.
- ✎ Enzymes are specific. Every enzyme acts specifically on a particular substrate. The specificity of the enzymes is related to the conformation of the active site where only few types of substances bind with.

- ❑ Small amount of enzymes can bring a change in large amount of substrates. Therefore, enzymes are effective in small amounts.
- ❑ The presence of enzymes does not alter the nature or property of the end product (S) of a reaction.
- ❑ Enzymes are destroyed by **heating** (work best at optimum temperature which is generally the normal body temperature).
- ❑ If enzymes are exposed to extremely high temperature than their optimum temperature they get **denatured**.
- ❑ At low temperature enzymes become **inactive**.
- ❑ Enzymes are sensitive to PH value (each has its own range of PH in which it functions most efficiently).
- ❑ For example, Pepsin works best at about PH 2 (acidic) trypsin at PH 8.5 (alkaline) and amylase at PH 7 (neutral).
- ❑ Therefore, the efficiency of enzyme is affected by temperature and PH.
- ❑ Enzymes are effective in small amounts.
- ❑ The number of moles of substrate converted by a mole of catalyst per minute is called the **turnover number**.
- ❑ Turnover numbers for catalysts generally lie between 100 and 3, 000, 000.

Naming and Classification of Enzymes

In 1898, the French microbiologist and biochemist Duclaus made the first attempts to introduce a practical rule for naming enzymes.

According to this rule, the **trivial** (working) name for an enzyme was made up of the ending **--ase** added to the name of the substrate subject to the action of the enzyme in question.

For example, sucrose + ase== sucrase.

However there are some enzymes that do not have **--ase** ending, but they are generally familiar (eg. rennin, pepsin, trypsin, etc.)

Analysis of different types of enzyme names shows that they have been named following different ways.

Some of the ways used in naming enzymes are:

- 1, Names given arbitrarily at the **time of discovery**, e.g. trypsin, pepsin, rennin and ptyalin.
- 2, Names given because of the **property of the product** formed, e.g. **invertase** (surase)
- 3, Names given by **adding the suffix--ase** to the name of the substrate; e.g. urease, which acts on urea.
- 4, Names given by the **type of reaction catalyzed**; e.g. dehydrogenases catalyze the removal of hydrogen.

Table 3.1 Examples of enzymes and the reactions they catalyze

Name of enzyme	Reaction catalyzed
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 DNSA
Pepsin	Digestion of protein in the stomachs of mammals

Different enzymes are named in different ways

- Most commonly enzymes are named by adding '**ase**' to part of the name of the substrate.
For example,
 - Lipase** (lipid hydrolyzing enzyme)
 - Sucrase** (sucrose hydrolyzing enzyme)
- Sometimes the enzymes are named on the basis of the reaction that they catalyze. For example,
 - polymerase** (aids in polymerization—joining similar units together)
 - dehydrogenase** (removal of hydrogen atoms or ions)
- Some enzymes have been named based on the source from which they were first identified.
For example, *Papayin* from papaya.
 - Others are named according to where they act. For example, *intestinal protease* acts on proteins in the intestine.
- The names of some enzymes end with '**in**', indicating that they are basically proteins.
 - For example, *pepsin*, *trypsin*, etc.
 - These enzymes usually have alternative names that tell us rather more about them.
 - For example, the alternative name for pepsin is gastric protease. This tells us that it acts on proteins and it does so in the stomach.
 - Because of the varied ways in which enzymes had been named, biologists at the **Enzyme Commission (EC)** decided to produce a systematic way of naming enzymes, based on the ways in which the enzymes act.
 - To appreciate this, we must first look at how enzymes are classified.
 - Enzymes are generally classified on the basis of the type of reactions that they catalyze.
 - Six groups of enzymes can be recognized.

Table 3.2 Classification of enzymes

Class	Reaction catalyzed	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	--Transaminases --Kinases
3, Hydrolases	Hydrolysis of a substrate	--Esterases -Digestive enzymes
4, Lyases	Non-hydrolytic removal of a group or addition of a group to a substrate	--Decarboxylases --Aldolases
5, Isomerases	Change of the molecular form of a substrate	--Phospho-hexo isomerase --Fumerases
6, Ligases (Synthetase)	Joining of two molecules by the formation of new bonds	Citric acid synthetase

- ❖ **Each class** of enzymes contains several different, but related, **subclasses**.
- ❖ Each sub class 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.

- ❖ **Hydrolase**—all the enzymes in class 3 hydrolyse some kind of bond
- ❖ **Peptidases**---all the enzymes in sub-subclass 4 of class 3 are peptidases and hydrolyze peptide bonds.
- ❑ **An 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.

3.2 Function of Enzymes

- ❖ We have been using enzymes for thousands of years –although the people who used them then didn’t know quite what they were using.
- ❖ Unknowingly, they used enzymes (in yeast) to make bread and beer.
- ❖ These are almost certainly the first uses of ‘enzyme’ technology.
- ❖ 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.
- ❖ When dough is baked to produce the bread, the tiny amount of alcohol formed is lost and the **carbon dioxide expands** to make the dough **rise** to make a ‘**loaf**’ of bread.
- ❖ When the beer is brewed, it is the carbon dioxide that is lost and the alcohol remains.
- ❖ However, enzyme technology is now very big business.
- ❖ Enzymes are used in many industries. They are used to produce washing powders—the enzymes in the washing powders digest the stains in the clothes.
- ❖ ‘Stone-washed’ denim jeans are now given their stone washed look by the action of enzymes.
- ❖ One of the appeals of using enzymes in industry is that they allow the reactions involved in the processes to be carried out at much lower temperatures.

Table 3.3 some industrial uses of enzyme technology

Sector	Application area	Benefits
Dairy	<ul style="list-style-type: none"> ❑ Biochymosin to produce cheese ❑ Lactase to produce lactose- free milk 	<ul style="list-style-type: none"> ❑ Supplies of natural rennet from calves livers are limited ❑ Lactose-intolerant people suffer fewer cramps
Detergents	<ul style="list-style-type: none"> ❑ Proteases, lipases and amylases in biological washing powders ❑ Proteases and amylases in dish washer detergents 	<ul style="list-style-type: none"> ❑ Many biological stains are removed effectively at low temperatures (saving energy) ❑ Remove food particles at lower temperatures and require fewer bleaching products to be added
Textiles	<ul style="list-style-type: none"> ❑ Proteases to remove hair and ❑ lipases to degrease animal hides ❑ Cellulase to bio-polish cotton fabrics ❑ Cellulase to bio-stone Denim 	<ul style="list-style-type: none"> ❑ Process is carried out much quicker than by traditional methods ❑ Produces a smoother and glossier finish ❑ The enzyme gives the ‘stone-washed’ effect much more easily
Food processing	<ul style="list-style-type: none"> ❑ Pectinase to process fruit juice ❑ Invertase to produce Liquid-center chocolates 	<ul style="list-style-type: none"> ❑ Clarifies fruit juice ❑ Sucrose paste in the chocolate is made liquid by injection of the enzyme

Pulp and paper	<ul style="list-style-type: none"> ✗ Amylase for starch conversion ✗ Xylanase enzymes in pre-bleaching the pulp ✗ Esterases in control of stikies (glues introduced during paper recycling) 	<ul style="list-style-type: none"> ✗ Reduces the quantity of starch in the paper and improves quality ✗ Produces a whiter paper ✗ Stickies would otherwise clog the machinery and reduce the quality of the paper
Medicine	<ul style="list-style-type: none"> ✗ Glucose oxidase in clinistix strips, tests for glucose ✗ Liver enzymes ✗ Pulmozyme to treat cystic fibrosis 	<ul style="list-style-type: none"> ✗ Allows easy diagnosis of diabetes by testing urine ✗ Testing for high levels of these in the blood confirms liver damage ✗ Reduces viscosity (stickiness) of mucus
Pharmaceutical	<ul style="list-style-type: none"> ✗ Streptokinase to dissolve clots of heart-attack patients ✗ Production of abacavir sulphate is controlled by enzymes 	<ul style="list-style-type: none"> ✗ Restores blood supply to are of heart muscle ✗ Abacavir sulphate is an important anti-AIDS drug

Table3.4 Functions of some enzymes

Enzyme	Function
Urease	Controls decomposition of small molecules of urea to carbon dioxide and ammonia
Dehydrogenase	Transfer of hydrogen molecule to coenzymes such as NAD^+
Polymerase	Joining of similar units together
Sucrase	Hydrolysis of sucrose
Lactase	Degrades lactose to glucose and Galactose
Lipase	For ripening of Danish cheese
Renin	To coagulate milk protein
Biochymyosis	For the production of cheese
Amylase	To reduce quantity of starch in order to increase quality of paper
Cellulase	To biopolish in cotton fabrics To biostone to make the stone washed more easily
Lipase	For ripening of Danish cheese
Protease	Helps to remove hair in textile industries
Pectinase	To clarify beer
Streptokinase	To dissolve clots of heart attack

Glucosidase	Diagnosis of diabetes
Xylanase	Production of white paper
Pulmozyme	To treat cystic fibrosis

How do enzymes act as catalysts?

- ◆ Catalysts speed up chemical reactions.
- ◆ In order for molecules to react, they must have sufficient energy.
- ◆ This energy to start off the reaction is called **activation energy** (or E_a).
- ◆ The reactant must 'climb an activation energy hill' before anything happens.
- ◆ Under normal conditions, very few molecules of reactants 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 can meet this lower energy requirement and so the 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 fig.3.8 pp.88.

How do enzymes lower activation energy?

There are two models of enzyme action:

1. Lock-and-key model

☞ This model was first proposed in 1894 by a German biochemist named Fischer

2. Induced-fit-model

☞ This model was proposed in 1958 by Koshland.

- ❖ Both of these models suggest that the enzyme catalyzes 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.
- The complementary molecule binds with the active site of the enzyme to form the **enzyme-substrate complex**.
- The complex causes the reactants to enter a transition state in which the activation energy of the 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**.
- $A + B + \text{Enzyme} \rightarrow \text{Intermediate} \rightarrow \text{Product} + \text{Enzyme}$
- This model sees the enzyme-substrate complex as the intermediate, which is the part of the pathway that requires less energy than the normal pathway.
- However, a **weakness** of this model is that it does not explain how the intermediate reduces activation energy.

2. The Induced-fit model

This model suggests that the active site and the substrate are not naturally complementary in shape, but the binding of substrate molecules 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. This is shown in figure 3.11 page 89.
- ☞ Most biologists now prefer the induced-fit model over the lock-and – key model as it explains other properties of enzymes, such as enzyme inhibition, in a more complete manner than the lock- and –key model.
- ☞ The **rate of a chemical reaction** is the rate at which reactants are converted into products.
- ☞ In the case of an enzyme-controlled reaction, this is determined by how many molecules of the 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.

Why do some enzymes need cofactor?

Sometimes an active enzyme isn't just a single molecule, but is made from **two molecules**, neither of which has enzymatic activity without the other.

two parts are the **apoenzyme** and the **cofactor**.

protein that combines with a cofactor, to form an active enzyme. The protein is inactive on its own.

The

Apoenzyme: a

Cofactor: is a small non-protein particle essential for the activity of some enzymes.

The cofactor combines with the apoenzyme to produce an active enzyme.

- ❖ Where an active enzyme molecule comprises an apoenzyme and a cofactor, the whole is sometimes referred to as the **holoenzyme**. See figure 3.12 page 90.

Cofactors include:

- **coenzyme and**
- **mineral ions**
- ❖ **Coenzymes** are organic molecules and many are derived from **vitamins**. They bind with the enzyme to give the catalytic activity.
- ❖ Table 3.5 shows some common coenzymes, the vitamins they are derived from, the enzyme with which they bind, and their functions.

Table 3.5 Common coenzymes and their function

Coenzyme	Vitamin	Enzyme	Function
DNA (Nicotinamide adenine dinucleotide)	Niacin	Oxidoreductase in respiration	Oxidation or hydrogen transfer in respiration
RNA (Flavin adenine dinucleotide)	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 page 91 shows some examples of enzymes that require mineral ions as cofactors.

Table 3.6 Enzymes that require mineral ions as cofactor

Enzyme	Mineral ion	Function
1. Carbonic anhydrase	Zinc ions (Zn^{++})	Cause CO_2 to react with water to form hydrogen carbonate
2. Alcohol dehydrogenase	Zinc ions (Zn^{++})	Oxidizes alcohol
3. 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, therefore, the **activity of the enzyme** are influenced by a number of external factors including: **1. Temperature** **2. pH** **3. Substrate concentration** **4. Presence of inhibitors**

Effect of temperature

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 within a molecule vibrate more energetically. This puts strain on the bonds that hold the atoms in place.
 - ❑ Bonds begin to break and, in the case of an enzyme, the shape of the molecule and the active site in particular, begin to change.
 - ❑ The enzyme begins to lose its tertiary structure and denature.
 - ❑ Figure 3.13 page 93 shows this.
 - ❑ In any enzyme catalyzed reaction, the rate doubles for every rise of 10°C .
 - ❑ Then there is maximum activity at optimum temperature.
 - ❑ After this there is decrease in the rate as the enzyme gets denatured due to high temperature.
 - ❑ On the other hand, if temperature is reduced to near or below freezing point, enzymes are **inactivated, but not denatured**.
 - ❑ They will regain their catalytic influence when the temperature rises to the normal range.
 - ❑ Slowing down of enzymatic activity at low temperature helps in food preservation, since the growth of bacteria and fungi would be arrested.
 - ❑ Low temperature also helps in storage of ripening fruits.
 - ❑ This has a wide application in quick freezing to preserve foods for longer periods.
 - ❑ Enzymes with higher optima have been used in biological washing powders for high temperature washes.

The Effect of pH

- ❖ Keeping all other conditions like temperature, substrate concentration, and enzyme concentration constant, the enzymes function over a narrow PH value.
- ❖ A change in PH leads to an alteration at the active site of enzyme.
- ❖ At extreme PH it can get denatured as well.

The Effect of Substrate Concentration

- ◆ The activity of an enzyme depends on the number of substrate molecules per second that bind to form enzyme-substrate complex.
- ◆ So the number of substrate molecules present must have an effect.
- ◆ A small number of substrate molecules means few collisions and so only a few enzyme-substrate complexes form.
- ◆ Increasing the concentration of substrate means more collisions and more enzyme-substrate complex

- ◆ So, the overall rate of reaction is increased.
- ◆ At a specific pH and temperature, for a given enzyme concentration, the rate increases with increasing substrate concentration.
- ◆ After a specific point the rate does not increase with increase in substrate concentration.
- ◆ The reason being that all active sites of the enzyme are saturated at a given moment and hence extra substrate doesn't affect the rate.
- ◆ 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 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, although the optimum pH of pepsin is between 1.0 and pH 3.0.

Significant change in pH can affect an enzyme molecule by:

1. Breaking ionic bonds that hold the tertiary structure. If this leads to denaturation of the enzyme molecule.
 2. 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. See figure 3.15 page 94 shows this effect.

The effect of enzyme concentration

- ❖ Assuming a constant large supply of substrate molecules, each enzyme molecule will work at maximum turnover.
- ❖ Therefore, 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

- ❖ Irreversible inhibitors bind strongly to enzymes, usually by covalent bond, permanently altering the structure of the enzyme molecule and inactivating it.
- ❖ The painkiller **aspirin** is an example of irreversible inhibitor.
- ❖ **Aspirin** 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 breaks easily releasing the inhibitor.

This allows the enzyme to become active again.

There are two main kinds of reversible molecules:

1. Competitive inhibitors, and
2. Non-competitive inhibitors

Competitive inhibitors: are molecules that inhibit enzyme activity by competing with the substrate **for the active site** (have shapes that are complementary to all, or part, of the 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. See fig.3.20 page 100.
- ❖ The overall effect on the rate of reaction depends on the relative concentration of substrate and inhibitor molecules.
- ❖ 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 the active site—hence the name, competitive inhibitor.
- ❖ If there were 99 substrate molecules for every inhibitor molecule, then 99% of the collision would be between enzyme and substrate and the reaction would proceed at 99% of the maximum rate.

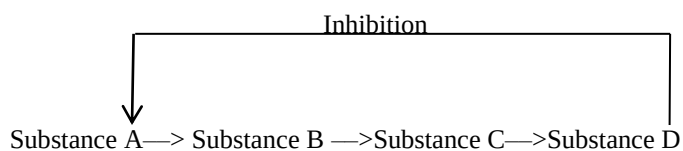
- ❖ If the ratio were 90 substrate molecules to 10 inhibitor molecules, there would be 10% inhibition and the reaction rate would fall to 90% of maximum.
- ❖ The painkiller ibuprofen acts as a competitive inhibitor of the enzyme-cyclo-oxidase-2, competing with the precursors of prostaglandins, which 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: is a molecule that alters the conformation of the active site by **binding with the allosteric site** of the enzyme; it prevents the substrate from binding and inhibits enzyme activity (they 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 the part of the enzyme molecule that includes the active site.
- ❖ Because of this, the active site is the different shape and can no longer bind with the substrate to catalyze the reaction.
- ❖ The effectiveness of a non-competitive inhibitor is in no way affected by the concentration of the substrate.
- ❖ Suppose there are enough inhibitor molecules to bind with the allosteric sites of 80% of the enzyme molecules, 80% of the enzyme molecules will be 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 are produced in cell as a result of a metabolic pathway (a series of reactions), which can be represented as: **Substance A—E1→ Substance B—E2→Substance C—E3→ Substance D**
- ❑ E1, E2 and E3 are enzymes catalyzing the reactions.
- ❑ All the reactions in 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 concentration 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 below.



- ❑ 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 are activated by a specific activator only when they are required.
- ❑ Figure 3.24 shows an enzyme of a metabolic pathway controlled by end-product inhibition.
- ❑ In this 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.

Review questions (Unit Two)

- 1, Which of the following substances can be used over and over again in an enzyme catalyzed reaction (2009 E.C.)?
A. Enzyme-substrate complex B. Substrate C. Enzyme D. Reaction product
- 2, What is the intermediate compound that is formed during an enzyme catalyzed reaction (2009 E.C.)?
A. Reactant B. Product C. Substrate D. Enzyme-substrate complex
- 3, For biological detergent to effectively remove oily and greasy dirt, which of the following enzymes should it contain? A. Amylase B. Protease C. Lipase D. Cellulase
- 4, Most co-enzymes are the derivatives of which of the following nutrients (2009 E.C.)?
A. Proteins B. Vitamins C. Carbohydrate D. fats
- 5, To produce glucose from starch, which of the following enzymes would one use (2009 E.C.)?
A. Isomerases B. Hydroses C. Lyases D. Ligases
- 6, Which class of enzyme inhibitors has similar shape as that of the normal substrate (2009 E.C.)?
A. Allosteric B. Denaturing C. Competitive D. Irreversible
- 7, Which of the following pairs of molecules are known to have catalytic activity?
A. Proteins and DNA C. Proteins and lip[ids
B. Proteins and RNA D. Proteins and carbohydrates
- 8, Which type of enzyme catalyzes the joining of two molecules by the formation of new bonds (2009 E.C.)?
A. Decarboxylase B. Dehydrogenase C. Ligase D. Oxidoreductase
- 9, Which of the following statements about enzymes is NOT correct (2009 E.C.)?
A. Enzymes speed up a chemical reaction
B. Enzymes are very specific in their reaction
C. The presence of an enzyme will change the outcome of a reaction
D. Enzymes lower the energy of activation for a reaction to occur
- 10, What happens when enzymes become denatured (2009 E.C.)?
A. They can normally catalyze the reactions C. Rate of reaction increases
B. Their active sites are changed D. Bonds holding amino acids are unaffected
- 11, Which of the following types of enzyme inhibitions can be removed when the end product of the metabolic pathway is depleted? A. Competitive inhibition C. Allosteric inhibition
B, Non-reversible-inhibition D. Reversible competitive inhibition
- 12, Which of the following can reverse an enzyme inhibition that is caused by an allosteric inhibitor (2009 E.C.)?
A. Adding more substrate C. Adding more end product
B. Depleting the end product D. Depleting the substrate
- 13, What is an Apoenzyme (2009 E.C.)?
A. A protein molecule C. A non-protein molecule

- B. An active enzyme D. A non-protein cofactor
- 14, Which of the following mechanisms do cells use to regulate enzyme catalyzed reaction in metabolic pathway?
- A. End product inhibition C. Enzyme denaturation
B. Irreversible inhibition D. Competitive inhibition
- 15, Into which of the following organic compounds can lipase, maltase, and sucrase be grouped (2007 E.C.)?
- A. Hormones B. Carbohydrates C. Nucleic acids D. Enzymes
- 16, If an enzyme is provided with the normal substrate plus another molecule having the same shape and size as the substrate, which one of the following would happen ((2003E.C.)?
- A. Allosteric inhibition C. Irreversible inhibition
B. Competitive inhibition D. End product inhibition
- 17, If one keeps on adding a substrate to a fixed amount of an enzyme, when does the reaction rate reach a plateau (2003 E.C.)?
- A. When all the substrate is converted to products
B. When all the active sites of the enzyme are occupied
C. When most of the enzyme molecules are consumed
D. When much of the products are accumulated
- 18, What do we call a substance upon which an enzyme acts (2004E.C.)?
- A. Product B. Activation energy C. substrate D. Enzyme-substrate complex
- 19, In which one of the following points does the induced-fit model of enzyme action differ from the lock-and-key model (2004 E.C.)?
- A. Enzymes lower the energy of activation
B. Substrates bind at the active site of the enzyme
C. During the reaction, an enzyme-substrate complex is formed
D. The shape of the enzyme and the active site are complementary
- 20, Which of the following mechanisms do cells use to regulate enzyme catalyzed reaction in metabolic pathways (2004E.C.)?
- A. Enzyme denaturation C. End product inhibition
B. Irreversible inhibition D. Competitive inhibition
- 21, In competitive inhibition, which one of the following factors determines the rate of inhibition/
- A. The enzyme concentration
B. The ratio of inhibitor to enzyme concentration
C. The substrate concentration
D. The reaction temperature
- 22, Which factor has a more negative effect on the function of enzymes than others (2004E.C.)?
- A. Optimal amount of substrate concentration optimal amount of substrate concentration
B. Neutral pH C. Very high temperature D. Optimal amount of salt concentration
- 23, Suppose 25% of the molecules of an enzyme are inhibited by a non-competitive inhibitor, which one of the following would happen if the amount of the substrate is increased by 50% (2004 E.C)
- A. The reaction rate would double
B. More enzyme molecules would get inhibited

- C. The rate of the reaction would decrease by 50%
- D. The rate of the reaction would remain unchanged

24, Suppose 25% of the molecules of an enzyme are inhibited by a non-competitive inhibitor, which one of the following would happen if the amount of the substrate is increased by 50%?

- A. The rate of the reaction would remain unchanged
- B. More enzyme molecules would get inhibited
- C. The reaction rate would double
- D. The rate of the reaction would decrease by 50%

25, In competitive inhibition, in which one of the following factors determines the rate of the inhibition (2004 E. C.)?

- A. The reaction temperature
- B. The substrate concentration
- C. The enzyme concentration
- D. The ratio of inhibitor to enzyme concentration

26, Some enzymes can only function in the presence of certain mineral ions. These mineral ions: Which factor has a more negative effect on the functions of enzymes than the others (2004 E.C.)?

- A. Bind tightly with the enzyme
- B. Bind loosely with the enzyme
- C. Bind loosely with the substrate
- D. Bind tightly with the apoenzyme

27, What are the environmental advantages of using enzymes in industry (2004 E.C.)?

- A. It makes high production possible with less input of heat
- B. It makes high production possible with high input of heat
- C. It makes high production possible with emission of CO₂
- D. It helps high production with supply of more heat and emission of more CO₂

28, Which of the following classes of enzymes digests carbohydrate (2005 E.C.)?

- A. Amylase
- B. Lipases
- C. Proteases
- D. Nucleases

29, One of the following molecules is building units of an enzyme molecule (2005)?

- A. Amino acids
- B. Glucose
- C. Nucleic acids
- D. Fatty acids

30, What is true about the rate of an enzyme catalyzed reaction if the enzyme concentration is kept constant and the substrate is excess? The rate would

- A. Not be determined
- B. Increased continuously
- C. Stay constant
- D. Decrease sharply

31, One of the following principles is most of the anti-HIV drugs currently in use working (2005 E.C.)?

- A. Inhibition of enzyme action
- B. Digesting viral particles
- B. Degradation of the viral DNA
- D. Phagocytosis of the viruses

32, When an enzyme is denatured by heat or extreme pH, which one of the following does it lose (2004 E.C.)?

- A. The peptide bond
- B. Secondary structure
- C. Primary structure
- D. Tertiary structure

33, In the cause of enzymatic chemicals, what do you call the substance that is acted up on by an enzyme (2006)?

- A. Polypeptide
- B. Coenzyme
- C. Vitamin
- D. Substrate

34, According to IUB the first part of “trivial” name of enzyme refers to the

- A. Substrate
- B. Reaction
- C. Product
- D. Co-enzyme

- 35, Which of the following are the common characteristics of all enzymes (2006 E.C.)?
- A. They act inside cells only
 - B. They require cofactors
 - C. They are proteins
 - D. They operate at any pH
- 36, To which class of enzymes do the digestive enzymes belong (2005)?
- A. Esterases
 - B. Hydrolases
 - C. Transferases
 - D. Isomerases
- 37, Which of the following types of enzyme inhibition can be removed when the end product of the metabolic pathway is depleted (2005 E.C.)?
- A. Allosteric inhibition
 - B. Non-reversible inhibition
 - C. Competitive inhibition
 - D. Reversible competitive inhibition
- 38, On which of the following principles are most of the anti-HIV drugs currently in use working (2005 E.C.)?
- A. Inhibition of enzyme action
 - B. Degradation of viral DNA
 - C. Digesting of viral particles
 - D. Phagocytosis of the viruses
- 39, Which group of organic compounds includes the enzymes (2006 E.C.)?
- A. Proteins
 - B. Lipids
 - C. Starches
 - D. Carbohydrates
- 40, An enzyme sucrose is an example of
- A. Hydrolases
 - B. Lyases
 - C. Transferases
 - D. Oxidoreductases
- 41, Which of the following pH values represents the strongest base (2006 E.C.)?
- A. 2
 - B. 7
 - C. 13
 - D. 15
- 42, Which region of human digestive tract contains enzymes that perform well at low pH (2006 E.C.)?
- A. Mouth
 - B. Small intestine
 - C. Stomach
 - D. Large intestine
- 43, For a biologist detergent to effectively remove oily and greasy dirt, which of the following enzymes should it contain (2006 E.C.)?
- A. Cellulose
 - B. . Protease
 - C. Amylase
 - D. Lipase
- 44, In the cause of enzymatic chemical reactions, what do you call the substance that is acted up on by on enzyme (2006 E.C.)?
- A. Polypeptide
 - B. . Coenzyme
 - C. Vitamin
 - D. Substrate
- 45, Which of the following is a coenzyme (2007 E.C.)?
- A. NAD
 - B. . Systematic errors
 - C. Water
 - D. Proteins
- 46, Which one of the following substances has a shape which is similar to that of the substrate of an enzyme (2007 E.C.)?
- A. The reaction product
 - B. A competitive inhibition
 - C. A cofactor
 - D. An allsteric inhibition
- 47, Which one of the following terms refers to how fast an enzyme acts on its substrate (2007 E.C.)?
- A. Turn over number
 - B. Substrate number
 - C. Enzyme number
 - D. product number
- 48, The optimum temperature of enzymes found in thermophilic bacteria is (2007 E.C.)?
- A. Lower than for enzymes in the human body
 - B. Higher than enzymes in the human body
 - C. The same as enzymes found in human body
 - D. Lower than enzymes found in warm blooded animals

49. Which of the following properties of enzymes makes it possible that a single enzyme molecule can act on many substrate molecules (2007 E.C.)?

- A. Enzymes are proteins
- B. Enzymes lower the activation energy
- C. Enzymes are reused over and over again
- D. Enzymes are substrate specific

50. The enzyme that breaks a complex molecule into two products by hydrolysis belongs to class

- A. Hydrolases
- B. Ligases
- C. Transferases
- D. Lyases

51. The enzyme that breaks covalent bonds without hydrolysis

- A. Hydrolases
- B. Transferases
- C. Ligases
- D. Lyases

52. Hexokinase is an example of :

- A. Hydrolases
- B. . Lyases
- C. Oxidoreductases
- D. Transferases

53. If the rate of the enzyme catalyzed reaction remains constant even when more substrate is added to the reaction, which of the following might be the reason (2007 E.C.)?

- A. Saturation of the enzyme
- B. Inactivation of the enzyme
- C. Inhabitation of enzyme-substrate complex formation
- D. Loss of substrate specificity by the enzyme

54. Which part of human alimentary canal contains digestive enzymes that function at acidic pH (2008 E.C.)?

- A. Stomach
- B. Mouth
- C. Esophagus
- D. Small intestine

55. According to lock-and-key hypothesis, an enzyme might not be effective?

- A. With a changed shape
- B. more than once
- C. Without heat
- D. Without ATP

56. In which area of enzyme application is invertase injected to sucrose paste in order to produce liquid chocolate (2008 E.C.)? A. Detergent making industry C. Pharmaceutical industry

- B. Pulp and paper industry
- D. Food processing industry

57. Which characteristic of RNA makes it suitable for moving out of the nucleus (2008 E.C.)?

- A. Inability to replicate
- B. its unstable nature
- C. Absence of thymine
- D. Smallness of its size

58. Which one of the following functions at high optimum pH than all the rest (2008 E.C.)?

- A. Pepsin
- B. Trypsin
- C. salivary amylase
- D. Enzymes in stomach

59. Which class of enzymes joins two molecules together by formation of new bonds (2008 E.C.)?

- A. Ligase
- B. Isomerase
- C. Lyase
- D. Hydrolase

60. In enzymes that contain non-protein organic molecules, in addition to the protein component called (2008 E.C.)

- A. Apoenzyme
- B. Coenzyme
- C. Holoenzyme
- D. Cofactor

61. What causes tomato fruits to ripen much more slowly when kept in a refrigerator than if left on a table at room temperature (2008 E.C.)?

- A. Low temperature slows the normal action of ripening enzymes

- B. Enzymes produced by bacteria normally inhibit ripening
- C. Humidity accelerates enzyme activity and ripening process
- D. Normal temperature asserts the action of ripening enzymes

62. Among the following factors that affect enzyme activity, which one does NOT cause enzyme denaturation (2009 E.C)?

- A. High pH
- B. High temperature
- C. Low pH
- D. Competitive inhibitor

UNIT FOUR

Cell Biology

The word '**cell**' is derived from a Latin word called '**cellula**' which means '**little rooms**' and this name is first given by an English biologist called **Robert Hooke in 1665**. Then after people have been using this name.

- Cells are called the **building units** of all organisms. This is true because all living things are made up of cells.
- Some organisms are made up of only a single cell and they are called **unicellular** organisms, while other groups of organisms are made up of many cells and they are called **multicellular** organisms.
- In sexually reproducing multicellular organisms a single cell called **zygote** (or fertilized egg) divides to form new cells again and again.
- This results in forming complex tissues, organs, and systems of an organism.
- The cell is a basic functional unit of an organism which is capable of carrying on all the activities necessary for life.
- This is because chemical reactions that take place in cells involve energy release needed to support life and build structures.

4.1 The Cell Theory

- ☞ Cell theory is an idea which states that cells are the fundamental units of life.
- ☞ This theory involves the collection of statements developed through the contribution of many biologists.
- ☞ Accordingly, the cell theory has the following key points:
 - 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
 - The cell retains a dual existence as a distinct entity unit of all living things and the building block in the construction of organisms.
 - Today, this has been modified and extended in the light of our increased knowledge of genetics and cell biology and now reads:
 - ☒ All 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
 - ☒ 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
 - ✓ The discovery of cells had to wait for the development of reliable microscopes that could magnify sufficiently to show the cellular structures of living organisms.
- ✓ Many biologists and other scientists contributed to the discovery of cells and the statement of the very first cell theory.

The timeline below shows some of the major contributors

A timeline for the development of the cell theory

1, Robert Hooke (1665)—with one of the earliest compound microscopes, makes drawing of cork and sees tiny structures that he calls ‘cells’.

However, although his microscope is a compound microscope, the lenses are not very good and magnification of more than 30x are very **blurred** and **do not show much detail**. Also, **Hooke saw only dead cells**.

2, Anton Van Leeuwenhoek (1674)—saw living, moving unicellular organisms (protocists) in a drop of water.

- He used a simple microscope with only **one lens**. It is really little more than a magnifying glass with a mount for the specimens.
- However, Anton van Leeuwenhoek is very skilled at grinding lenses and so his microscope can achieve magnification of **300x**.
- He called the moving organisms ‘**animalcules**’. He also saw bacteria (from his teeth), which he also called ‘**tiny animalcules**’.

3, The French biologist Rene Dutrochet (1824)---concluded that all organisms are composed of cells. This follows many years work in which he also discovered:

- ♥ 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
- ✓ In many ways, **Dutrochet** is the man who first states the cell theory by recognizing 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’.

4, Matthias Schleiden and Theodor Schwann--put forward the first clearly stated cell theory. It stated that:

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

5, Rudolf Virchow, a German doctor who developed many surgical techniques and promotes several fields of modern medicine declares that: ‘**Omnis cellula e cellula**’, which means that a cell can only arise from another cell like it.

With this he completed the first accepted versions of the cell theory:

- All organisms are made up of one or more cells
- All cells come from pre-existing
- 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 construction of organisms.

Today, this has been modified and extended in the light of our 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 (there is 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
- ☞ Besides these major steps in the development of a cell theory, there have been other developments in the study of cell biology. Some of these are listed below.

Table 4.1 **Key events in the study of biology**

Year	Event
1595	Jansen built the first compound microscope
1626	Redi postulates that living things do not arise from spontaneous generation
1665	Hooke described 'cells' in cork
1674	Leeuwenhoek discovered protozoa
1833	Brown described the cell nucleus in cells of an orchid
1839	Schleiden and Shwann proposed a cell theory
1857	Kollinker described mitochondria
1858	Virchow states <i>omnis cellula e cellula</i>
1869	Miescher isolated DNA
1879	Fleming described chromosome behavior during mitosis
1898	Golgi described the Golgi apparatus in cells
1939	The first transmission electron microscope
1953	Watson and Crick proposed the double helix structure of DNA
1965	The first scanning electron microscope was made
2000	Human genome DNA sequence draft

Units to measure cells

Cells are extremely small and can be seen properly only when magnified and viewed through the lenses of a microscope.

Cell dimensions are expressed in **micrometers** (one millionth of meter); micrometers sometimes are called **microns**.

There are three smaller units commonly used:

1. Millimeters—1/1000 of a meter
2. Micrometers—1/1000 of millimeter
3. Nanometer—1/1000 of a micrometer

Animal cell is 1000 times bigger than the bacterium.

- As cells increase in size, the volume increases faster than the surface area and the **surface-area-to volume ratio decreases**.

- The amount of energy that must be released in respiration is decided largely by the **volume**.
- 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.
- 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.

Discovery of the cell

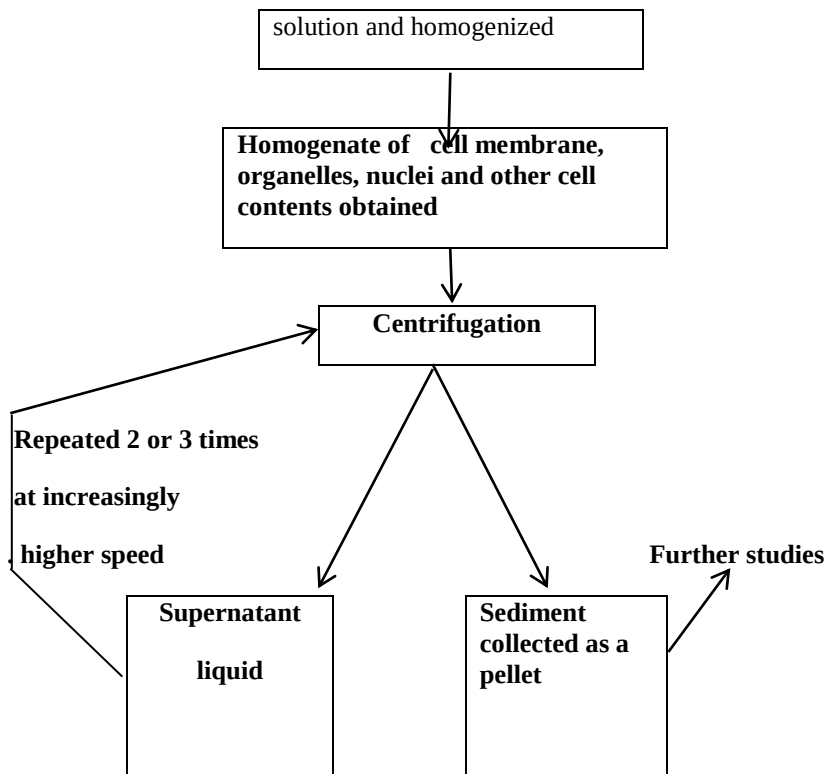
4. The discovery of cells was made possible by the development of the microscope in the early seventeenth century.
5. In 1665, the English Scientist Robert Hooke (1635-1703) used a microscope to examine a thin slice of cork.
6. Hooke wrote, 'I would exceedingly plainly perceive it to be all perforated and porous' and he further described it as consisting of 'a great many little boxes'.
7. When he turned his microscope to the stem of elder trees carrots and ferns. He found that each showed a similar formation.
8. These little boxes reminded him of the small rooms in which monks lived, so he called them **cells**.
9. What Hooke had observed were actually the remains of dead plant cells.
10. The first person to observe living cells was a Dutch lens crusher, Anton van Leeuwenhoek (1632-1723).
11. Although Van Leeuwenhoek's microscope was rather simple (simple microscope) it was powerful enough to enable him to open up a whole new world—the world of microscopic organisms, which had never been seen before.
12. Cell biology as a science began its rapid advance in the 1950s when investigators began using a new powerful tool, the electron microscope.
13. Instead of using visible light, the electron microscope directs a beam of electrons through the specimen.
- ❏ The detailed structure of a cell, as seen with electron microscope, is referred to as the **ultra-structure**.
- ❏ Microscopes of various kinds are most important tools in **cytology**, the study of cell structure.
- ❏ Modern cell biology is developed from an investigation of cytology with biochemistry, the study of metabolism and its products.
- ❏ A biochemical approach called cell **fractionation** has been particularly important in this multidisciplinary synthesis of cell biology.

Cell fractionation

- ☞ **Cell fractionation** is a technique used to isolate cell compartments in a state in which they can be studied further.
- ☞ The instrument used to fractionate cells is the **centrifuge**, an instrument that spins test tubes at various speeds.
- ☞ The fastest machines, called **ultracentrifuge**, can spin at more than 100,000 revolutions per minute.
- ☞ Fractionation begins with **homogenization**, the disruption of cells.
- ☞ The objective of homogenization is to break the cells without severely damaging the organelles.
- ☞ This is done by vibrating cells with ultrasound that forces the cells to pass through small spaces.
- ☞ The parts of the soupy homogenates are separated by spinning in a centrifuge, first at a low speed to cause nuclei and other larger particles to settle to the bottom of the test tube, forming a **pellet**.
- ☞ The supernatant (unsedimented) fraction is decanted (transferred) into another tube and centrifuged again at a faster speed, sedimenting organelles that were too small to pellet during the first, slower spin.
- ☞ The process is repeated, increasing the speed with each step, collecting smaller and smaller components of the homogenized cells.

The process is summarized in the following flow diagram.

Tissue mixed with isotonic



4.2 Types of cells

Cells can be grouped into two types based on their structure and complexity. Accordingly, they are divided as prokaryotic and eukaryotic.

1. Prokaryotic cells

- ❑ They were the first type of cells to be formed when life first evolved.
- ❑ They lack nucleus and membrane bounded organelles.
- ❑ The word prokaryotic is derived from Greek pro (before) and karyos (nuclear).
- ❑ Prokaryotic cells are much smaller and have simpler structures as compared to eukaryotic cells; even so these cells must carry out all the same functions that a eukaryotic cell carries out in order to survive.
- ❑ There is therefore some division of labor within the cell.
- ❑ There are specialized regions for certain functions (see figure 4.14 page 121).

2. Eukaryotes

- ✓ Eukaryotic cells are cells that have complex structures as compared to prokaryotic cells.
- ✓ The word eukaryotic is derived from Greek eu (true) and **karyos** (nuclear).
- ✓ Eukaryotic cells have features which make them different from prokaryotic cells. They are:
 - Eukaryotes have nuclear materials which are enclosed by nuclear membrane
 - Eukaryotes have distinct internal membrane system which surrounds cell **organelles**.
 - Also, there are many more membranes in the cell. Some of these form the complex membrane system that is found throughout the cell ---the **endoplasmic reticulum**.
 - In addition to these, several of the organelles are surrounded by membranes. These are :
 - Nucleus
 - Mitochondria
 - Lysosomes
 - Golgi apparatus
 - Chloroplasts (if present)
- These are called membrane-bound organelles.
- ✓ Eukaryotic cells have complex membrane system that are found inside cells organelles

- ✓ Also, there are many more membranes in the cell. Some of these form the complex membrane system that is found throughout the cell ---the **endoplasmic reticulum**.
- ✓ The membranes make the cell able to function more efficiently because the reactions that take place in one membrane-bound organelle are not affected by other cellular reactions.
- ✓ Also, membranes of the endoplasmic reticulum separate areas of the cytoplasm and allow them to function independently.

Eukaryotic cells have three major parts. They are:

1. Cell membrane (plasma membrane)
2. Nucleus
3. Cytoplasm

Cell membrane (plasma membrane) -is the outer semi-permeable layer of the cell. It is also called a lipo-protein layer because it is composed of protein sandwiched in between lipid bilayers.

Cell membrane helps for:

- Regulation of the material movement in and out of the cell
- Maintaining the cell shape
- Communication with other cells

Nucleus—is large structure which is surrounded by double membrane and it contains **nucleolus** and **chromosomes**.

Nucleus is important because:

- It contains hereditary information of an organism in the chromosomes.
- It controls and directs the cellular activities.

Cytoplasm--- is part of protoplasm found outside the nuclear membrane.

- ❖ It is filled with jelly fluid and it encompasses the largest proportion of the cell.
- ❖ **Cytoplasm** is also known as the **center for the chemical reactions** of the cell.
- ❖ It consists of thousands of little structures called **organelles**.
- ❖ Each organelle in the cytoplasm has specific activity to perform.

Among various organelles found in the cytoplasm, some of the major ones are:

- | | |
|--------------------------|--------------|
| 1. Endoplasmic reticulum | 5. Ribosome |
| 2. Golgi apparatus | 6. Lysosomes |
| 3. Mitochondria | 7. Vacuole |
| 4. Chloroplasts | 8. Centriole |

Note: **Protoplasm** is the living portion of the cell as distinguished from the non-living cell wall.

Thus, it consists of cell membrane, cytoplasm and nucleus. See figure 4.15.a generalized animal cell and figure 4.16 a generalized plant cell page 122.

Origin of eukaryotic cells

- One theory is that the 'modern' eukaryotic cell was formed when several of the more primitive cells 'got together'.
- Over millions of years 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 would eventually evolve into the **endoplasmic reticulum** (EPR) of eukaryotic cells.
- The next stage in the 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 protoctozoan 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 photosynthesize and would, in time, evolve into **chloroplasts**.
- The cells that contained these would be autotrophic and the forerunners of the plant cells.
- This theory of the origin of eukaryotic cells is called the **endosymbiont theory** and was first proposed by the biologist **Lynn Margulis**.

Endosymbiont theory—is the theory of the origin of eukaryotic cells.

The **archaeobacteria** are thought to be the **oldest** organisms on Earth.

- They evolved when conditions on Earth were **very harsh** and are still only found where it is very hot, or where there are large concentrations of gases like methane or sulphur dioxide.
- The eubacteria are what we really mean when we talk about bacteria.
- These are the bacteria that inhabit our intestines, decay organisms, convert milk to yoghurt and so on.

Table 4.1 **The difference between prokaryotic and eukaryotic cells**

Feature	Prokaryotic cells	Eukaryotic cells
Size	1—10 micro meter	10—100 micro meter
Nucleus	No membrane bound	Nucleus surrounded by nuclear membrane
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 photosynthesize)	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 but it is 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

1. Cell membrane(plasma membrane)

- Controlling what enters and leaves the cell; the plasma membrane moves substances 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 reorganized by hormones and the 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 exchangers with that environment.
- ❖ The basis of plasma membrane is a **phospholipid bilayer**.
- ❖ But a plasma membrane is much more complex than a simple bilayer.
- ❖ There have been several models of the structure of plasma membrane.

Table 4.2 **some history about plasma membrane model**

Year	Event
1665	Robert Hooke discovers cells, but only sees dead cells and has no idea of a cell membrane
1895	Charles Overton shows that the cell membrane is composed of some kind of lipid
1905	Langmuir proposes a lipid monolayer as a basic membrane structure
1910— 1920	Evidence accumulates to show that the lipid in the membrane must be a phospholipid
1925	E Gorter and G Grendel suggest that the plasma membrane is a phospholipid bilayer
1935	Davson and Danielli know that proteins are also found in plasma membrane and suggest a ' sandwich ' model
1959	Based on electron microscope evidence that appears to support the Davson-Danielli model, J D Robertson proposes the unit membrane model—he suggests that all membranes are essentially the same
1972	S J Singer and G L Nicholson propose the fluid mosaic model of membrane structure. As more and more supporting evidence accumulates, this is essentially the model we accept today

The Davison –Danielli model

- ❖ In 1935, **Davson** and **Danielli** knew that both proteins and phospholipids were involved in the structure of plasma membranes.
- ❖ Without any direct observational evidence to assist them (the very first electron microscope were only just being built and they could not reveal membrane structure) Davson and Danielli suggested a kind of sandwich of protein and phospholipid. See figure 4.20 page 127.
- ❖ This was based on what they knew of the proportions of the two substances in the membrane.
- ❖ The **protein** was to form the '**bread**' of the sandwich with the **phospholipid** forming the '**filling**'.
- ❖ In 1954 they proposed a revised model in which they included **protein-lined pores**.
Figure 4.20 page 127 shows the Davison-- Danielli models of 1935 and 1954.
- ❖ As more and more evidence accumulated about how molecules moved across membranes, it became clear that the Davson--Danielli model could NOT adequately explain all the new evidence. **The model therefore had to be rejected.**
- ❖ In 1972, Singer and Nicholson proposed a totally different arrangement of the phospholipids and proteins in the plasma membrane.
- ❖ They retained the idea of phospholipid bilayer, **but rejected the sandwich arrangement.**
- ❖ Instead, they suggested that proteins were studded into the bilayer at different points.
- ❖ They also suggested that the arrangement was **not static**, but was **fluid and constantly changing**.

- ❖ Figure 4.21 page 128 shows the difference between the Davson--Danielli model and the original fluid mosaic model.
- ❖ As our understanding of the processes that occur at the plasma membrane has increased and we have learned more of cell structure and function, the **fluid mosaic model** has become more sophisticated.
- ❖ Our current idea of membrane structure still assumes this fluid mosaic nature, but there is now much more detail to the model, as figure 4.22 (page 128) shows.
- ❖ The key features of the model as we currently understand it are:
 - I. **Phospholipid** bilayer as the **basis** for the membrane.
 - II. **Integral proteins** (also known as intrinsic proteins and trans-membrane proteins) that span the membrane.
 - ☞ Some of these proteins play an important role in moving substances across the membrane.
 - ☞ **There are three main types of these transport proteins:**
 1. **Channel proteins**—these proteins have a channel through them along which a specific ion can pass; there are different channel proteins for different ions.
 2. **Carrier proteins**—these proteins act in a more sophisticated way to move larger molecules through the membrane by facilitated diffusion or active transport; the ones involved in active transport are often referred to as **pumps**.
 3. **Peripheral proteins**—(also known as extrinsic proteins) that span only one layer (or sometimes less) of the membrane.

They have a range of functions; some are enzymes others anchor integral proteins to the cytoskeleton.
 - III. **Glycoproteins and glycolipids**—protein and lipid molecules that have carbohydrate chains attached to them and often serve as signals to other cells.

They also act as receptor sites for hormones and drugs. The carbohydrate component of each can be cell-specific and so allow identification of the cell by the immune system.
 - IV. **Cholesterol**—reduces the fluidity of the membrane.

Why the fluid mosaic model is called the fluid mosaic model?

- It is fluid mainly because the phospholipids in the membrane can move and change position. Figure 4.23 (page 129) shows some ways which they do this.
- The nature of the fatty acids (saturated or unsaturated) and the amount of cholesterol in the membrane both influence the fluidity of the membrane.
- The '**mosaic**' part of the name comes from the way the proteins in the membrane give a patchwork appearance when viewed from the inside or outside. This is rather like a mosaic. See figure 4.23 page 129.

How do substances cross the plasma membrane?

Not all particles can actually pass through a plasma membrane unaided.

This is because of the largely lipid nature of the membrane.

To pass through the plasma membrane by simple diffusion particles must be:

- Small in size
- 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 the really large particles, such as proteins.

We can group the processes by which substances cross the plasma membranes into two main types:

1. **Passive processes**—these 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

2. **Active processes**—these require energy from the cell's metabolism in the form of ATP to drive the transport

Table 4.3 Transport processes

Passive processes

1. Simple diffusion

- ❖ In fluids—**liquids and gases**—the particles that make up the fluid are free to move around.
- ❖ This kinetic energy is what drives diffusion.
- ❖ If particles are, for some reason, concentrated in a small area, they will move in such a way that the particles 'spread out' and occupy all the space that is available to them.
- ❖ This is a result of random particular motion.
- ❖ Diffusion need not involve a membrane.
- ❖ When particles diffuse across the plasma membrane, there must be a concentration difference between the two sides of the membrane (a concentration gradient) to drive the process.
- ❖ As diffusion proceeds, the high concentration will decrease and the low concentration will increase until the two concentrations are the same.
- ❖ At this point there will be no further net diffusion.
- ❖ This means that although particles will still move across the membrane, they will move equally in both directions, so there will be **no** overall effect.
- ❖ We say that the concentrations are in equilibrium. Figure 4.24 and 4.24 (page 131). Show this.

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

1. **Concentration gradient** — a bigger difference in concentration results in faster diffusion than a smaller gradient
2. **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 for other situations where particles must cross some kind of barrier, a shorter distance results in faster diffusion.
3. **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 **Ficks law of diffusion**:

$$\text{Rate of diffusion} \rightarrow \frac{\text{Surface area of membrane} \times \text{Concentration gradient}}{\text{Diffusion gradient}}$$

The rate of diffusion is also influenced by **temperature**.

Diffusion occurs faster at higher temperature because the particles have **more kinetic energy** and so move faster.

2. Facilitated diffusion

Facilitated diffusion—is essentially the same process as diffusion, in that it depends on a concentration gradient to all particles to cross the membrane.

- However, it differs in that the particles must be helped to diffusion across the membrane(their diffusion must be 'facilitated') by a carrier protein or a channel protein with an ion pore. See figure 4.26A and 4.26B (131).
- Figure 4.26A shows facilitated diffusion of an ion **through an ion pore** and figure 4.26B shows a **carrier protein** moving particles across a membrane.
- **Note** in both cases that the particles are moving from a high concentration to a low concentration (as with simple diffusion).
- However, also note that whilst the ions can simply move straight through the **ion pore** of a channel protein, the carrier protein must undergo a **conformational change** (change in shape) 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 (or channel proteins) presents.

3. Osmosis

Osmosis—is the process by which water moves across a partially permeable membrane. It is effectively, the diffusion of water.

- ❖ However, we do not refer to the concentration of water molecules, but to **water potential**.
- ❖ We can say that osmosis is the 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--- (psi).
- ❖ Water potential is measured in units of pressure—pascals (Pa), kilopascals (KPa) or megapascals (MPa).
- ❖ Pure water has a higher water potential than any other system. It is defined as Zero: $\psi(\text{pure water}) = 0$ Pa
- ❖ All other systems (cells, solutions and suspensions) have a water potential that is lower than that of water. Therefore, their water potential values must be **negative**.
- ❖ So we can define osmosis more accurately as follows:

Osmosis—is the 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.

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

1. Surface area of the membrane
2. Difference in water potential
3. Distance the molecules must travel

Why water potential values are negative?

- The water potential of a system is due to the concentration of free water molecules 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.

What happens to cells placed in solutions of different concentrations?

- ❑ This depends on what type of cell. Animal cells have no cell wall, whereas plant cells have cell wall and this has a significant influence on the outcome.
- ❑ The difference in water potential between cell and solution will determine whether water enters or leaves by osmosis.
- ❑ When comparing the water potential of a solution to that of a cell, we could describe it as:
 1. **Isotonic**—having the same water potential as the cell
 2. **Hypertonic**—having a lower (more negative) water potential than the cell
 3. **Hypotonic**—having a higher (less negative) water potential than the cell

Animal cells

In hypertonic solution—the RBCs lose water by osmosis and shrink

In the hypotonic solution—the RBCs gain water by osmosis and swell.

The pressure will eventually burst the weak plasma membrane; this is called **haemolysis**.

There is no change in the isotonic solution.

Plant cells

- ☞ In the **hypertonic solution**—the cytoplasm of the cells lose water by osmosis and shrink.
- ☞ Because of this, there is no pressure from the cytoplasm on the cell wall.
- ☞ The cell is said to be **flaccid**.
- ☞ If the cytoplasm shrinks too much, it loses contact with the cell wall and we say the cell has been **plasmolyzed**.
- ☞ In the **hypotonic solution**—the plant 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**.
- ☞ There is no change in the **isotonic solution**.
- **Turgidity** is important in supporting young, non-woody plant stems.
- If the plant is kept well watered, the cells **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 **plasmolysed** and become **flaccid**.
- They will no longer press against each other and the support will be lost. This plant will **wilt**.
- See figure 2.28 and 4.29 Page 134).

Active transport

1. Active transport
 1. Endocytosis
 2. Phagocytosis
 3. Pinocytosis
 4. Receptor – mediated endocytosis
 5. Exocytosis
1. **Active transport**—Sometimes substances must be moved against a concentration gradient—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 the metabolic energy is used to drive the process.
 - ❖ In living organisms, this energy is released from the ATP produce in respiration.
 - ❖ When the energy is released from ATP, it is broken down into ADP and Pi (inorganic phosphate)
 - ❖ The proteins used to actively transport substances across plasma membranes are called **pumps**.
2. **Endocytosis**—In this process, large particles are engulfed by a cell.
 - ❖ There are several ways in which it can happen, but, essentially, part of the plasma membrane surrounds the particles to form a vesicle which is then processed by the cell.
 - ❖ Figure 4.33 shows **three** different types of endocytosis.
 - ❖ All of them require ATP to move the membrane around the particles to form the vesicle.
3. **Phagocytosis**—This involves the creation of pseudopodia (extension of the 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.
4. **Pinocytosis**—This 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.
5. **Receptor-mediated endocytosis**—the membrane infolds to form vesicles only on regions where particles have bound to specific receptors.
 - ♣ The binding stimulates the enfolding.
6. **Exocytosis** — in this process, substances is 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.

Passive processes		Active processes	
Process	Brief description	Process	Brief description

Simple diffusion	Particles move from a high concentration to a low concentration	Active transport	Particles move from a low concentration to a higher concentration using a carrier protein (pump)
Facilitated diffusion	Particles move from a high concentration to a low concentration through an ion pore or carrier proteins	Endocytosis	Large particles are engulfed by the plasma membrane invaginating and forming a vesicle
Osmosis	Water molecules move from a high water potential to a lower water potential	Exocytosis	Large particles are secreted by a vesicle in the cell merging with the plasma membrane to release the substance

Table 4.4 The transport processes compared

Process	Influence of concentration	Requirement of ATP	Type of particles moved	Transport proteins needed
Simple diffusion	Occurs from high to low	No	Lipid soluble, small size, non-polar, non-charged	No
Facilitated diffusion	Occurs from high to low	No	Ions and Medium- sized particles	No
Osmosis	Occurs from high to low (water potential)	No	Water molecule	No
Active transport	Occurs from low to high	Yes	--Ions and medium-sized, --Non-lipid soluble particles	Yes
Endocytosis	Can occur either way	Yes	Very large particles	Yes
Exocytosis	Can occurs either way	Yes	Very large particles	Yes

The other cell organelles—what are they like and what do they do?

1. The nucleus
2. Mitochondria
3. Ribosome
4. Endoplasmic reticulum
5. Golgi apparatus (Golgi body)
6. Lysosomes

Organelles in plants

- 1, Cell wall
2. Vacuole
3. Chloroplast

The nucleus

The **nucleus** typically occupies about 10% of the volume of a cell.

It has several components:

- ❖ The **nuclear envelope**—is a double membrane that surrounds the nucleus.
- ❖ There are many **nuclear pores**, which 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.
- ❖ The function of nucleolus—is synthesis of components of ribosomes, which then pass through the nuclear pores into the cytoplasm.
- ❖ Chromatin—consists of DNA molecules bound with protein called histones.
- ❖ For most of the cell cycle, the chromatin fibers are loosely dispersed throughout the nucleus.
- ❖ Just before a cell is about to divide, the chromatin condenses into distinct, recognizable structures called **chromosomes**.

Mitochondria

Mitochondria—are the sites of most of the reactions of aerobic respiration.

They are surrounded by **two membranes**.

The inner membrane is folded into **cristae** to increase the available surface area.

Some of the reactions of the aerobic respiration take place in the **fluids matrix**.

The folded inner membrane provides a larger surface area for the electron-transport system, **which produces most of the ATP**. See fig.4.37 pp.138.

Note:

- ATP is the 'energy storage molecule' of cells.
- Energy released in respiration is stored in ATP molecules, to be released and used when needed.
- Cells that are very active (such as **muscle cells** or **epithelial cells** that absorb molecules from the gut) use a great deal of ATP and, therefore, contain many mitochondria.

Ribosomes

Ribosomes—are the sites of protein synthesis

They can be found free in the cytoplasm, but are also bound to the membrane system of the endoplasmic reticulum, forming **rough endoplasmic reticulum**.

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. See figure 4.38 page 139.

Endoplasmic reticulum

Endoplasmic reticulum (ER)—is a membrane system found through out the cytoplasm of eukaryotic cells.

There are two types of endoplasmic reticulum:

1. Rough endoplasmic reticulum
2. Smooth endoplasmic reticulum

Rough ER—has ribosomes on its surface and is responsible for the manufacture and transport of proteins.

- ❖ Protein molecules manufactured by the ribosomes pass through small **pores** into the lumen (inner space) of the ER.
- ❖ They are then moved in a vesicle to the Golgi body.

Rough ER—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 ER—has no ribosomes on its surface.

- ❖ It is concerned with the synthesis of lipids. It is also associated with carbohydrate metabolism and detoxification.

Golgi apparatus (or Golgi body)

- ❑ The Golgi apparatus—consists of a number of flattened membrane-bound sacs in which proteins are modified.
- ❑ Proteins may be converted into Glycoproteins, for example.
- ❑ Many of the modifications added in the Golgi apparatus act as a kind of 'tag', which determine the final destination of the molecule.
- ❑ Think of the Golgi apparatus as a cellular post office that labels and then distributes molecules!
- ❑ Many of the modified molecules are released from the Golgi apparatus in vesicles to be carried to other parts of the cell or to the plasma membrane to pass out of the cell by exocytosis to be used elsewhere.
- ❑ Some vesicles form the lysosome. See fig. 4.39 & 4.40 page 139.

Lysosomes

Lysosomes—have no specialized internal structure and are surrounded by a **single membrane**.

- ✓ They are formed in the **Golgi apparatus** and contain digestive enzymes that break down cellular waste and debris.
- ✓ Lysosomes are particularly abundant in phagocytic white blood cells.
- ✓ Here enzymes from the lysosomes digest foreign cells that have been engulfed.
- ✓ The organelles we have described so far are found in all eukaryotic cells.
- ✓ However, not all eukaryotic cells are the same.
- ✓ In particular, there are important differences between plant and animal cells.

Cell wall

- ❖ The **criss-cross arrangement** of cellulose fibers in the cell wall gives it both strength and elasticity.
- ❖ Because there are large 'gaps' (on a molecular scale) between the fibers, the 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 a vacuole is full of liquid (mainly water), it exerts pressure on the cytoplasm and, in turn, on the cell wall.
- ❖ If vacuole loses water by osmosis, the pressure reduces and turgor is lost. The cell becomes **flaccid**.

Chloroplasts

Chloroplasts are surrounded by **two membranes**, like mitochondria, but, unlike mitochondria, the inner membrane is not folded.

There are **two main regions** in chloroplasts that are linked to the stages of photosynthesis:

1. Membranous regions called **grana** (each of which is a stack of **thylakoid**) where the light-dependent reactions occur, and
2. A fluid **stroma**—where the light-independent reactions occur. ---See figure 4.42 page 141

How have biologists been able to study the different organelle?

1. *Journal of Management Studies*, 1996, 33, 1, 1-14.

- A. Simple diffusion
- B. Facilitated diffusion
- C. Osmosis
- D. Active transport
12. Which of the following cell types can be reach in lysosomes?
 - A. Nerve cell
 - B. Phagocytic cells
 - C. Muscle cell
 - D. Red blood cells
13. Which of the following requires expenditure of ATP (2004 E.C.)?
 - A. Osmosis
 - B. Facilitated diffusion
 - C. Simple diffusion
 - D. Endocytosis
14. Among the following identify the cellular structure in which nucleic acid is not found
 - A. Chloroplast
 - B. Mitochondria
 - C. Golgi body
 - D. Ribosome
15. Suppose we consider four hypothetical cells (designated A,B,C and D) having cubic shape with their sides measuring 2,4,6,and 8 arbitrary units, respectively which of these cells has the largest surface area to volume ratio (2004 E.C.)?
 - A. Cell A
 - B. . Cell B
 - C. Cell C
 - D. Cell D
16. Suppose three potato cylinders are kept for some time in 15%, 8% and 4% sucrose solutions respectively, and the third cylinder is kept in distilled water, which of the cylinders will more flaccid (2005 E.C.)?
 - A. The cylinder in 4% solution
 - B. The cylinder in 15% solution
 - C. The cylinder in 8% solution
 - D. The cylinder in 8% solution
17. Which of the following scientist (s) is (are) most closely associated with the statement of cell theory?
 - A. Darwin and Mendel
 - B. Schwann and Scheleiden
 - C. Louis Pasteur
 - D. Robert Hooke
18. Which one of the following is the main constituent of biological membranes (2005 E.C.)?
 - A. Phospholipids
 - B. Glycoproteins
 - C. Glycolipids
 - D. Cholesterol
19. If a suspension of a mixture of cellular organelles is spun in a centrifuge which organelle settles to the bottom first (2005 E.C.)?
 - A. Mitochondria
 - B. Chloroplast
 - C. Nuclei
 - D. Ribosomes
20. If a size of a cell increases, which one of the following gets smaller (2005 E.C.)?
 - A. The volume of cell
 - B. The surface area to volume ratio of the cell
 - C. The surface area of the cell
 - D. Volume to surface area ratio of the cell
21. Which of the following is an important function of the Goli apparatus (2005 E.C.)?
 - A. Protein synthesis
 - B. Packaging of protein for export out of the cell
 - C. Removing of debris from the cell
 - D. Storage of waste materials not needed by the cell
22. What distinguishes living cells from non-living matter?
 - A. The organization of the different molecules
 - B. The environment in which they are found
 - C. The molecules from which they are made
 - D. The creator
23. In which of the following features are eukaryotic cells distinguished from prokaryotic cells (2005 E.C.)?
 - A. They have mitochondria
 - B. Their nuclei lack membranes
 - C. They have no DNA
 - D. They have smaller ribosome
24. What will happen if human red blood cells are kept in in a hypotonic solution (2005 E.C.)?
 - A. Lose water by osmosis and burst
 - B. Lose water by osmosis and shrink
 - C. Taking in water by osmosis, swell and burst
 - D. Take in water by osmosis, swell and remain unchanged
25. The detailed structure of cell as seen through electron microscope is known as
 - A. Homogenization
 - B. Ultra structure
 - C. Cytoplasm
 - D. Cell fractionation
26. In which types of solution is the water potential more negative than in the cells (2005 E.C.)?
 - A. Hypotonic
 - B. Isotonic
 - C. Hypertonic
 - D. Equal solute and solvent concentration
27. Which of the following paired organelles are membranes bounded (2005 E.C.)?
 - A. Ribosomes and peroxisomes
 - C. Mitochondria and ribosomes

- B. Chloroplasts and ribosomes D. Chloroplasts and mitochondria
28. Most cell membranes are primarily composed of which compounds (2005 E.C.)?
 A. Proteins and lipids C. Chitin and starch
 B. DNA and ATP D. Nucleotides and amino acids
29. If the red blood cells shrink when placed in a certain solution, what is the strength of the solution relative to the strength of the protoplasm of the cells (2005 E.C.)?
 A. Hypotonic B. Hypertonic C. Isotonic D. Hydrostatic
30. Which of the following cell types can be rich in lysosome (2005 E.C.)?
 A. Red blood cells C. Phagocytic cells
 B. Nerve cells D. Muscle cells
31. One of the following would be harder to see under the ordinary light microscope that is more likely to be available in school laboratories (2005 E.C.)?
 A. Nucleus B. A bacterium C. A mitochondrion D. Ribosome
32. Which of the following is largely made up of phospholipids (2003 E.C.)?
 A. Cell wall B. Cell membrane C. Nucleus D. Chromosomes
33. The growth of cells is limited by the ratio between
 A. Nucleus and cytoplasm C. Organelles and cytoplasm
 B. Organelles and surface area D. Volume and surface area
34. One of the following organelles of the eukaryotic cells does protein synthesis take place (2006 E.C.)?
 A. The nucleus B. The ribosome C. The chloroplast D. The mitochondria
35. Which of the following structures is NOT present in animal cells (2006 E.C.)?
 A. Cell wall B. Nucleus C. Protoplasm D. nucleic acid
36. What is the general term for the part of the protoplasm that lies outside the nucleus (2006 E.C.)?
 A. Cytosol B. Central vacuole C. Cytoplasm D. Plasma membrane
37. In the cell membrane, the phospholipids
 A. Are arranged so that polar head parts face water
 B. Form a single layer interrupted by spaces and pores
 C. Are arranged so that non-polar parts face the outside of the cell
 D. Cannot move
38. Which of the following cellular structures is possessed by all cells (2006 E.C.)?
 A. Cell membrane B. nucleus C. Cell wall D. Golgi apparatus
39. Which of the following eukaryotic cell organelles was a free living cell before eukaryotic cells evolved (2006 E.C.)? A. Nucleus B. Chloroplast C. Ribosome D. Nucleolus
40. Which of the following mechanisms moves digested amino acids and glucose across the plasma membrane of the cell lining the wall of the small intestine (2006 E.C.)?
 A. Osmosis C. Simple diffusion
 B. Facilitated diffusion D. Active transport
41. If a cell fails to clear its cellular debris, which one of its organelles is most likely NOT functioning (2006 E.C.)?
 A. Nucleus B. Mitochondria C. Endoplasmic reticulum D. Lysosomes
42. Among the following identify the organelle in which nucleic acid is NOT found (2006 E.C.)?
 A. Mitochondria B. Chloroplast C. Ribosome D. golgi apparatus
43. The cell membrane consists principally of
 A. proteins embedded in a polymer of glucose C. Proteins embedded in phospholipids bilayer
 B. Proteins embedded in carbohydrate bilayer D. Proteins embedded in a protein layer
44. Suppose a hypothetical cube-shaped cell has sides of 10 micrometers, what is the surface area to volume ratio of this cell (2006 E.C.)? A. 6:10 B. 10:10 C. 3:6 D. 4:8
45. In which of the following solutions does an animal cell undergo haemolysis (2006 E.C.)?
 A. In hypotonic solution C. In Hypertonic solution
 B. In Isotonic solution D. In both hypotonic and hypertonic solutions
46. Which of the following will happen if a plant cell is kept in a solution that is stronger than its protoplasm (2006 E.C.)? A. The cell will become liquid C. The protoplasm will get plasmolysed
 B. The central vacuole will expand D. The cell will swell and burst
47. Which of the following methods is a passive transport
 A. Endocytosis B. Facilitated diffusion C. Phagocytosis D. Exocytosis
48. Which of the following is NOT true about mitochondria and chloroplast (2007 E.C.)?

- A. Both contain chlorophyll
B. Both contain nucleic acid
C. Both have double membrane
D. Both transduce energy
49. Among the following scientists who contributed to the cell theory, identify the one who stated that '*a cell can arise only from another cell like it*'.
A. Robert Hooke B. Matthias Schleiden C. Theodor Schwann D. Rudolf Virchow
50. Which one of the following modes of transport is used by cells to move substances against their concentration gradient (2006 E.C.)?
A. Osmosis B. Facilitated diffusion C. Simple diffusion D. Active transport
51. Which of the following will primarily happen if the enzymes in the lysosomes of a cell are defective (2006 E.C.)?
A. Cellular debris will not be removed C. Chromosome replication will cease
B. ATP production will stop D. Diffusion process will stop
52. By what mean do red blood cells obtain glucose from their surroundings?
A. By the use of channel proteins C. A and B are answers
B. By facilitated diffusion D. By simple diffusion
53. Of the following four cells whose surface area to volume ratio is given, which cell can more efficiently transport its needs of materials across the cell surface (2006 E.C.)?
A. 24:8 ratio B. 54:27 ratio C. 96:64 ratio D. 150:125 ratio
54. The movement of particles from higher concentration gradient to lower concentration gradient is called
A. Osmosis B. Simple diffusion C. Facilitated diffusion D. Active transport
55. Which of the following has a bigger size than all the others (2006 E.C.)?
A. A ribosome taken from animal cell C. A nerve cell taken from a human brain
B. A mitochondrion taken from a plant cell D. A glucose molecule taken from a plant cell
56. Which of the following parts of a plant cell is NOT a living component of a cell (2006 E.C.)?
A. Cell membrane B. Cytoplasm C. cell wall D. Nucleus
57. According to the fluid-mosaic model of the plasma membrane what does the word "mosaic" refers to (2006 E.C.)?
A. The hydrophobic property of fatty acids C. The bilayer nature of the membrane
B. The arrangement of the proteins D. The movement of phospholipids
58. Sodium-potassium pump transports
A. Na^+ out of the cell and K^+ into the cell C. Na^+ into the cell and K^+ out of the cell
B. Both Na^+ and K^+ into the cell D. Both Na^+ and K^+ out of the cell
59. In certain cell, if 2K^+ ions are pumped into the cell and 3Na^+ ions are pumped out of the cell, then which of the following statement holds true?
A. The condition created will favor the diffusion of cations into the cell
B. The conditions created will restrict the entry of negatively charged ions
C. The inner side of the cell becomes more negative than the outer
D. All of these are correct
60. The sodium-potassium pump is an example of
A. Active transport B. Facilitated diffusion C. Passive transport D. Osmosis
61. What the substance that helps to keep the biological membrane in a fluid state (2006 E.C.)?
A. Waxes B. Water C. Cholesterol D. Phospholipids
62. What happens when a plant cell absorbs in more water (2009 E.C.)?
A. It shrinks B. It becomes turgid C. It becomes wilted D. It swells and bursts
63. Which of the following organelles is common to both plant and animal cells (2009 E.C.)?
A. Cell wall B. Mitochondria C. Chloroplast D. Central vacuole
64. If a cell fails to form lysosomes, which of the following cellular functions will get disrupted first (2009 E.C.)?
A. Protein synthesis C. chromosome replication
B. Removal of cellular debris D. Transport across cell membrane
65. When a cell takes liquid substances into its cytoplasm the process is
A. Exocytosis B. Phagocytosis C. Pinocytosis D. Osmosis
66. For a substance to easily pass across the cell membrane by simple diffusion which of the following properties should it possess (2009 E.C.)?
A. Large size C. Positive charge
B. Ability to dissolve in lipid D. Negative charge
67. What happens when red blood cells are kept in a hypertonic solution (2009 E.C.)?
A. The same net gain and loss of water
B. More water gets into the cell than leaving it

- C. More water goes out of the cell than getting in
 D. The cells prevent water from getting in or leaving out
68. Among the following which one best describes the cells of bacteria (2009 E.C)?
 A. Eukaryotic C. Both eukaryotic and prokaryotic
 B. Prokaryotic D. Neither prokaryotic nor eukaryotic
69. Groups of plastids that are primarily involved in storage functions are
 A. Amyloplasts B. Leucoplasts C. Chloroplasts D. Chromoplasts
70. The matrix of chloroplast is
 A. Grana B. Lamellae C. Stroma D. Thylakoid
71. The endosymbiotic hypothesis for the origin of eukaryotic cells provides an explanation for the origin of which of these furniture (s)?
 A. Mitochondria C. Chloroplasts
 B. Nucleus D. A and B are correct answers
72. Which knowledge about cell biology did scientists discover after all the others (2009 E.C)
 A. The first understanding that living things are made of cells
 B. Knowledge about how chromosomes behave during mitosis
 C. First understanding about the double helix structure of DNA
 D. First understanding about the DNA sequence in human genome

UNIT FIVE

Energy transformation

5.1 Cellular Respiration

How do cells generate ATP from food?

- ❖ The food we eat must first be converted to smaller molecules that the cells can use.
- ❖ The first step is, therefore, digestion.
- ❖ Energy supplying foods should be broken down into their constituent parts, i.e., the large polymeric molecules in food are broken down during digestion into their monomers.
- ❖ For example, proteins are converted into amino acids; polysaccharides are converted into simple sugars; and fats into fatty acids and glycerol through the action of digestive enzymes.
- ❖ After digestion, the small organic molecules derived from food enter into the **cytosol** of the cell, where their gradual **oxidation** begins.
- ❖ The digestion outside of the cell (in digestive system) is called **extracellular digestion**.
- ❖ Once inside the cell, glucose is broken down to produce ATP in two path ways. They are called **aerobic** and **anaerobic** respiration.
- ❖ The first pathway requires **no oxygen** and is anaerobic metabolism. This pathway is called **glycolysis** and it occurs in the cytoplasm outside the mitochondria.
- ❖ During glycolysis, glucose is broken down into **pyruvate**.
- ❖ Other foods like fats can also be broken down for use as fuel.
- ❖ Each reaction is designed to produce some hydrogen ions that can be used to make energy packets (ATP).
- ❖ In glycolysis ATP is generated anaerobically.
- ❖ For each glucose molecule **two ATP** molecules are expended in preparing the glucose molecule and four ATP molecules are formed by **substrate-level phosphorylation** (formation of energy-rich phosphate compounds such as ATP by transfer of **phosphate** from a metabolic substrate to ADP directly with no respiratory chain involvement) a **net yield of two ATP** molecules.
- ❖ The second stage of extracting energy from glucose, after glycolysis, is a cycle of aerobic respiration known as the **Kreb's cycle** or the **citric acid cycle**.
- ❖ The pyruvate left over from glycolysis is first converted to a **two carbon** molecule, which feeds into the cycle.
- ❖ In the Krebs cycle, **two more ATP** molecules are extracted by substrate-level phosphorylation and a large number of electrons are removed and donated to electron carriers.
- ❖ It is harvesting of these electrons that leads to the greatest amount of ATP formation.

- ❖ When the cycle is completed the six carbon glucose molecules have been divided into **six molecules of CO₂** and **36 ATP** molecules have been generated, (**4 by substrate-level phosphorylation and 32 by oxidative phosphorylation**).
- ❖ Each ATP molecule represents the capture of 7.3 kilocalories of energy per mole of glucose; therefore, 36 ATP molecules represent a total capture of $7.3 \times 36 = \mathbf{263 \text{ kilocalories per mole}}$.
- ❖ The total energy content of the chemical bonds of glucose is only 686 kilocalories per mole, so we have succeeded in harvesting 38% of the available energy.
- ❖ By contrast a car converts only about 25% of the energy in gasoline into useful energy.

ATP: The energy currency of the cell

- The chief energy currency of all cells is a molecule called **adenosine triphosphate, or ATP**.
- **ATP** is the cell's chief energy currency. ATP is like cash on your pocket for cells.
- Each ATP molecule is composed of **three subunits**.
 1. The first subunit is a five-carbon sugar called **ribose**.
 2. The second subunit is **adenine**, an organic molecule composed of two-carbon-nitrogen rings.
 - Each of the nitrogens in the ring has an unshared pair of electrons that weakly attract hydrogen ions.
 - Adenine therefore, acts as a chemical base and is usually referred to as a **nitrogenous base**.
 - Adenine plays another major role in the cell: it is one of the four nitrogenous bases that are the principal components of the genetic material (DNA).
 3. The third subunit is a **triphosphate group** (three phosphate groups linked in a chain)
- ❖ The covalent bonds linking these three phosphates are usually indicated by a line that bends (~) and sometimes called **high-energy bonds**.
- ❖ When one is broken slightly more than 7 kilocalories of energy are released per mole of ATP.
- ❖ These phosphate bonds possess what a chemist would call “high transfer potential”, that is they are bonds that have low activation energy and are **broken easily**, which releases their energy.
- ❖ In a typical energy transaction only the outer most of the two high energy bonds is broken, breaking off the phosphate group on the end.
- ❖ When this happens adenosine diphosphate (ADP) and 7 kilocalories of energy are expended per mole of ATP.
- ❖ Because almost all endergonic reactions in the cell require less than 7 kilocalories of activation energy per mole, ATP is able to power all of the cell's activation.
- ❖ Thus although the high-energy bond of ATP is not highly energetic in an absolute sense—for example, it is not nearly as strong as a carbon-hydrogen bond, it is more energetic than the activation energies of almost all energy-requiring cell activities.
- ➔ ATP is essentially the adenine nucleotide with two extra 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 are still left with a phosphorylated molecule, but this only has two nucleotides. It is **adenosine Di-phosphate—or ADP**.
- ➔ ATP is sometimes described as a **phosphorylated nucleotide**.
- ➔ Phosphorylated nucleotide—the adding of one or more phosphate group to a molecule.
 - ❖ Notice that ATP is formed in both photosynthesis and in cellular respiration so the energy to form the ATP comes from sun light and food.
 - ❖ Sunlight energy cannot be used directly by plants to drive the synthesis of proteins—or other molecules.
 - ❖ The same applies to the energy held in a glucose molecule.
 - ❖ These two energy sources must be used to produce ATP, which is used to transfer the energy to the relevant cellular processes.
 - ❖ We say that it is coupled to these processes. See figure 5.4 page 153.
- ✓ **Coupled reactions**—are reactions in which energy-requiring chemical reactions are linked to energy-releasing reactions,
- ✓ Cells contain a pool of ATP, ADP and phosphate.
- ✓ ATP is constantly being cleaved into ADP plus phosphate to drive the endergonic, energy-requiring processes of the cell.

- ✓ Using the energy derived from food stuffs and from stored fats, or starches and glycogen, ADP and phosphate are recombined to form ATP, with 7 kilocalories of energy per mole contributed to each newly formed high energy bond.
- ✓ Thus, the ATP/ADP system serves as a universal energy exchange system, shuttling between **energy releasing** and **energy requiring** reactions.

ATP is adapted to this role because it:

- Releases energy in relatively small amounts that are closely matched to the amount of energy required in many biological processes occurring inside cells.
- Releases energy in a single-step hydrolysis reaction, so the energy can be released quickly
- It 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 plasma membrane
- Muscle contraction
- Conduction of nerve impulses
- The initial reactions of respiration (the later reactions releases 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.
- It obviously involves ADP and P_i joining to form ATP and this requires input of energy.
- The formation of ATP involves an enzyme called **ATP synthase**.

Figure 5.5 shows the structure of ATP synthase molecule. The ATP synthase in this diagram is in one of the membranes of a mitochondrion, but it could be in a membrane of a chloroplast.

In both photosynthesis and aerobic respiration, many of the reactions generate the hydrogen ions that will pass through the ATP synthase to produce ATP.

How is ATP produced in respiration?

There are two main ways by which respiration can produce ATP.

1. The aerobic pathway (aerobic respiration)=requires the presence of oxygen, and
2. The anaerobic pathway (anaerobic respiration and fermentation) — this can take place in the absence of oxygen

How is ATP produced in aerobic respiration?

- ❖ A small amount of ATP is produced in a way that does not involve the ATP synthase molecule; this method is called **substrate level phosphorylation**.
- ❖ In this process, another molecule such as phosphoenol pyruvate (the *substrate*) is able to transfer a phosphate group directly to ADP.
- ❖ There is **no** ATP synthase involved and **no** P_i .
- ❖ The process is still catalyzed by an enzyme, it is just **not** ATP synthase.
- ❖ As about 90% of the ATP produced in aerobic respiration is produced by ATP synthase, many of the reactions of this process are geared to to producing hydrogen ions that will spin the rotor of the ATP synthase molecule.
- ❖ Many different organic molecules can be respired—they are called respiratory substrates.
- ❖ However, glucose is the most commonly respired substrate so we will begin by looking at how this molecule is respired.

How are hydrogen ions transferred from glucose to ATP synthase?

Two molecules are important in this transfer process:

1. NAD (Nicotinamide Adenine Dinucleotide)
2. FAD (Flavin Adenine Dinucleotide)

- ❖ Both are coenzymes and are capable of accepting hydrogen ions.
- ❖ When this happens, we say that the molecules have been **reduced**.
- ❖ We write the reduced forms of the molecules as NADH and FADH or NAD (reduced) and FAD (reduced).
- ❖ These molecules can release their hydrogen ions and become **oxidized** again.
- ❖ The hydrogen ions can then be used to turn the rotor of ATP synthase.

Cellular respiration—the process by which food molecules is broken down by enzymatic reactions to release energy for work.

There are two types of cellular respiration

1. **Aerobic respiration**
2. **Anaerobic respiration**

Stages of aerobic respiration of glucose

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

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

Glycolysis: The anaerobic stage

- ❖ Cellular respiration begins with a biochemical pathway called **glycolysis** which yields relatively small amount of ATP (2ATP).
- ❖ **Glycolysis** literally means '**splitting sugar**'. Therefore glycolysis is the sequence of reactions that convert a glucose molecule (a six carbon compound) into **two molecules of pyruvate** (a three carbon compound) with the **production of ATP**.
- ❖ Each reaction of glycolysis is regulated by **specific types of enzymes** and the whole reactions take place in the **cytoplasm** of a cell.
- ❖ It is the **anaerobic stage of cellular respiration**, because it does not require utilization of O₂.
- ❖ During this stage of cellular respiration **2 net ATP molecules** are produced from **one glucose** molecule.
- ❖ The major reason why glycolysis takes place in the cytoplasm of the cell are:

- 1, The glucose molecule is too large, that it cannot diffuse through mitochondrial membrane
- 2, There are no carrier proteins used to transport the glucose molecule across the mitochondrial membrane.

- ❖ Pyruvate can enter the mitochondria and all the other stages take place inside the mitochondria.
- Figure 5.8 page 156 shows where the stages of aerobic respiration take place.

What happens in glycolysis?

The following reactions take place in the glycolysis:

- Two molecules of ATP are used to 'phosphorylate' each molecule of glucose. This makes the glucose more reactive.
- In the phosphorylation process, it is converted to another six-carbon sugar (fructose 1,6-biphosphate)
- The fructose 1,6-biphosphate is split into two molecules of the three-carbon sugar, glyceraldehyde-3 phosphate (GP).

The above three reactions can be shortly summarized as:
 $\text{Glucose} + 2\text{ATP} \rightarrow 3\text{GP} + 2\text{ADP} + 2\text{Pi}$

- During these reactions two hydrogen atoms are removed and enough chemical energy is released to produce four ATP molecules
$$2\text{GP} + 4\text{ADP} + 4\text{Pi} \longrightarrow 2\text{pyruvate} + 4\text{H} + 4\text{ATP}$$
- Each molecule of Gp is then converted into pyruvate, with the production of two molecules of ATP (by substrate level phosphorylation) and one molecule of reduced NAD

At the end of glycolysis, there is a net gain of two ATP molecules per molecule of glucose (two molecules are used initially and then four are produced).

Two molecules of reduced NAD are also produced (per molecule of glucose).

The molecules of pyruvate pass in to the mitochondria through **carrier molecules** in the mitochondrial membrane.

Table 5.1 Glycolysis leads to either fermentation or aerobic respiration

- ❖ Glycolysis involves **ten** series of reactions.
- ❖ The reactions can be condensed into four main steps.
- ❖ All these chemical reactions are catalyzed by specific enzymes.
- ❖ All of the reactions of Glycolysis take place in the **cytosol** of the cell.

Step 1

- ❖ Two phosphate groups are attached to glucose forming a new six-carbon compound.
- ❖ The phosphate groups are supplied by two molecules of ATP, which are converted into two molecules of ADP, which are converted into two molecules of ADP in the process.
- ❖ The purpose of the energy supplied in the form of phosphate group is to activate the stable compound (glucose)

Step 2

- The six-carbon compound formed in step 1 is split into two three-carbon molecule of PGAL (phosphoglyceraldehyde).

Step 3

The two PGAL molecules are oxidized, and each receives a phosphate group.

- The product of this step is two molecules of a new three-carbon compound.
- The oxidation of PGAL is accompanied by the reduction of two molecules of **NAD⁺** to **NADH**,
- NAD or nicotinamide adenine dinucleotide, is an organic molecule that accepts electrons during redox reactions.

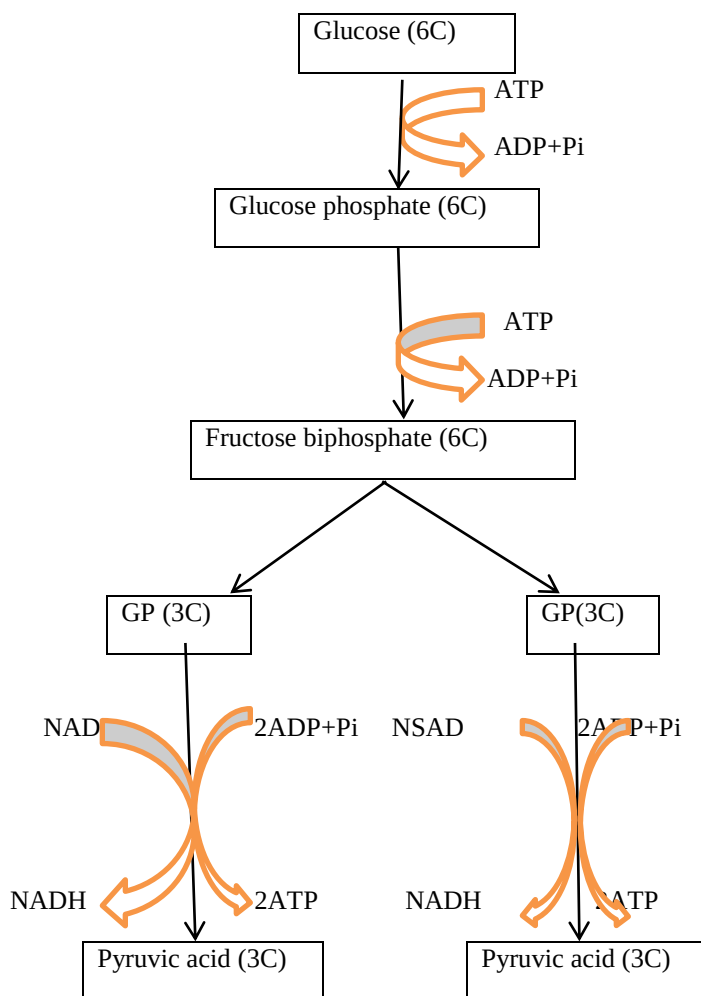
Step 4

- The phosphate group added in step 1 and step 3 are removed from the three-carbon compounds formed in step 3.
- This reaction produces two two molecule of **pyruvic acid**.
- Each phosphate group is combined with a molecule of ADO to make a molecule of ATP
- Because a total of four phosphate groups are added in step 1 and step 3, four molecules of ATP are produced.
- **Notice** that two ATP molecule were used in step 1 but **four** were produced in step 4, therefore, glycolysis has a net yield of **two ATP** molecules for every molecule of glucose that is converted into pyruvic acid.
- What happens to the pyruvic acid depends on the type of cell and on whether oxygen is present.
- The oxidation of glucose to pyruvic acid by the pathway is called glycolysis
- This process can occur whether or not oxygen is present, because no molecular oxygen is used; it is frequently termed anaerobic respiration.

We can summarize the results of glycolysis as follows:

1. The breaking down of a molecule of glucose (a six-carbon compound) to two molecules of pyruvic acid (a three-carbon compound).
 2. The use of two molecules of ATP as activation energy and the synthesis of four new molecules of ATP, for a net gain of two molecules of ATP.
 3. The production of two molecules of NADH.
- ❏ If no oxygen is present i.e., if the conditions are anaerobic, the pyruvic acid formed by glycolysis will accept the hydrogen from NADH, freeing the NAD^+ for further use as hydrogen acceptor and enabling glycolysis to continue.
- ❏ The addition of hydrogen to pyruvic acid results in the formation of **lactic acid** (a three-carbon compound) in animal cells and some unicellular organisms or in the formation of **ethyl alcohol** (a two-carbon compound and **carbon dioxide**) in plant cells and in many unicellular organisms; see fig 5.22 page 16

The overall stages of glycolysis



❖ A summary of the overall reaction of glycolysis

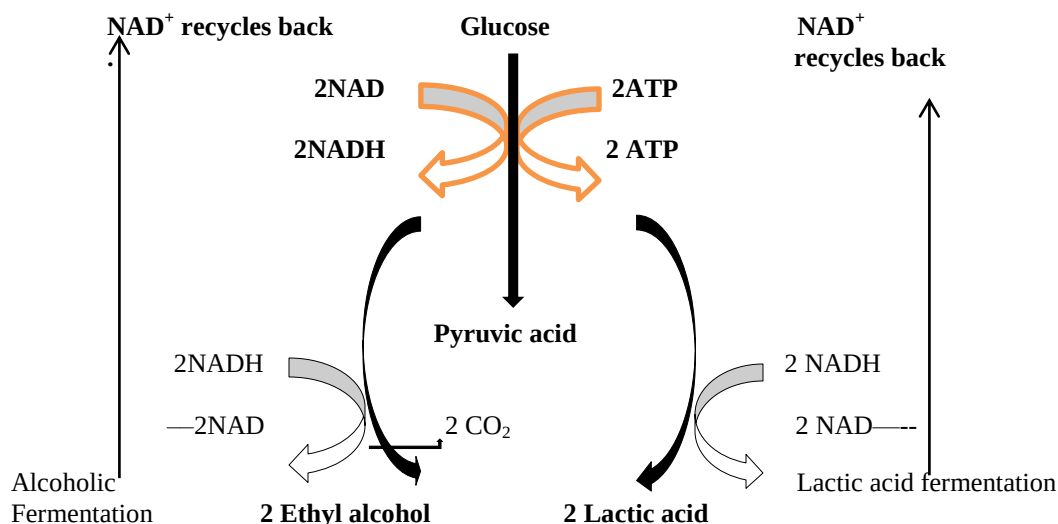


- ❖ The other products of glycolysis follow either of **two main pathways** depending on whether there is oxygen in the cell.
- ❖ If oxygen is absent, the products of glycolysis may enter the **alcoholic fermentation pathway** or **lactic acid fermentation pathway** that yield no additional ATP.
- ❖ **Alcoholic fermentation:** Yeasts and a few other microorganisms use alcoholic fermentation, which produces ethyl alcohol and carbon dioxide.
- ❖ A summary of alcoholic fermentation after glycolysis is:

$$\text{Pyruvic acid} + \text{NADH} \longrightarrow \text{Alcohol} + \text{CO}_2 + \text{NAD}^+$$
- ❖ Alcoholic fermentation is used to produce beverages.
- ❖ It is also the process that causes bread dough to rise.
- ❖ When yeast cells in the dough run out of oxygen, the dough begins to ferment, giving off tiny bubbles of carbon dioxide.
- ❖ These bubbles form the air spaces you see in the slices of bread.
- ❖ **Lactic acid fermentation:** Most microorganisms carry out fermentation carrying a chemical reaction that converts pyruvic acid to lactic acid.
- ❖ Unlike alcoholic fermentation, lactic acid fermentation does not give off carbon dioxide.
- ❖ However, like alcoholic fermentation, lactic acid fermentation also regenerates NAD^+ so that glycolysis can continue.
- ❖ **Lactic acid fermentation** after glycolysis can be summarized as:

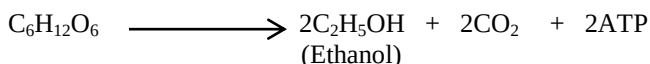
$$\text{Pyruvic acid} + \text{NADH} \longrightarrow \text{Lactic acid} + \text{NAD}^+$$
- ❖ Certain bacteria that produce lactic acid as a waste product during fermentation are important to industry.
- ❖ For example, prokaryotes are used in the production of a wide variety of foods and beverages-----such as cheese, yogurt, and sour cream.
- ❖ Humans are lactic acid fermenters. During brief periods without oxygen, many of the cells in our bodies are capable of producing ATP by lactic acid fermentation.

Glycolysis

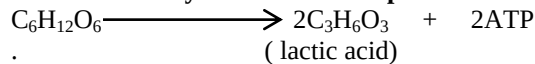


Because they operate in the absence of oxygen, glycolysis and the fermentation pathways are called **anaerobic respiration**.

A summary of anaerobic respiration in yeast cells



A summary of anaerobic respiration in animal cells



Link reaction

- In the link reaction, pyruvate is then converted into a two carbon-compound that enters into a cycle of reactions—the Krebs cycle (named after Sir Hans Krebs who discovered the reactions involved).
- Both this stages (link reaction and Krebs cycle) take place in the **fluid matrix** of mitochondria.
- In the link reaction, a molecule of pyruvate reacts with a molecule called **coenzyme A (CoA)** to form a molecule of **acetyl Coenzyme A (acetyl CoA)**. In the reaction:
 - Hydrogen is lost and reduced NAD (NADH) is formed; removing hydrogen from a molecule is called **dehydrogenation**.
 - A carbon atom is lost to form carbon dioxide; removing carbon a molecule is called **decarboxylation**

The acetyl coA then reacts with a C-4 molecule called **oxaloacetate**. In the reaction, acetyl CoA breaks down into:

- ☞ **A two-carbon 'acetyl' group**, which reacts with the C 4 compound oxaloacetate to form a C6 compound (citric acid), 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.

The aerobic stage

Aerobic respiration has two major stages:

1, The Krebs cycle

2, The electron transport chain (ETC)

- ❖ In the Krebs cycle, the oxidation of glucose that began with glycolysis is completed.
- ❖ As glucose is oxidized, NAD^+ is reduced to NADH
- ❖ In the electron transport chain **NADH** is used to make ATP.
- ❖ The reaction of the Krebs cycle and the electron transport chain occur **only if oxygen is present** in the cytosol of the cell.
- ❖ In **prokaryotes**, the reactions of the Krebs cycle and the electron transport chain takes place in the **cytosol** of the cell.
- ❖ In eukaryotic cells, however, these reactions take place in the mitochondria rather than in the cytosol.
- ❖ The pyruvic acid that is produced in glycolysis diffuses across the double membrane of mitochondria and enters the mitochondrial matrix.
- ❖ The mitochondrial matrix is the space inside the inner membrane of a mitochondrion.
- ❖ The mitochondrial matrix contains the enzymes needed to catalyze the reactions of the Krebs cycle.
- ❖ When pyruvic acid enters the mitochondrial matrix, it reacts with a molecule called **coenzyme A** to form **acetyl coenzyme A**, abbreviated **acetyl CoA**.

$$\text{Pyruvic acid} + \text{NAD}^+ + \text{CoA} \rightarrow \text{Acetyl CoA} + \text{CO}_2 + \text{NADH} + \text{H}^+$$

(3C-compound)
(2C-compound)

The Krebs cycle

- The Krebs cycle is named in honor of Sir **Hans Krebs**, who was largely responsible for explaining the pathway in the 1930s.
- The catabolic pathway is also known as the **citric acid cycle**, or **TCA**, for **tricarboxylic acid cycle**.
- The Krebs cycle has five main steps
- In eukaryotic cells all the five steps occur **in the mitochondria**.

Step 1

- Two carbon molecules of **acetyl CoA** combines with a four-carbon compound, **oxaloacetic acid** (oxaloacetate), to form a six-carbon compound, called **citric acid** (citrate).
- In here, the reaction regenerates CoA.

Step 2

- **Citrate** loses a carbon atom (**decarboxylation**) and hydrogen atom to form a **five carbon** compound and **CO₂** is produced.
- By **losing** a hydrogen atom with its electron, citric acid is oxidized.
- The hydrogen atom is transferred to NAD⁺, reducing it to NADH

Step 3

- The five-carbon compound formed in step 2 is then further decarboxylated to form a four-carbon compound and CO₂ is again produced; a molecule of ATP is also synthesized from ADP by **substrate level phosphorylation**.
- Again, NAD is reduced to **NADH**.

Step 4

- The four-carbon compound in step 3 releases hydrogen atom (undergoes several molecular transformations) to regenerate the original four-carbon compound (**oxaloacetate**) and the cycle is complete and can begin again with oxaloacetate reacting with another molecule of **acetyl CoA**.
- In this time, the hydrogen atom is used to reduce FAD to **FADH**.
- Like NAD⁺, FAD accepts electrons during redox reaction.
- See figure 5.11 and 5.12 page 159.

Step 5

The four-carbon compound formed in step 4 releases a hydrogen atom to regenerate oxaloacetic acid, which keeps the Krebs cycle operating. The hydrogen atom reduces NAD⁺ to **NADH**

A summary of the overall reactions of the Krebs cycle:



- ❖ Recall that in glycolysis one glucose molecule produces **two** pyruvic acid molecules, which then form **two** molecules of acetyl CoA.
- ❖ Thus, one glucose molecule causes **two turns** of the Krebs cycle.
- ❖ These two turns produce **six** NADH, **two** FADH₂, **two** ATP, and **four** CO₂ molecules.
- ❖ The CO₂ is a waste product that diffuses out of the cells and is given off by the organism.
- ❖ But note that each glucose molecule yields only **two** molecules of ATP through the Krebs cycle the same number as in glycolysis.
- ❖ The **bulk** of the energy released by the oxidation of glucose still has **not** been transferred to ATP.
- ❖ The transfer requires the **NADH** and **FADH₂** made in the pathways you studied about so far.
- ❖ Glycolysis produces **two** NADH molecules and that the conversion of pyruvic acid to acetyl CoA produces **two more**.
- ❖ Adding **six** NADH molecules from the Krebs cycle gives a total of **10** NADH molecules and **2** FADH₂ from the Krebs cycle derive the next stage of aerobic respiration.
- ❖ That is where **most** of the energy transfer from glucose to ATP actually occurs.

Electron transport chain (ETC)

- ❖ The **electron transport chain** and **chemiosmosis** together make up the process of oxidative phosphorylation.
- ❖ Whereas the reactions of link reaction and Krebs cycle takes place in the fluid matrix of the mitochondrion, the reactions of the electron transport chain and chemiosmosis take place on the inner mitochondrial membrane.
- ❖ Figure 5.13 page 159 shows an electron –micrograph of a mitochondrion.

On the citrate, the following events take place:

- The hydrogen atoms carried by NADH and FADH₂ 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 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 **NADH** make this happen at all three pumps

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

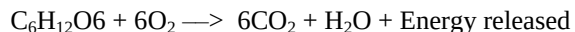
1. **NADH dehydrogenase** (also a proton pump)
 2. **Ubiquinone** (also a proton pump), and
 3. A number of carriers called **cytochromes** (these are proteins that contain iron); two of them form a complex that acts as the third proton pump. The arrangement of these pumps is shown in figure 5.14 page 160.
- ❖ At the end of electron transport chain, the electrons combine with protons and with **oxygen** to form **molecules of water**.
 - ❖ Because of this, oxygen is known as the terminal **electron acceptor**.
 - ❖ Whereas **NADH₂** is dehydrogenated by the NAD dehydrogenase complex, **FADH** is dehydrogenated by **ubiquinone**.
 - ❖ Some electrons from FADH only operate two of the **three proton pumps**.
 - ❖ Because of the action of the proton pumps, **protons accumulate** in the inter-membrane space creating a higher concentration there than in the matrix (on the outer side of the membrane).
 - ❖ The proton gradient results in protons diffusing through the ATP synthase molecule (down the concentration gradient) making the synthase rotor spin and produce ATP from ADP and P_i
 - ❖ The diffusion of hydrogen ions through the ATP synthase is **chemiosmosis**.
 - ❖ The oxidation of one molecule of NADH results in six protons passing through ATP synthase and so leads to the synthesis of three molecules of ATP.
 - ❖ The oxidation of one molecule of FADH results in four protons passing through ATP synthase and so leads to the synthesis of just two molecules of ATP.
 - ❖ By adding up the number of 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.

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

6NADH (from Krebs' cycle) + 2NADH (from glycolysis) + 2 FADH (from Krebs cycle) + 30 ADP + 30P_i → 36ATP + 8NAD + 2FAD

- In practice, this is not achieved because some energy (the equivalent of just two over molecules of ATP) is used to drive the proton pumps. The actual yield is about 36 molecules of ATP per molecule of glucose.
- Figure 5.15 page 161 summarizes the production of ATP in aerobic respiration.

The summary equation for aerobic respiration is:



- ☞ In prokaryotic cells, the electron transport chain lines the cell membrane.
- ☞ ATP is produced by the electron transport chain when NADH and FADH₂ release hydrogen atoms, regenerating NAD⁺ and FAD.
- ☞ The electron transport chain constitutes the second stage of aerobic respiration.
- ☞ In eukaryotic cells, the electron transport chain lines the **inner membrane of mitochondria**.
- ☞ The inner membrane has many long folds called **cristae**.
- ☞ The electrons in the hydrogen atoms from NADH and FADH₂ are at high energy level.
- ☞ In the electron transport chain the high-energy electrons are passed along a series of molecules.
- ☞ As they move from molecule to molecule, the electrons lose some of their energy.
- ☞ The energy the electrons lose is used to pump the protons of the hydrogen atoms from the mitochondrial matrix to the other side of the inner membrane (intermediate space).
- ☞ This pumping builds up a high concentration of protons in the space between the inner and outer mitochondrial membrane.
- ☞ In other words, a concentration gradient of protons is created across the inner mitochondrial membrane.
- ☞ Each time two electrons pass from NADH to the final electron acceptor (oxygen), **three molecules of ATP are formed** from ADP and phosphate.
- ☞ Each time a pair of electrons passes from FADH₂, **two molecules of ATP are formed**.
- ☞ The concentration gradient of protons drives the synthesis of ATP by chemiosmosis—the process in which the movement of down the their concentration gradient across a membrane is coupled to the synthesis of ATP.
- ☞ See figure 5.15 (page 160) which shows the carrier molecules in the electron transport chain on the inner membrane of a mitochondria.
- ☞ ATP synthase molecules are located in the inner mitochondrial membrane.
- ☞ ATP synthase makes ATP from ADP as protons move down their concentration gradient into mitochondrial matrix.
- ☞ The molecules that act as electron carriers in the electron transport chain are:
 1. Reduced NAD dehydrogenase (also a proton pump)
 2. Ubiquinone (also a proton pump)
 3. A number of carriers called cytochromes

The role of oxygen

- ❖ ATP can be synthesized by chemiosmosis only if electrons continue to move from molecule to molecule in the electron transport chain .
- ❖ Obviously, the last molecule in the electron transport chain cannot keep all of the electrons it accepts.
- ❖ If it did, the electron transport chain would come to a halt. Here is where oxygen comes into play in aerobic respiration.
- ❖ Oxygen serves as the final acceptor of electrons. By accepting electrons from the last molecule in the electron transport chain, oxygen allows additional electrons to pass along the chain.
- ❖ As a result, ATP can continue to be synthesized by chemiosmosis.
- ❖ Oxygen also accepts the protons that were once part of hydrogen atoms supplied by NADH and FADH₂.
- ❖ By combining with both electrons and protons (H⁺), oxygen forms water as shown in the following equation;

$$\text{O}_2 + 4\text{e}^- + 4\text{H}^+ \longrightarrow 2\text{H}_2\text{O}$$

Energy yield (the energy balance sheet)

Table 5 Net yield of ATP molecules (complete oxidation of glucose)

- ❖ In some of the eukaryotic cells like muscles and nerve cells 2 ATP are required for transporting NADH produced in glycolysis into the mitochondria for further oxidation.
- ❖ So in such cases the net gain is 36 ATP molecules.
- ❖ In heart and liver cells **38 ATP molecules are produced**.

Process	ATP	Substrate oxidation Products	Net ATP molecules
Glycolysis	4 ATP produced 2 ATP consumed 2 net ATP gained	2NADH=2x3=6ATP	2+6=8ATP
Krebs cycle	2 ATP by substrate level phosphorylation	8NADH=8x3=24 ATP	2+24+4=30ATP 2 of the NADHs are from pyruvate oxidation reaction
Net ATP yield $\longrightarrow$			38 ATP

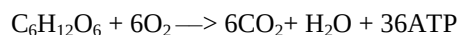
⇒ In some of the eukaryotic cells like muscles and nerve cells 2ATPs are required for transporting NADH produced in the glycolysis into the mitochondria for further oxidation.

⇒ So in such cases the net gain of 36 ATP molecules. In heart and liver cells 38 ATP molecules are formed.

Respirometers

Respirometers come in several different forms, but they all work on the principle that oxygen is used in aerobic respiration and CO₂ is produced.

The overall summary for the aerobic respiration of glucose is:



This equation predicts that the volume of O₂ used (6O₂) is equal to the volume of carbon dioxide (6CO₂). This is the basis of how **respirometers** work.

5.2 Photosynthesis

- ❏ All organisms use energy to carry out the functions of life.
- ❏ Some organisms obtain this energy directly from sunlight.
- ❏ They capture part of the energy in light and store it within organic compounds
- ❏ The process by which this energy transfer takes place is called **photosynthesis**.
- ✓ In eukaryotic cells photosynthetic pigments are organized within a membrane that is contained within an organelle called **chloroplasts**.
- ✓ The chloroplast is a double membranous organelle containing **chlorophylls and other pigments**. **Pigments absorb light**.
- ✓ Located in the membrane of the thylakoids (the structural units of photosynthesis) are a variety of pigments, the most important of which are called **chlorophylls**.
- ✓ There are several different types of chlorophylls. The two most common types are **chlorophyll a** and **chlorophyll b**.

- ✓ Chlorophyll a absorbs **less blue light** but **more red lights** than chlorophyll b absorbs.
- ✓ Neither chlorophyll a nor chlorophyll b absorbs much **green light**.
- ✓ Instead, they allow green light to be **reflected** or **transmitted**.
- ✓ Only chlorophyll a is directly involved the light reactions of photosynthesis.
- ✓ Chlorophyll b assists chlorophyll a in capturing light energy, and therefore chlorophyll b is called an **accessory pigment**
- ✓ Other compounds found in the thylakoid membrane, including the **yellow, orange** and **red carotenoids** also function as accessory pigments.
- ✓ By absorbing colors that chlorophyll a cannot absorb, the accessory pigments enable plants to capture more of the energy in light.

Photosynthetic structures

- ❖ In eukaryotes the photosynthetic apparatus is located in special intercellular organelle called **chloroplasts**.
- ❖ Chloroplasts similar to mitochondria contain also DNA, RNA, and the apparatus for protein synthesis, i.e., potentially they are capable of self-reproduction.
- ❖ In size, chloroplasts are several times as large as mitochondria.
- ❖ The number of chloroplast per cell varies over a range from 1 (in algae) to 40 (in higher plants).
- ❖ Chloroplasts are of spherical or oval shape.
- ❖ A chloroplast possesses two-outer and inner membranes (see figure 5.29 page 171).
- ❖ Disk-like stacks of flattened vesicles extend from the inner membrane. These stacks are called the **grana**.
- ❖ The number of grana per chloroplast in algae does not exceed 1 while in higher plants 50 grana link with each other through membranous bridges called **lamellae**.
- ❖ The aqueous medium of the chloroplast in which the grana are immersed is called the **stroma**.
- ❖ The vesicle-like structures, which the grana are composed of are referred to as **thylakoids**.
- ❖ One granum contains **10 to 20** thylakoids.
- ❖ The elementary structural and functional photosynthetic unit of the thylakoid membrane which contains necessary light-trapping pigment and components of the energy conversion apparatus is called the **quantasome**.

Stages of photosynthesis

Photosynthesis is the conversion of light energy to chemical energy with the subsequent use of chemical energy in the synthesis of carbohydrates from **carbon dioxide**.

- ◆ When energy is changed from one form to another, we say it has been **transduced**.
- ◆ Light energy is transduced to **chemical energy** in a chloroplast during photosynthesis. The chloroplast is a transducer organelle.
- ◆ This process is **endergonic** and requires much energy.
- ◆ Therefore, the overall process is made up of two stages, commonly referred to as the **light reaction (light-dependent reaction)** and the **dark reaction light-independent reaction**.
- ◆ In chloroplasts the **two** stages are spatially separated:
 1. The light reaction is carried out in the **grana** (or **thylakoid**).
 2. The dark reaction is accomplished in the **stroma**.
- ✓ The light reaction proceeds in the light. At this stage, the sun light energy is converted to the ATP chemical energy, and the energy-deficient water electrons are transformed to become the energy-rich NADPH electrons.
- ✓ The oxygen liberated during the light reaction is a **by-product** of this process.
- ✓ The energy-rich light reaction products, ATP and NADPH are used in the next stage which can proceed **without light**.
- ✓ **The reductive synthesis** of glucose from CO₂ occurs during the **dark reaction**.
- ✓ The dark reaction cannot be accomplished independently of the light reaction.

The light-dependent reaction (light reaction)

- 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 NAD—this provides the hydrogen ions for a key reduction reaction.
- **NADP** is very similar to NAD is used in respiration and it has the same function—transporting hydrogen ions.
- In the thylakoid membrane, there two photochemical centers or photosystems commonly denoted as **photosystem I** and **photosystem II**. See figure 5.32 page 173
- Either of the two photosystems cannot replace the other one, since **functionally these systems are different**.
- The photosystems consist of **pigment molecules**, together with various **enzymes** and **electron acceptor molecules**.
- Both **photosystem I and II** contain chlorophyll molecules organized so as to pass energy to a special pair of pigment at the reaction centers of the photosystems.
- This cluster of pigment molecule is called an **antenna complex**.
- Only the reaction center molecule is positioned to the electron transport chain.
- Energy absorbed by other molecules in the photosystem is transferred to the reaction molecule, where light-dependent reaction begins.
- The photosystems contain various pigments:
 - green pigments, chlorophyll a and b;
 - yellow pigments, carotenoids; and
 - red or blue pigments.
- In this variety of pigments only **chlorophyll a** is **photochemically active**.
- The other pigments play a **minor role** and act merely as photon collectors (a kind of focusing lenses) or light guides to the photochemical center.
- A photosystem consists of a number of pigment molecules all clustered around one chlorophyll molecule called the **reaction center molecule**.
- This cluster of pigment molecules is called an **antenna complex**.
- Only the reaction center molecule is positioned next to the electron transport chain.
- Energy absorbed by other molecules in the photosystem is transferred to the reaction center molecule, where the light-dependent reactions begin.
- Different pigment molecules in the **antenna complex** can absorb different wave lengths of light, making the whole system more efficient.
- The pigments in the **antenna complex** include chlorophyll a, chlorophyll b and carotenoids.
- The reaction center molecule is always **chlorophyll a**.
- The range of wave lengths each molecule absorbs is the **absorption spectrum**.
- Figure 5.31A page 172 shows the **absorption spectrum** of chlorophyll a, chlorophyll b and carotenoids.
- Figure 5.31B shows the **action spectrum** for different wave lengths of light. This shows how effective photosystem is at each wave lengths.

What happens in photosystem I and photosystem II

1. Electrons (e⁻) in chlorophyll molecules in photosystem 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:

$$2\text{H}_2\text{O} \longrightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$$
 - This light-dependent splitting of water is called **photolysis**.
 - The electrons replace those lost from the chlorophyll molecule.
3. The primary electron acceptor passes the electrons to the next molecule in an electron transport chain (plastoquinone or 'Pq').
 - The electrons 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 electrons lose energy as they are passed from one carrier to the next.

4. One of the molecules in the cytochromes complex is a proton (hydrogen ion) pump.
 - As electrons 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 an accumulation of protons inside the thylakoid, which drives the chemiosmotic synthesis of ATP.
5. Electrons in the 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 (hydrogen ions) and NADP in the stroma of the chloroplast to form reduced NADP.

Photosynthetic unit is 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 described above is 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. Figure 5.34 shows this system.
- ❏ Here, we can see that electrons lost from the chlorophyll molecule are returned to it. Hence the name 'cyclic'.
- ❏ This process usually only happens when sugars cannot be synthesized from some reason—such as lack of carbon dioxide.

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

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

A summary of the light-dependent reactions

Light energy is used to excite electrons which then:

- Cause the transfer of protons to the inside of the thylakoid membrane as they pass along the first transport chain; this eventually leads to the formation of ATP, and
- React with hydrogen ions and NADP at the end of the second electron transport chain to form reduced NADP; this reaction could only happen because of the extra energy possessed by the electrons

The ATP and reduced NADP are used to drive the synthesis of carbohydrates in the light-independent reactions of photosynthesis.

The light-independent reaction (Dark reaction)

- ❖ The light-independent reactions of photosynthesis occur in the stroma of the chloroplasts.
- ❖ They comprise a complex cycle of reactions that involves the addition of carbon dioxide to a pre-existing five-carbon molecule within the chloroplast.
- ❖ The resulting molecules are modified to generate the original molecule whilst, at the same time, synthesizing glucose.
- ❖ The sequence of reactions was discovered by Malvin Calvin, an American biologist.
- ❖ Because of his work, the light-independent reactions are also referred to as the **Calvin cycle**.
- ❖ In 1950s Malvin Calvin experimented with unicellular algae called *chlorella* by exposing them to radioactive carbon dioxide.
- ❖ After different periods of time, the algae were killed and the chemicals in the algae that contained radioactive carbon (which must have come from the carbon dioxide) 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 three-carbon atoms called **glycerate phosphate (GP)**.

The main stages of the light-independent reactions are:

1. Carbon dioxide reacts with ribulose biphosphate (RuBP)—a five-carbon compound in the stroma; the reaction is catalyzed by the enzyme **Rubisco**.
 2. Two molecules of the three-carbon compound GP are formed from this reaction as figure 5.36 page 176 shows.
 3. Each molecule of the GP is converted to TP (triose-phosphate—another three-carbon compound); this is the reduction reaction using hydrogen ions from reduced NADP and energy from ATP.
 4. Some of the TP formed is used to regenerate the RuBP (ATP is again required) whilst some is to form glucose and other useful organic compounds.
- ❖ Figure 5.35 page 175 summarizes the light-independent reactions of photosynthesis. It shows how three 'turns of the cycle' result in an output of one molecule of TP.
 - ❖ Six turns of the cycle would give an output of two molecules of TP — enough to make one molecule of glucose.
 - ❖ TP can also be converted to lipids, amino acids and from these into nucleotides and all the other organic molecules found in plants.

TP is the basis for the synthesis of all organic molecules. See Figure 5.37 page 177 (The light-independent reaction).

Factors that affect the rate of photosynthesis

Table 5. Factors affecting the rate of photosynthesis

Factor	Effect on photosynthesis
Light intensity	Low light intensity can limit the light-dependent reactions by reducing the number of electrons in chlorophyll molecules that are photo-excited
Carbon dioxide	Can limit the light-independent reactions by influencing the rate of the initial reaction with RuBP
Temperature	Can limit the rate of enzyme action , for example, ATP synthase and Rubisco (light-independent reactions)

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?

1. Very low intensities—respiration is still occurring and is taking in oxygen faster than photosynthesis is producing it
2. Medium light intensities—photosynthesis is producing more oxygen than respiration uses, the rate of photosynthesis increases with increasing light intensity
3. 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 CO₂ concentration on the rate of photosynthesis?

- ❖ At very low concentrations of CO₂, little photosynthesis takes place, although respiration is still using up oxygen.
- ❖ As the CO₂ concentration increases, so does the rate of photosynthesis.
- ❖ Again, however, it begins to level off at higher concentrations.
- ❖ This may be due to some other factor, or it could be due to the **saturation of Rubisco**.

How does temperature affect the rate of photosynthesis?

- ❖ Many of the reactions in both the light-dependent stage and the light-independent stage are controlled by enzymes, which are affected by temperature.
- ❖ Once the temperature exceeds the optimum, the enzyme denatures and the rate of photosynthesis **decreases rapidly**.

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

- ☞ Increasing the 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 the rate at which reduced NADP and ATP can be used, which, in turn, limits the amount of NADP and ADP + P_i that can be reused by the light-dependent reactions.
- The whole process is therefore limited, even though the intensity continues to increase. This is shown in figure 5.42 page 179.

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

1. The wave length of the light—photosynthesis takes place faster in red and blue wave lengths because wave lengths are absorbed more efficiently than others; leaves are green because green wave lengths are reflected
2. The amount of chlorophyll present

The function of the photochemical center is assigned to special forms of chlorophyll a which are:

- In **photosystem I**, the pigment **700** (P700) absorbing light at a wave length of about 700nm, and
- In the **photosystem II**, the pigment **680** (P680) absorbing light at wave length of 680nm.
- ❖ Absorption of photons (the particulate unit of light, carrying a quantum of energy) by the photosystem II leads to decomposition of water in the photochemical system P680
- ❖ The electrons released from water molecules are boosted to a higher energy level from which they are transferred to an electron acceptor molecule.
- ❖ The electrons then pass downhill along an electron transport chain to photosystem I.
- ❖ As the electrons pass along this transport chain, ATP is formed from ADP, via the same mechanism by which ATP is formed along the electron transport chain of the mitochondrion.
- ❖ This process is known as **non-cyclic photophosphorylation**. This is because:

- The phosphorylation is light-dependent
- The electrons lost from the chlorophyll are not recycled in any way.
- ❖ Plants sometimes generate ATP by cyclic photophosphorylation because in this pathway the electrons take the cyclic path, falling back to the point of origin rather than flowing through to NADPH. It involves photosystem I but not photosystem II.
- ❖ When electrons reach photosystem I, they have already expended their excitation energy in driving the proton pump and thus contain only the same amount of energy as other electrons of this photosystem.
- ❖ **Photosystem I** now absorbs a photon, boosting one of its pigment electrons to a high-energy level.
- ❖ The electron is then channeled to **ferredoxin** and is used to generate **reducing power**.
- ❖ **In plants and algae** ferredoxin contributes two electrons to reduce NADP^+ , nicotine adenine dinucleotide phosphate, generating **NADPH**.
- ❖ By using this molecule instead of NAD^+ , used in oxidative respiration, plants and algae keep the flow of electrons in the two processes separate.

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

- ➔ A concentration difference in hydrogen ions (protons) develops across a membrane, creating a concentration gradient
- ➔ Protons from photosystem I pass from the stroma into the interior of the thylakoid
- ➔ Protons can then return to the stroma down a concentration gradient, via the enzyme complex (ATPase).
- Thus, the energy produced in the first photo event is spent in ATP synthesis; the energy of the second photoevent creates **reducing power**.
- **These two processes together comprise the light reactions of eukaryotic photocenters.**

The dark reaction (light independent reaction)

- ❖ The products of light reaction, ATP and NADPH which are formed in the chloroplast **stroma**, are immediately used in the reduction of CO_2 to glucose.
- ❖ Assimilation of CO_2 is a cyclic process commonly referred to as Calvin cycle.
- ❖ **Three major phases** are distinguished in the Calvin cycle:
 1. **Fixation of CO_2 with rubulose biphosphate (RuBP)**
 2. **Production of triose phosphates by reduction of phosphglycerate**
 3. **Regeneration of ribulose biphosphate (RuBP)**

The Calvin cycle (the three –pathway)

The Calvin cycle follows the following steps:

Step 1

- ❖ CO_2 diffuses into the stroma from the surrounding cytosol. An enzyme **Rubico** combines a CO_2 molecule with a five carbon carbohydrate called **RuBP**.
- ❖ The product is a six-carbon molecule that splits immediately into a pair of three carbon molecules known as **PGA** (phosphoglycerate).

Step 2

- ❖ **PGA** is converted into another three-carbon molecule, **PGAL**, in a two –part process.
 - First, each PGA molecule receives a phosphate group from a molecule of ATP.
 - The resulting compound then receives a phosphate from **NADPH** and releases a phosphate group, producing **PGAL**’
- ❖ In addition to **PGAL**, these reactions produce **ADP**, NADP^+ and **phosphate**.
- ❖ These three products can be used again in the light reactions to synthesize additional molecules of NADPH.

Step 3

- ❖ Most of the PGAL is converted back into RuBP in a complicated series of reactions.
- ❖ These reactions require a phosphate group from another group of ATP.
- ❖ However, some PGAL molecules are not converted into RuBP.
- ❖ Instead, they leave the Calvin cycle and can be used by the plant cell to make other organic compounds
- ❖ For every three molecules of CO₂ that enter the cycle, the molecule of the 3-carbon compound glyceraldehyde phosphate is produced and 3 molecules of RuBP are regenerated.

Factors affecting the rate of photosynthesis (Limiting factors)

1. Intensity of light
2. CO₂ concentration
3. Temperature
4. Wave length of light

Intensity of light:

- The light-independent reactions are dependent on the light-dependent reactions for ATP and NADPH.
- At low intensities the rate at which these are produced is too slow to allow the light-independent reactions to proceed at maximum rate, so light is a limiting factor.
- The rate of photosynthesis increases linearly with increasing light intensity
- Low light intensity can limit the light-dependent reactions by reducing the number of electrons in chlorophyll that are photo excited.
- Very high light intensities may bleach chlorophyll and slow down photosynthesis, but plants normally exposed to such conditions are usually protected by devices such as thick cuticle and hairy leaves.

Carbon dioxide concentration

- CO₂ is needed in light-independent reactions where it used to make sugars.
- Because of its very low concentration in atmosphere (0.03%) it acts as a limiting factor in natural photosynthesis
- If CO₂ supply increases the rate of photosynthesis increases markedly.

Temperature

- Both the light-dependent and light-independent reactions are enzyme controlled and therefore temperature sensitive.
- Once temperature exceeds the optimum (about 25%), the enzyme denatures and the rate of photosynthesis decreases rapidly.

Wave length of light

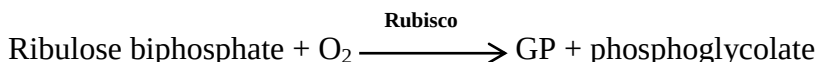
- Photosynthesis takes place faster in red and blue wave lengths.
- These wave lengths are absorbed more efficiently than others; leaves are green because green wave lengths are reflected.

Are there other ways of photosynthesizing?

C3 photosynthesis and photorespiration

What we have just described is the method of photosynthesis that takes place in plants living in temperate environments, such as those found in Europe. It is called C3 photosynthesis—because the first compound formed in the light-independent reactions of the Calvin cycle is GP, which contains three-carbon atoms.

- C3 plants have leaves that are adapted to this method of photosynthesis.
- These leaves are generally broad, to catch as much sunlight as possible.
- The cells that contain most chloroplasts (the 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 the day, the stomata are open for most of the time to allow the entry of carbon dioxide, but they can be closed if the water loss is too great on a hot day.
- The spongy mesophyll has air spaces that allow easy diffusion of carbon dioxide and oxygen between the palisade layer and the stomata. Figure 5.45 page 181 shows the structure of the leaf of a C3 plant.
- However plants in the tropics have a problem.
- Here, it can be very hot and the leaves close their stomata to minimize the water loss.
- When C3 plants do this, the concentration of carbon dioxide in the leaves falls and the enzyme Rubisco starts to behave in an unusual way.
- In this low concentrations of carbon dioxide, Rubisco binds with oxygen, not carbon dioxide.
- This means that RuBP is oxidized to **one molecule of GP** (not two) and a molecule of **phosphoglycolate**.
- In addition, carbon dioxide is produced in the process.
- This process is called **photorespiration** because it involves **oxidation of carbon**.



The one molecule of GP formed in photorespiration can re-enter the Calvin cycle by a complex series of reactions.

These reactions involving a chloroplast, an organelle called a peroxisome and a mitochondrion are summarized in figure 5.46 page 181.

Peroxisomes are named this way because they produce and then break down **hydrogen peroxide**.

It is not necessary to try to remember all these reactions. Instead, think of the two phases of photorespiration:

1. Rubisco catalyzes a reaction between oxygen and RuBP to form one molecule of GP (not two) and one molecule of phosphoglycolate
2. The phosphoglycolate is converted to GP in reactions in chloroplasts, peroxisomes and mitochondrion.

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

1. The CO₂ is oxidized, which is the reverse of photosynthesis—the reduction of carbon to carbohydrate
2. The ribulose biphosphate must be resynthesized and the phosphoglycolate removed
3. ATP is used in the synthesis of RuBP.

C4 photosynthesis (4-carbon photosynthetic pathway)

- ❏ To get round the problem of photorespiration reducing the efficiency of photosynthesis, plants that grow in tropical areas like Ethiopia (such as maize, crabgrass, sorghum and sugar cane) have evolved a different photosynthetic pathway called **C4 photosynthesis**.
- ❏ As the name suggests, the first compound formed in the light-independent reactions is the C4 compound called **oxaloacetate** (contains four carbon atoms) not GP (a C3 compound).
- ❏ The light-dependent reactions are the same as in the C3 plants, but there is a difference in how the glucose is synthesized in the light-independent reactions.

- ❑ The structure the C4 plant leaf is essentially 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 the Calvin cycle to take place in these cells.
- ❑ The light-dependent reactions in the C4 pathway also involve a set of reactions not bound in C3 plants.
- ❑ These reactions take place in the **mesophyll cells**, which have chloroplasts with thylakoids and so can carry out the light-dependent reactions.
- ❑ However, they do not have the enzymes to catalyze the reactions of the Calvin cycle.
- ❑ Instead, the following reactions take place:

CO₂ reacts with a C3 compound called PEP to form a C4 compound called **oxaloacetate**. This is catalyzed by the enzyme **PEP carboxylase**.

Oxaloacetate is converted into another C4 plants (malate), which then passes from the mesophyll cell into a bundle sheath cell.

In the bundle sheath cell, malate is converted to pyruvate with the release of a molecule of carbon dioxide, which starts the reaction of the Calvin cycle by binding with RuBP.

Pyruvate is converted back to PEP; this reaction requires ATP. These reactions are summarized in 5.48 page 183.

Overall, the C4 cycle uses two more molecules of ATP to deliver a molecule of CO₂ to Rubisco than does 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 **of**:

1. Low CO₂ concentration
2. High light intensity
3. High temperature

Figure 5.49 page 183 compares the efficiency of C3 and C4 photosynthesis under different concentrations of CO₂.

Why C4 plants experience a low concentration of CO₂?

- *This is not because the composition of air in tropical regions is any different from that in other regions.*
- *It is because C4 plants (grasses, maize) often grow very close together*
- *Together and so compete for both CO₂ in the air, reducing its concentration.*

Cacti do it yet another way!

In extreme heat of deserts, having stomata open during the day is a sure path to desiccation and death for the plants.

But if they don't open their stomata, how will they get the CO₂ they need for photosynthesis?

The answer is obvious really—the stomata open at night when temperatures fall.

Cacti use what is essentially the same set of reactions as C4 plants, but they separate the stages not by carrying them out in different cells, but by carrying them out at different times.

The **CAM** photosynthesis cycle is as follows

1. *At night, the plants open their stomata to allow in CO₂, which then reacts with PEP in mesophyll cells to form oxaloacetate, and then malate just as in the C4 pathway*
2. *The malate is then stored in the vacuoles of these cells overnight*
3. *During the day, the light-dependent reactions regenerate ATP and reduced NADP so that the Calvin cycle can*

continue

4. Malate is released from the vacuoles and is broken down to glycerate, releasing CO₂ for the reactions of the Calvin cycle

Note: See fig. 5.50 page 184: The C₄ and CAM photosynthetic Pathway

Table 5. A comparison of C₃ and C₄ photosynthesis

Feature	C ₃	C ₄
Bundle sheath cells	Lack chlorasts	Have chloroplasts with no thylakoids
Enzyme used to fix CO ₂	Rubisco	Pepco(PEP carboxylase)
Optimum temperature	15—25°C	30—44°C
Optimum CO ₂ concentration	700ppm	400ppm
Fixation of CO ₂	Mesophyll cells	Mesophyll cells
Calvin cycle	Mesophyll cells	Bundle sheath cells

- ❖ The crop plants that are grown in Ethiopia (such as sorghum and wheat) are all C₄ plants and are, therefore, well adapted to photosynthesis efficiently in the hot, bright days found in this country.
- ❖ Crop plants that are grown in temperature areas (such as peas and carrots) would not photosynthesize as efficiently, because they are C₃ plants.
- ❖ They would, therefore, not produce high yields.

Review questions

- Which of the following plants use CAM photosynthesis (2009 E.C.)?
 - Sugar cane
 - Maize
 - Sorghum
 - Cactus
- When a drop of iodine solution is added to a solution of food stuff and the food stuff turns dark blue, what does the food stuff contain (2009 E.C.)?
 - Reducing sugar
 - Disaccharide
 - glucose
 - Starch
- Which of the following stages of photosynthesis can take place in the dark (2009 E.C.)?
 - Photolysis of water
 - Photosystem I
 - Photosystem II
 - Calvin cycle
- The molecule of which pigment is located at the reaction center of the photosystem?
 - Chlorophyll a
 - Carotenoid
 - Chlorophyll b
 - Xanthophyll
- At which stage is most of the ATP generated in aerobic respiration?
 - Krebs' cycle
 - ETC
 - Glycolysis
 - Link reaction
- Glycolysis occurs in the ----- (2009 E.C.)?
 - Cytoplasm
 - Nucleus
 - Mitochondria
 - Chloroplast
- In photosynthesis which of the following does NOT happen?
 - Organic compounds are produced from inorganic substances
 - Water is split to generate electrons and protons
 - Carbohydrate is synthesized from H₂O and CO₂
 - Oxygen is produced from CO₂
- Anaerobic metabolism refers to the generation of ATP (2009 E.C.);
 - Without the involvement of ADP
 - Without the use of the oxygen
 - Without the use of glycogen
 - By the conversion of pyruvate to lactate
- Which of the following groups of plants carry out light dependent and independent reactions of photosynthesis in separate cells?

- A. CAM plants B. C-4 plants C. C3-plants D. Plants without chlorophyll
10. The conversion of one molecule of glucose to two molecules of pyruvate results in the net formation of (2009 E.C.); A. Two molecules of ATP C. 3 molecules of ATP
B. Six molecules of water D. 38 molecules of ATP
11. Which of the following is a reactant in the Calvin cycle? A. O₂ B. CO₂ C. H₂O D. Glucose
12. C-4 plants
A. Lose more water than C-3 plants during photosynthesis
B. Are usually found in cool, and moist environment
C. Fix CO₂ into four carbon compounds
D. Have no stomata
13. During each turn of Krebs cycle
A. Two ATP molecules are produced C. Glucose combines with a four carbon molecule
B. Two CO₂ molecules are produced D. Pyruvic acid combines with oxaloacetic acid
14. If present in the fermentation system, which one of the following would negatively affect alcohol production by yeasts?
A. Oxygen B. Glucose C. Water D. Fermentation enzyme
15. During alcohol fermentation, pyruvic acid in the presence of pyruvate decarboxylase is first converted to----- (2009 E.C.)?
A. Glucose B. Lactic acid C. Lactose D. Acetaldehyde
16. How many ATP can be produced if 4FADH₂ and 12 NADH give their electrons to the ETC in the presence of oxygen?
A. 18 ATP B. 38ATP C. 44 ATP D. 48 ATP
17. The matrix is the inner most compartment of the mitochondrion and the site of the:
A. Glycolysis B. Link reaction C. Electron transport Chain D. Krebs cycle
18. By accepting electrons and protons, the oxygen used in aerobic respiration turns into
A. H₂O B. CO₂ C. C₆H₁₂O₆ D. ATP
19. The advantage of anaerobic respiration is
A. many ATP molecules are produced from each molecule of glucose
B. energy can be produced when oxygen is in short supply
C. pyruvic acid is converted into lactic acid
D. more efficient than aerobic respiration
20. During the Krebs cycle, to which of the following molecules is most of the energy released from food transferred (2009 E.C.)? A. ATP B. NAD C. ADP D. AMP
21. When 4 ADP is phosphorylated it means
A. 4 ATP is catabolized releasing energy C. Energy is released to be used for other reactions
B. Energy is absorbed to form 4 ATP D. Energy is wasted
22. How many Calvin cycle would be required to form one glucose molecule using 6CO₂?
A. One cycle B. three cycles C. Two cycles D. Four cycles
23. Which of the following happens during the dark reaction of photosynthesis?
A. Carbon dioxide is fixed C. Oxygen is produced from split of water
B. NADH is produced D. ATP is produced
24. The enzyme for ETC are present in the
A. Outer mitochondrial membrane B. Matrix C. Inner mitochondrial membrane D. Cytosol
25. Which of the following is true about the first stage of photosynthesis?
A. Temperature dependent B. Light dependent C. ATP driven D. Glucose-driven
26. Which of the following is true about photosystem II?
A. It replenishes its lost electrons from photolysis of water
B. Its reaction center molecule is P680
C. It passes its excited electrons to photosystem I
D. The energy lost from its excited electrons reduced NADP
27. In which process is ATP generated during short distance high speed running?
A. Anaerobic respiration C. Mitochondrial energy transformation
B. Aerobic respiration D. The Krebs' cycle
28. During which stage of aerobic respiration does oxidative phosphorylation occur (2009 E.C.)?

- A. Glycolysis B. link reaction C. Krebs' cycle D. Chemiosmosis
29. Which of the following is true about C-4 plants?
 A. They use energetically expensive method requiring more ATP expenditure than C-3 plants
 B. The use PEP-carboxylase to trap CO₂
 C. They have more advantage in areas like dense forest and drought stricken areas, where CO₂ shortage occurs in the atmosphere
 D. All the above are correct
30. Oxidative phosphorylation is
 A. Production of ATP driven by ETC C. Production of CO₂
 B. Addition of phosphorus D. Addition of enzymes
31. Which of the following processes of photosynthesis DOES NOT require the presence of light to take place?
 A. Reduction of NADP B. Carbon fixation
 B. ATP formation D. The splitting of water
32. During anaerobic respiration, what is the gross number of ATP molecules that are produced per glucose molecule (2009 E.C.)? A. Two B. Three C. Four D. Six
33. In cellular respiration, which of the following molecules enters the krebs' cycle?
 A. Acetyl CoA B. Glucose C. Pyruvic acid D. Lactic acid
34. When ATP breaks down to ADP and P, the energy released is
 A. 30.6KJ B. 30.6J C. 40.6KJ D. 40.6J
35. The energy released from a molecule of glucose accounts
 A. 600Kcal B. 2881KJ C. 686Kcal D. B and C are correct answers
36. If an actively growing potted seedling is kept horizontally, which of the following would eventually happen to the seedling (2009 E.C.)?
 A. The shoot would bend upwards C. The root would bend upwards
 B. The seedling would stop growing D. The seedling would grow horizontally
37. What is the importance of chemiosmosis in photosynthesis and cellular respiration
 A. Combining hydrogen and carbon C. Splitting of water molecules
 B. Synthesizing of ATP D. Operating the proton pump
38. Which of the following is NOT one of the stages in cellular respiration?
 A. Glycolysis B. Calvin cycle C. Krebs' cycle D. ETC
39. How many molecules of ATP will be generated as a result of FADH₂ in an actively respiring mitochondrion? A. 3 B. 4 C. 3 D. 2
40. Before the Krebs cycle is proceed, pyruvic acid must be converted into
 A. NADH B. Acetyl CoA C. Glucose D. Citric acid
41. In lactic acid fermentation
 A. Electrons pass through the ETC C. NAD⁺ is generated for use in glycolysis
 B. Lactic acid is converted into pyruvic acid D. Oxygen is consumed
42. What does the absence of chloroplasts in unicellular organism indicate (2006E.C.)?
 A. Reproduction by sexual means C. Heterotrophic nutrition
 B. Autotrophic nutrition D. Complete lack of metabolic processes

ANSWERS FOR ALL REVIEW QUESTIONS

UNIT ONE

1	D	8	B	15	D	22	A	29	A	36	C	43	B	50	C	57	D	65	D
2	D	9	C	16	C	23	A	30	A	37	B	44	D	51	A	58	C	66	D
3	C	10	A	17	D	24	B	31	C	38	A	45	B	52	D	60	B		
4	C	11	B	18	A	25	B	32	A	39	D	46	A	53	D	61	D		
5	B	12	C	19	C	26	D	33	A	40	B	47	A	54	C	62	D		
6	B	13	D	20	C	27	D	34	C	41	D	48	C	55	B	63	C		
7	C	14	C	21	A	28	A	35	D	42	A	49	B	56	C	64	D		

UNIT TWO

1	D	11	D	21	C	31	B	41	B	51	D	61	D	71	D	81	B	91	C
2	D	12	C	22	D	32	B	42	D	52	D	62	C	72	A	82	B	92	C
3	C	13	A	23	A	33	B	43	C	53	A	63	B	73	C	83	D	93	A
4	C	14	B	24	B	34	D	44	A	54	A	64	A	74	B	84	B	94	A
5	C	15	A	25	B	35	C	45	C	55	A	65	A	75	C	85	D	95	D
6	A	16	D	26	D	36	D	46	D	56	C	66	C	76	D	86	D	96	D
7	C	17	B	27	B	37	B	47	B	57	C	67	C	77	B	87	D		
8	C	18	B	28	B	38	D	48	B	58	C	68	A	78	D	88	C		
9	C	19	C	29	D	39	C	49	C	59	A	69	C	79	A	89	C		
10	C	20	B	30	A	40	C	50	A	60	A	70	D	80	A	90	D		

UNIT THREE

1	C	11	C	21	C	31	A	41	C	51	D	61	A
2	D	12	B	22	C	32	D	42	C	52	D	62	C
3	C	13	A	23	D	33	D	43	D	53	D		
4	B	14	A	24	A	34	C	44	D	54	A		
5	B	15	D	25	D	35	C	45	A	55	A		
6	C	16	B	26	B	36	B	46	B	56	A		
7	B	17	B	27	A	37	A	47	A	57	D		
8	C	18	C	28	A	38	A	48	B	58	B		
9	C	19	D	29	A	39	A	49	C	59	A		
10	B	20	C	30	C	40	A	50	C	60	D		

UNIT FOUR

1	C	11	D	21	B	31	D	41	D	51	A	61	D	71	D
2	B	12	B	22	A	32	B	42	D	52	C	62	B	72	A
3	D	13	D	23	A	33	D	43	C	53	A	63	B		
4	C	14	C	24	C	34	B	44	A	54	B	64	B		
5	D	15	A	25	B	35	A	45	A	55	C	65	C		
6	B	16	B	26	C	36	C	46	C	56	C	66	B		
7	D	17	B	27	D	37	A	47	B	57	D	67	C		
8	C	18	A	28	A	38	A	48	A	58	A	68	B		
9	D	19	C	29	B	39	B	49	D	59	D	69	A		
10	D	20	B	30	C	40	D	50	D	60	A	70	C		

UNIT FIVE

1	D	6	A	11	B	16	C	21	B	26		31	B	36	A	41	C
2	D	7	D	12	C	17	D	22	B	27	A	32	C	37	D	42	C
3	D	8	B	13	B	18	A	23	A	28	C	33	A	38	B		
4	A	9	C	14	A	19	B	24	C	29		34		39	D		
5	B	10	A	15	D	20	A	25	B	30		35		40	B		