

FSc Part-I · Punjab Board · English Medium

Biology 1st Year

Complete Notes — All 14 Chapters

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FSc Part-I Biology — Punjab Board

CHAPTER 1

Introduction

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Introduction from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It sets the foundation for the whole course: what biology actually studies, the many branches into which the subject is divided, and the different levels at which living organisms can be organized and studied, from subatomic particles all the way up to the biosphere. These notes are prepared by freebooks.pk.

The chapter then looks at how life is distributed in space (biomes) and in time (through fossils and phyletic lineages), explains the biological method that scientists use to investigate problems, and closes with the many practical contributions biology has made to food production, disease control, cloning technology and environmental protection. Together these ideas give the vocabulary and the way of thinking needed for every later chapter.

Learning Objectives

- Define biology and describe the scope of the subject.
- Identify the major branches / fields of specialization of biology and state what each one studies.
- List the levels of biological organization from subatomic particles to the biosphere, and explain how each level is built from the one below it.
- Explain how biomes describe the distribution of living things in space.
- Describe how fossils and geological time are used to study the distribution of life in time, and explain the idea of a phyletic lineage.
- Explain the biological (scientific) method: observation, hypothesis, deductive and inductive reasoning, theory and scientific law.
- Describe the contribution of biology to food production, disease control, cloning and the protection of the environment.

Key Concepts

What Is Biology?

Biology is the study of living things; the word literally means the study of life. As a branch of science, it is a way of understanding nature, and biologists focus on the living part of nature together with the non-living factors that affect it. Defining life itself is difficult, and questions such as “why should there be life” are left to philosophers rather than biologists. Instead, biologists work with a practical description: living organisms are highly organized, are made of one or more cells, carry a genetic program, can acquire and use energy, carry out and control chemical reactions, grow, maintain a fairly constant internal environment, reproduce, and respond to their environment. Anything showing all of these characteristics together is considered a living thing and a proper subject for biological study.

Major Branches / Fields of Specialization

Because biology is such a wide subject, it is divided into many branches for convenience of study. Classical branches include Ecology (environmental relations), Embryology (development), Physiology (functions), Morphology or Anatomy (structure and form),



Palaeontology (fossils), Histology (tissues), Evolution (ancestral history), Genetics (heredity) and Zoogeography (distribution of animals).

Newer, more specialised branches include Molecular Biology (the structure of organisms, cells and organelles at the molecular level), Environmental Biology (organisms in relation to their environment), Microbiology (bacteria, viruses, protozoa and microscopic algae and fungi), Freshwater Biology (organisms living in rivers, lakes and other freshwater bodies), Marine Biology (life in seas and oceans), Parasitology (parasites and host-parasite relationships), Human Biology (the structure, function and evolution of human beings), Social Biology (the social behaviour and communal life of human beings), and Biotechnology (the use of living organisms or their processes in manufacturing and services).

Levels of Biological Organization

Only 16 of the 92 naturally occurring chemical elements are commonly used to build the compounds that make up living organisms; these are called bioelements, and in the human body just six of them account for 99% of the total mass. Because these same 16 elements occur in every organism yet behave differently from non-living matter, bioelements must have special properties that make them suitable as the basis of life.

Biological organization is complex, and biologists study it at a series of levels, each built from the level below. Starting from the smallest: subatomic particles (protons, electrons, neutrons) combine to form atoms; atoms bond together to form molecules (micromolecules such as CO₂ and water, or macromolecules such as starch and proteins); molecules arrange into organelles, which are the specialised working parts of a cell; organelles are organized within a cell, the basic unit of life; similar cells group into tissues; tissues combine into organs; organs work together as organ systems; organ systems make up an organism; organisms of the same species living in the same place form a population; populations of different species sharing a habitat form a community; a community together with its non-living surroundings forms an ecosystem; and all the ecosystems of the planet together make up the biosphere, the part of the Earth that supports life.

The prokaryotic cells of bacteria have only a limited number and type of organelles, while eukaryotic cells are rich in membranous organelles; a cell membrane, however, is present in every cell, prokaryotic or eukaryotic. Organisms interact with one another in several ways at these levels, including predation, parasitism, commensalism, mutualism and competition.

Living World in Space and Time

The living world is distributed in space as well as in time. In space, the distribution of organisms can be studied through biomes: a biome is a large regional community determined mainly by climate, and biomes are named after their dominant plant type or main ecosystem feature.

In time, the history of life is reconstructed mainly from fossils. As new sediment layers are laid down over geological time, older organisms are found in deeper layers (provided the sequence has not been disturbed), and comparing the radioactive isotopes in different layers



gives an estimate of the relative age of the fossils they contain. This fossil record lets biologists place organisms in a time sequence and study how life has changed.

Today nearly 2.5 million species are known to science, of which insects alone make up about 53% and vascular plants about 17.6%; careful estimates put the true total number of species anywhere between 5 and 30 million, meaning the great majority are still undiscovered. The idea of a phyletic lineage describes how today's life arose: it is an unbroken series of species arranged from ancestor to descendant, with each later species evolving from the one immediately before it. A complete record of every lineage would trace back to the common origin of early life, but this record is incomplete because many soft-bodied ancient organisms left no fossils.

The Biological (Scientific) Method

Biological science, like other sciences, is systematized knowledge built through experimental inquiry. The method begins with a chance observation, made using the senses and classified as either qualitative or quantitative (quantitative observations are more accurate because the variables are measurable and recorded as numbers). From organized observations, a scientist forms a hypothesis: a tentative explanation that still needs to be tested.

A hypothesis can be formed in two main ways. Deductive reasoning moves from the general to the specific: it applies an "if ... then" style of logic to a general principle to predict a specific outcome (for example, if all birds have wings, and sparrows are birds, then sparrows have wings). Inductive reasoning moves the other way, from the specific to the general: it starts from particular observations and builds up a general principle (for example, noting that sparrows, eagles, parrots and crows all have wings and are birds, and concluding that all birds have wings). Hypotheses may also arise from intuition, aesthetic preference, philosophical ideas, analogy with other processes, or accidental discovery, but however they are formed they must still be tested rigorously.

A hypothesis that survives repeated attempts at falsification becomes well supported and is generally accepted; a series of such well-tested, related hypotheses is called a theory. A good theory is predictive, has explanatory power, and is productive if it suggests further new hypotheses. If a theory keeps surviving determined attempts to disprove it, it may eventually be accepted as a scientific law: a uniform, virtually irrefutable fact of nature. Because life is so variable, biology has comparatively few laws; examples include the Hardy-Weinberg law and Mendel's laws of inheritance, which are studied in later chapters.

Biology in the Service of Mankind: Food and Disease

Biology has helped raise living standards by improving food production and controlling disease. Selective breeding, guided by the principles of genetics, has produced better varieties of wheat, rice, corn, chicken, cattle and sheep, including broiler chickens bred for quick, cheap white meat. Genetic engineering introduces genes for disease resistance and other useful traits into plants, producing transgenic plants (plants carrying foreign DNA), which can then be multiplied by cloning techniques such as tissue culture. Biological control of pests, for example using a wasp that parasitizes the aphids attacking walnut trees, avoids the toxicity and resistance problems caused by chemical pesticides, and some bacteria are



used directly as bio-pesticides. Hydroponic culture, in which plants are grown in aerated water with dissolved nutrient salts, is used to test which nutrients a plant actually needs, and food-preservation techniques such as pasteurization (developed by Louis Pasteur) protect milk and other foods from spoilage over long transport and storage.

In disease control, three approaches are used together: preventive measures (avoiding known modes of transmission, for example of HIV/AIDS or hepatitis through blood or contaminated instruments), vaccination or immunization (a technique first developed by Edward Jenner in 1796 using cowpox, from the Latin vacca meaning cow, which has since eliminated smallpox and controls diseases such as polio, whooping cough, measles and mumps), and drug treatment or gene therapy (antibiotics against bacteria that have not developed resistance, radiotherapy and chemotherapy against cancer, and gene therapy, which inserts a normal copy of a defective gene into the patient, often via bone-marrow cells). Combining all of these approaches with community awareness is called integrated disease management.

Biology in the Service of Mankind: Cloning and the Environment

Cloning produces a cell or individual and all of its genetically identical, asexually produced offspring. Few animals clone naturally, but in 1997 scientists in Scotland succeeded in cloning a sheep by replacing the nucleus of a fertilized egg with a nucleus from an adult cell and implanting the resulting embryo in a womb; other mammals such as mice and cows have since been cloned the same way. A second cloning method simply splits a single egg or early embryo into separate embryos, the same natural process that produces identical twins, and this has already been used to produce genetically identical farm animals. Possible future uses include commercial production of animals of known pedigree, though the idea of cloning human embryos as a source of transplant tissue remains highly controversial.

Industrialization has raised living standards but has also damaged the environment: industrial waste and effluents, including toxic and even carcinogenic materials and heavy metals such as lead and chromium, are released into air, soil and water. Biologists have pushed for compulsory treatment of industrial effluents and are investigating bioremediation, the removal of pollutants using living organisms (for example, algae that absorb heavy metals), as well as identifying endangered species that need protection. In Pakistan, rivers and canals are heavily polluted by city sewage and industrial waste, harming freshwater fish populations, and vehicle exhaust adds significant lead to city air, showing the practical need for measures such as lead-free petrol.

Important Definitions

Term	Definition
Biology	The study of living things; literally, the study of life.
Bioelement	One of the 16 chemical elements (of the 92 that occur naturally) commonly used to build the compounds of living organisms.
Organelle	



Term	Definition
	A specialised structure within a cell that performs a specific function, such as a mitochondrion or ribosome.
Population	A group of living organisms of the same species located in the same place at the same time.
Community	Populations of different species living and interacting together in the same habitat.
Biome	A large regional community of organisms determined mainly by climate and named after its dominant plant type.
Hypothesis	A tentative explanation of an observation, formed by deductive or inductive reasoning and still to be tested.
Scientific law	A uniform, virtually irrefutable fact of nature; a theory that has survived repeated, rigorous attempts at falsification.

Key Facts

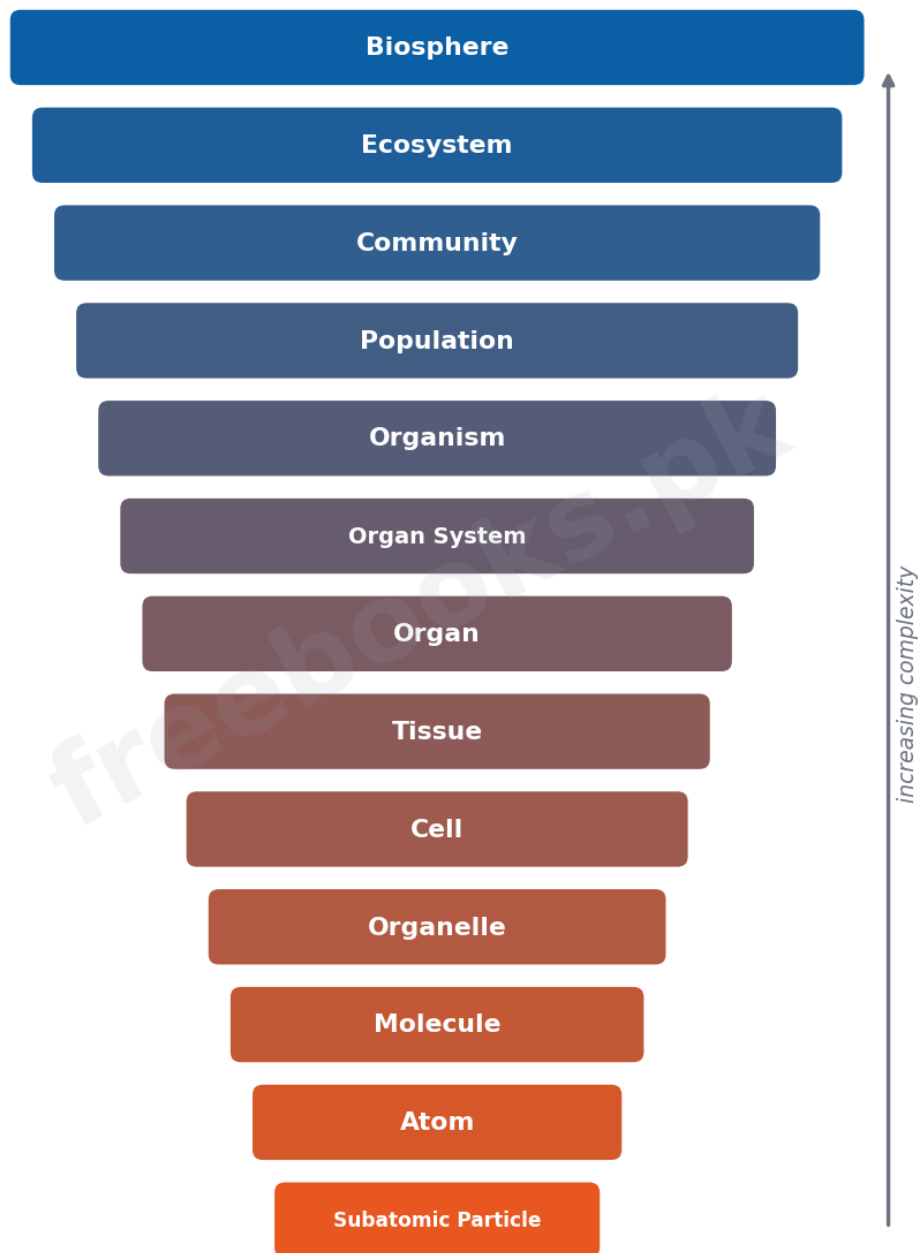
Item	Fact
Elements used by life	16 of the 92 naturally occurring chemical elements are commonly used to build living matter (bioelements).
Bioelements in the human body	Just 6 bioelements account for 99% of the total mass of the human body.
Known species today	About 2.5 million species are currently known to science; insects alone make up roughly 53%.
Estimated total species	Careful estimates put the true total number of species between 5 and 30 million.
Reasoning in science	Deductive reasoning: general to specific. Inductive reasoning: specific to general.
Order of scientific confidence	Hypothesis -> Theory (well-tested, related hypotheses) -> Scientific law (never falsified).
First vaccination	Edward Jenner used cowpox to develop vaccination in 1796 (Latin vacca = cow).
First cloned mammal (sheep)	Scientists in Scotland successfully cloned a sheep in 1997.

Diagrams & Illustrations

Levels of Biological Organization: a step diagram from the smallest to the largest level of biological organization: subatomic particle, atom, molecule, organelle, cell, tissue, organ, organ system, organism, population, community, ecosystem and biosphere.



Levels of Biological Organization

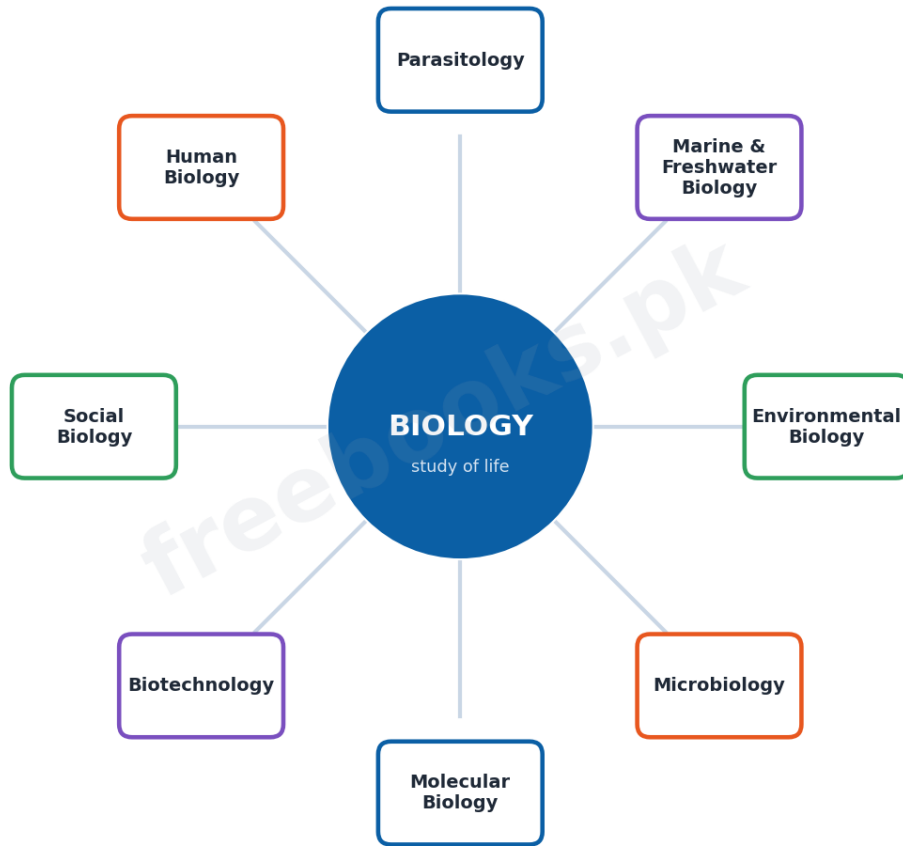


Levels of Biological Organization

Major Branches of Biology: a concept map with Biology at the centre and its major branches / fields of specialization around it, including Molecular Biology, Microbiology, Environmental Biology, Marine and Freshwater Biology, Parasitology, Human Biology, Social Biology and Biotechnology.



Major Branches / Fields of Specialization of Biology

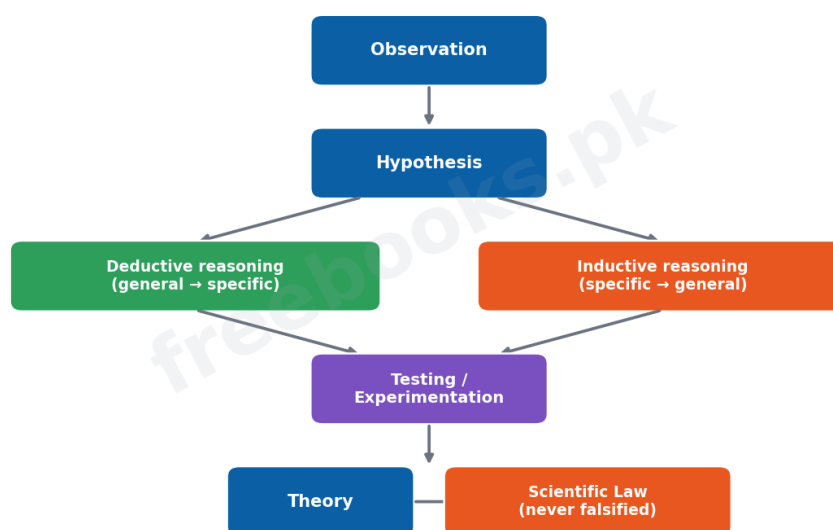


Major Branches of Biology

The Biological (Scientific) Method: a flowchart of the biological method: observation leads to a hypothesis, formed by deductive or inductive reasoning, which is tested experimentally; a well-tested hypothesis becomes a theory, and a theory that is never falsified becomes a scientific law.



The Biological (Scientific) Method



The Biological (Scientific) Method

Short Questions & Answers

Q1. Differentiate between Environmental Biology and Freshwater Biology.

Ans. Environmental Biology studies organisms in relation to their whole environment, including human impact, while Freshwater Biology specifically studies organisms living in rivers, lakes and other freshwater bodies along with the physical and chemical properties of that water.

Q2. What are bioelements, and why are they significant in the human body?

Ans. Bioelements are the 16 (of 92 naturally occurring) chemical elements commonly used to build living matter; in the human body just six of them make up 99% of the total mass, showing how a small set of elements supports almost all of life's chemistry.

Q3. Differentiate between population and community.

Ans. A population is a group of organisms of the same species living in the same place at the same time, while a community consists of populations of different species living and interacting together in the same habitat.

Q4. What is a hypothesis, and how does it differ from a theory?

Ans. A hypothesis is a tentative explanation of an observation that still needs to be tested, while a theory is a series of related hypotheses that have been repeatedly tested without being falsified, giving it stronger, more general support.

Q5. Differentiate between deductive and inductive reasoning.

Ans. Deductive reasoning moves from a general principle to a specific conclusion (if all birds have wings and sparrows are birds, then sparrows have wings), while inductive reasoning moves from specific observations to a general principle (several birds are seen to have wings, so all birds are concluded to have wings).

Q6. Define cloning and give one example of its practical use.



Ans. Cloning is the production of a cell or individual and all of its genetically identical, asexually produced offspring; for example, in 1997 scientists in Scotland cloned a sheep by transferring an adult cell's nucleus into an egg whose own nucleus had been removed.

Long Questions & Answers

Q1: Describe the levels of biological organization from atoms to the biosphere.

Living matter is built up in a series of levels, each formed from the level below it. Subatomic particles such as protons, electrons and neutrons combine to form atoms, the basic units of the chemical elements. Atoms bond to form molecules, which may be simple micromolecules such as water and carbon dioxide or large macromolecules such as starch and proteins. Molecules are organized into organelles, the specialised working parts of a cell such as mitochondria and ribosomes, and organelles function together inside a cell, the basic unit of life. Groups of similar cells performing the same job form tissues, and different tissues working together form organs, such as the stomach. Organs that cooperate to carry out one overall function make up an organ system, and organ systems together make up a whole organism. Organisms of the same species sharing a place and time form a population, and populations of different species sharing a habitat form a community. A community together with its non-living surroundings, such as soil, water and climate, forms an ecosystem, and all of Earth's ecosystems together make up the biosphere, the zone of the planet that supports life. Each level shows properties that are not found at the level below it, which is why biologists study organisms at all of these levels rather than just one.

Q2: Explain the biological method used in solving a biological problem, including the role of deductive and inductive reasoning.

The biological, or scientific, method begins with a chance observation made through the senses; observations may be qualitative (descriptive) or quantitative (numerical and more precise). From these observations a scientist proposes a hypothesis, a tentative explanation that must be tested. A hypothesis can be formed by deductive reasoning, which starts from an accepted general principle and predicts a specific outcome using "if ... then" logic (for example, if all green plants need sunlight for photosynthesis, then a green plant kept in the dark will not make glucose), or by inductive reasoning, which starts from specific observed cases and builds up a general principle (for example, observing that several different kinds of birds all have wings and concluding that wings are a general feature of birds). Occasionally hypotheses also arise from intuition, analogy, or accidental discovery. Once formed, a hypothesis is tested repeatedly; if it survives many honest attempts at falsification, confidence in it grows, and a set of such well-supported, related hypotheses becomes a theory. A good theory both explains existing observations and predicts new ones. If a theory continues to withstand rigorous testing over time and is never falsified, it may eventually be accepted as a scientific law, a virtually irrefutable statement of how nature behaves; because life is so complex and variable, biology has comparatively few laws, such as the Hardy-Weinberg law and Mendel's laws of inheritance.



Q3: Discuss the major branches of biology and how newer specializations like biotechnology have developed alongside the classical branches.

Because biology covers every aspect of living things, it has been divided into many branches for convenience of study. The classical branches focus on particular aspects of organisms: Ecology studies environmental relations, Embryology studies development, Physiology studies functions, Morphology or Anatomy studies structure and form, Palaeontology studies fossils, Histology studies tissues, Evolution studies ancestral history, Genetics studies heredity, and Zoogeography studies the distribution of animals. Alongside these, more specialised, often more applied branches have grown in importance: Molecular Biology examines organisms, cells and organelles at the molecular level; Environmental Biology and, more specifically, Freshwater Biology and Marine Biology study organisms in relation to their surroundings on land, in fresh water and in the sea; Microbiology studies bacteria, viruses, protozoa and microscopic fungi and algae; Parasitology studies parasites and their relationships with hosts; Human Biology and Social Biology focus on the structure, function and social behaviour of human beings; and Biotechnology applies living organisms and biological processes to manufacturing, agriculture and medicine. These newer branches did not replace the classical ones; rather, they grew out of them as scientists combined biology with chemistry, physics and technology to solve practical problems in food, health, and industry, which is why biology today is described as an extremely wide-based science with volumes of information organized into many specialized fields.

Q4: Explain the contribution of biology to disease control, with reference to preventive measures, vaccination and drug treatment/gene therapy.

Biology contributes to disease control through three combined approaches. Preventive measures rely on biological knowledge of how diseases spread; for instance, knowing that AIDS is caused by HIV and hepatitis by its causative virus, both transmitted through blood transfusion, contaminated syringes or surgical instruments, or (for HIV) sexual contact, allows doctors to advise people to avoid these specific points of contact. Vaccination or immunization, a technique that traces back to Edward Jenner's use of cowpox in 1796 (the word vaccine comes from the Latin vacca, meaning cow), trains the body's immunity in advance and has eliminated smallpox worldwide while keeping diseases such as polio, whooping cough, measles and mumps under control through routine childhood immunization; experimental vaccines, including one against AIDS, continue to be developed. Drug treatment and gene therapy act once a person is already sick: antibiotics can kill bacteria that have not developed resistance, radiotherapy exposes cancerous tissue to short-wave radiation at intervals, chemotherapy uses anticancer chemicals that unfortunately can also affect normal cells, and gene therapy repairs defective genes by isolating a normal copy of the gene and inserting it into the patient, often through bone-marrow cells. Using all of these methods together, combined with community awareness of a disease's causes and remedies, is known as integrated disease management, and it is considered a highly effective way to eliminate or control dangerous diseases in a population.



Q5: What is the role of the study of biology in the welfare of mankind, considering food production, cloning and the environment?

Biology has improved human welfare in several connected ways. In food production, selective breeding based on genetics has produced higher-yielding, disease-resistant crop and livestock varieties, genetic engineering has created transgenic plants carrying useful foreign genes, biological pest control using natural enemies (such as a wasp that parasitizes aphids) avoids the toxicity and resistance problems of chemical pesticides, hydroponic culture allows precise study and growth of plants without soil, and techniques such as pasteurization preserve food during storage and transport. In cloning, techniques developed from the successful cloning of a sheep in Scotland in 1997, and from splitting early embryos, can multiply animals of known genetic value, though the cloning of human embryos remains ethically controversial. In environmental protection, biology has drawn attention to the damage caused by industrial effluents and heavy metals, promoted bioremediation methods such as using algae to absorb pollution, and pushed for the identification and protection of endangered species; in Pakistan specifically, biologists have highlighted the pollution of rivers and canals by sewage and industrial waste and the need for measures such as lead-free petrol to protect both freshwater life and human health. Taken together, these contributions show biology moving beyond pure classification of living things into an applied science that directly improves food security, health and the environment.

MCQs with Answers

1. Biology is best defined as the study of:

(a) matter and energy (b) living things (c) the earth's crust (d) chemical reactions only

Correct Answer: (b) living things. The word biology literally means the study of life / living things.

2. Which branch of biology studies organisms living in seas and oceans?

(a) Freshwater Biology (b) Marine Biology (c) Parasitology (d) Microbiology

Correct Answer: (b) Marine Biology. Marine Biology studies life in seas and oceans and the physical/chemical characteristics of the sea.

3. Which branch of biology deals with bacteria, viruses, protozoa and microscopic fungi/algae?

(a) Human Biology (b) Social Biology (c) Microbiology (d) Biotechnology

Correct Answer: (c) Microbiology. Microbiology is the study of microorganisms such as bacteria, viruses, protozoa and microscopic algae and fungi.

4. How many bioelements commonly form the compounds of living organisms?

(a) 6 (b) 10 (c) 16 (d) 92

Correct Answer: (c) 16. 16 of the 92 naturally occurring elements are commonly used to build living matter; these are the bioelements.

5. Which is the smallest level of biological organization mentioned in the chapter?

(a) Cell (b) Molecule (c) Subatomic particle (d) Organelle

Correct Answer: (c) Subatomic particle. Subatomic particles (protons, electrons, neutrons) are the smallest level, combining to form atoms and then molecules.



6. A group of organisms of the same species living in the same place at the same time is called a:

(a) Community (b) Population (c) Ecosystem (d) Biome

Correct Answer: (b) Population. This is the definition of a population; a community includes populations of different species.

7. Reasoning that moves from a general principle to a specific conclusion is called:

(a) Inductive reasoning (b) Deductive reasoning (c) Experimental reasoning (d) Analogical reasoning

Correct Answer: (b) Deductive reasoning. Deductive reasoning moves from the general to the specific, using "if ... then" logic.

8. The technique of vaccination was first developed by:

(a) Louis Pasteur (b) Gregor Mendel (c) Edward Jenner (d) Charles Darwin

Correct Answer: (c) Edward Jenner. Edward Jenner developed vaccination in 1796 using cowpox (Latin vacca = cow).

9. In 1997, scientists in Scotland succeeded in cloning a:

(a) Cow (b) Mouse (c) Sheep (d) Goat

Correct Answer: (c) Sheep. The first successfully cloned mammal from an adult cell was a sheep, cloned in Scotland in 1997.

10. The removal or degradation of environmental pollutants using living organisms is called:

(a) Biotechnology (b) Bioremediation (c) Biodiversity (d) Biogeography

Correct Answer: (b) Bioremediation. Bioremediation uses living organisms, such as algae absorbing heavy metals, to reduce pollution.

Quick Revision Summary

- Biology is the study of living things; living organisms are organized, made of cells, carry genetic information, use energy, grow, maintain internal balance, reproduce and respond to the environment.
- Major branches include Molecular Biology, Environmental Biology, Microbiology, Freshwater and Marine Biology, Parasitology, Human Biology, Social Biology and Biotechnology, alongside classical branches like Ecology, Genetics and Evolution.
- Levels of organization (smallest to largest): subatomic particle, atom, molecule, organelle, cell, tissue, organ, organ system, organism, population, community, ecosystem, biosphere.
- 16 of 92 natural elements are bioelements; just 6 make up 99% of human body mass.
- Biomes describe life's distribution in space; fossils and geological time chart describe life's distribution in time; a phyletic lineage is an unbroken ancestor-to-descendant series of species.
- Biological method: observation -> hypothesis (deductive or inductive reasoning) -> testing -> theory -> scientific law (e.g. Hardy-Weinberg law, Mendel's laws).
- Biology serves mankind through better food production (selective breeding, genetic engineering, biological pest control), disease control (prevention, vaccination since



Jenner 1796, drug treatment/gene therapy), cloning (sheep, Scotland, 1997), and environmental protection (bioremediation, endangered species). Notes by freebooks.pk.

Exam Tips

- Learn the exact order of levels of biological organization (subatomic particle to biosphere) by heart; a common MCQ and short-question topic.
- Be ready to define at least 5-6 branches of biology in your own words, not just name them.
- Practise distinguishing similar pairs: population vs community, deductive vs inductive reasoning, theory vs scientific law.
- Remember key names and dates: Edward Jenner (vaccination, 1796), Louis Pasteur (pasteurization), Scotland 1997 (first cloned sheep).
- For "role of biology in welfare of mankind" questions, cover all four angles: food, disease control, cloning, environment — examiners often ask for at least two.
- In fill-in-the-blank and true/false questions from the exercise, watch for commonly confused facts, e.g. vaccination history and which bioelements dominate body mass.

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FSc Part-I Biology — Punjab Board

CHAPTER 2

Biological Molecules

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Biological Molecules from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It introduces biochemistry, the branch of biology that studies the chemical compounds and reactions of living things, and explains why carbon and water are central to life. It then works through the four major classes of organic molecules found in every cell: carbohydrates, lipids, proteins and nucleic acids, along with the conjugated molecules formed when these classes combine. These notes are prepared by freebooks.pk.

Understanding how a monosaccharide becomes a polysaccharide, how amino acids fold into a functional protein, and how nucleotides pair up inside the DNA double helix gives the chemical vocabulary needed for cell biology, genetics and physiology in later chapters. The chapter also introduces key scientists — Sanger, Chargaff, Watson and Crick — whose work revealed these structures.

Learning Objectives

- Define biochemistry and distinguish organic from inorganic compounds in living cells.
- Explain why carbon's tetravalency and water's polarity make them central to life chemistry.
- Classify carbohydrates into monosaccharides, oligosaccharides and polysaccharides with examples.
- Describe the main classes of lipids and explain why they store more energy than carbohydrates.
- Describe amino acids, the peptide bond, and the primary, secondary, tertiary and quaternary levels of protein structure.
- Describe the structure of a nucleotide and explain the DNA double helix, including Chargaff's base-pairing rule.
- Differentiate the three types of RNA (mRNA, tRNA, rRNA) and state their roles in protein synthesis.
- Explain what conjugated molecules are, with examples such as glycoproteins and nucleoproteins.

Key Concepts

Introduction to Biochemistry

Biochemistry is the branch of biology that studies the chemical components and chemical processes of living organisms; because every structure in an organism has a biochemical basis, biochemistry underlies the understanding of anatomy and physiology, and processes such as photosynthesis, respiration, digestion and muscle contraction can all be described in biochemical terms. Living matter is built of organic compounds (mainly carbohydrates, proteins, lipids and nucleic acids) and inorganic substances (water, carbon dioxide, acids, bases and salts); water and proteins together make up the bulk of both bacterial and mammalian cells, with nucleic acids, carbohydrates and lipids present in smaller amounts.



All the chemical reactions of a cell are together called metabolism, which has two coordinated sides: anabolic reactions build complex substances from simpler ones and require energy, while catabolic reactions break complex molecules down into simpler ones and release energy. Anabolism and catabolism run side by side, so that molecules broken down in one pathway are reused as building blocks in another, which is why carbohydrates, proteins and lipids are constantly interconverted inside living cells.

Importance of Carbon

Carbon is the basic element of organic compounds and occupies the central position in the chemistry of life because it is tetravalent: it forms four covalent bonds arranged symmetrically in a tetrahedron, giving a very stable configuration. Carbon atoms also bond to one another to form stable branched or unbranched chains and rings, and this ability is responsible for the huge variety of organic compounds; these C-C bonds form the basic skeleton of organic molecules.

Carbon commonly combines with hydrogen, oxygen, nitrogen, phosphorus and sulphur. The C-H bond is a key source of chemical energy for cellular activity, carbon-oxygen linkages (glycosidic bonds) give stability to complex carbohydrates, and carbon-nitrogen linkages (peptide bonds) build proteins. Large organic macromolecules such as cellulose, fats and proteins are usually insoluble in water and form the structural parts of cells, while small molecules such as glucose, amino acids and fatty acids act as an energy source or as subunits for building macromolecules; some, like ATP, are unstable enough to be broken down immediately to release energy for metabolism.

Importance of Water

Water is the medium of life and the most abundant compound in organisms, making up anywhere from about 65% to 89% of body mass depending on the tissue (for example, about 20% in human bone cells but about 85% in brain cells). Because of its polarity, water is an excellent solvent for polar and ionic substances, which dissociate or disperse in it and can then move and react freely; this is why almost all of a cell's enzyme-catalysed reactions happen in an aqueous medium, while non-polar molecules such as fats stay insoluble and help form membranes that create separate compartments in the cell.

Water also has a very high heat capacity, absorbing large amounts of heat with only a small rise in its own temperature (because much of the energy goes into breaking hydrogen bonds), which lets it act as a temperature stabilizer for organisms. Its high heat of vaporization means evaporating a small amount of water removes a large amount of heat, giving a cooling effect when water is transpired from plants or perspired by animals. Water molecules also ionize reversibly into H^+ and OH^- ions, which take part in many cellular reactions, and water acts as a lubricant and protective cushion, for example in tears and around internal organs.

Carbohydrates

Carbohydrates, or saccharides, are hydrated carbons composed of carbon, hydrogen and oxygen in the general formula $C_x(H_2O)_y$; chemically they are polyhydroxy aldehydes or



ketones, or compounds that yield such subunits on hydrolysis. They occur abundantly in living organisms, playing both structural roles (such as cellulose in plant cell walls) and functional roles (as the main energy source in cells), and are classified into three groups: monosaccharides, oligosaccharides and polysaccharides.

Monosaccharides are simple sugars, sweet and water-soluble, that cannot be hydrolysed further; common examples by carbon number are trioses, tetroses, pentoses, hexoses and heptoses, with glucose (a hexose) being the most biologically important, formed naturally in plants by photosynthesis and normally present at about 0.08% in human blood.

Oligosaccharides yield 2 to 10 monosaccharides on hydrolysis and are joined by glycosidic bonds; the physiologically important disaccharides are maltose, sucrose and lactose, with sucrose ($C_{12}H_{22}O_{11}$) yielding glucose and fructose on hydrolysis. Polysaccharides are the most complex and abundant carbohydrates, usually branched, tasteless and only sparingly soluble; starch (the main plant storage carbohydrate, in amylose and amylopectin forms) and glycogen (animal starch, stored mainly in liver and muscle) both yield glucose on hydrolysis and give a blue or red colour respectively with iodine, while cellulose, the most abundant carbohydrate in nature, forms plant cell walls and is not digestible by humans, only by herbivores with cellulase-producing gut microbes.

Lipids

Lipids are a chemically varied group of compounds related to fatty acids; they are insoluble in water but soluble in organic solvents, and include fats, oils, waxes, cholesterol and related compounds. Because they have a high proportion of C-H bonds and very little oxygen, lipids store roughly double the energy of an equal mass of carbohydrate, and besides energy storage they form cellular membranes, provide thermal insulation, waterproofing and mechanical protection.

Acylglycerols, such as triacylglycerol (a triglyceride), are esters formed from glycerol and fatty acids; fatty acids themselves are straight (in animals) or sometimes branched (in plants) carbon chains with a carboxyl group, which may be saturated (no double bonds, usually solid fats) or unsaturated (one or more double bonds, usually liquid oils). Waxes are mixtures of long-chain alkanes, alcohols, ketones and esters that protect leaves, fruits and insect exoskeletons from water loss and abrasion. Phospholipids are derivatives of phosphatidic acid (glycerol, fatty acids and phosphoric acid, often with a nitrogenous base such as choline) and are major structural components of cell membranes. Terpenoids are built from repeating isoprenoid units and give rise to compounds such as steroids and carotenoids.

Proteins: Amino Acids and Levels of Structure

Proteins are the most abundant organic compounds in cells, often over 50% of dry weight, and perform an enormous range of roles: building cell structures, acting as enzymes that control metabolism, working as hormones, transporting substances (as in haemoglobin), defending the body as antibodies, and enabling movement. Proteins are polymers of amino acids, each of which has an amino group and a carboxyl group attached to the same (alpha) carbon, differing from one another only in their side chain (R group); of about 170 known



amino acids, roughly 20 commonly make up proteins. Amino acids join through peptide bonds, formed when the amino group of one reacts with the carboxyl group of another, releasing water; two linked amino acids form a dipeptide, and many linked together form a polypeptide chain.

A protein's properties depend on four levels of structure. The primary structure is the specific number and sequence of amino acids in the chain (Sanger showed insulin has 51 amino acids in two chains linked by disulphide bridges, while haemoglobin has four chains, two alpha of 141 amino acids and two beta of 146 amino acids); even a single wrong amino acid, as in sickle-cell haemoglobin, can disrupt normal function. The secondary structure is a regular local folding pattern such as the coiled alpha-helix (about 3.6 amino acids per turn, held by hydrogen bonds) or the folded beta-pleated sheet. The tertiary structure is the overall three-dimensional folding of a single polypeptide into a compact globular shape, stabilized by ionic, hydrogen and disulphide bonds, typically burying hydrophobic amino acids inside and keeping hydrophilic ones on the surface. The quaternary structure describes how multiple folded polypeptide chains associate together, as in haemoglobin. By overall shape, proteins are classified as fibrous (insoluble, structural, e.g. keratin, silk, fibrin) or globular (soluble, functional, e.g. enzymes, antibodies, haemoglobin).

Nucleic Acids: DNA and RNA

Nucleic acids, first isolated in 1869 by Friedrich Miescher from the nuclei of pus cells, are polymers of nucleotides and occur as DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). Each nucleotide has three parts: a five-carbon pentose sugar (deoxyribose in DNA, ribose in RNA), a nitrogenous base, and a phosphoric acid group; a base plus a sugar (without phosphate) is called a nucleoside. The nitrogenous bases are the single-ringed pyrimidines (cytosine, thymine, uracil) and the double-ringed purines (adenine, guanine); DNA uses adenine, guanine, cytosine and thymine, while RNA uses adenine, guanine, cytosine and uracil in place of thymine.

DNA is the hereditary material, controlling a cell's properties and activities; its nucleotides join through phosphodiester linkages into long polynucleotide chains. In 1951 Erwin Chargaff showed that the amount of adenine always closely matches thymine, and guanine closely matches cytosine, in DNA from many different organisms. Using X-ray diffraction data from Maurice Wilkins and Rosalind Franklin, James Watson and Francis Crick proposed that DNA consists of two antiparallel polynucleotide strands wound into a double helix, held together by hydrogen bonds between complementary bases: two hydrogen bonds between adenine and thymine, and three between guanine and cytosine, with about 10 base pairs in each full turn of the helix. The amount of DNA per cell is constant for a given species and is halved in germ cells (sperm and ova) compared with body cells; the sequence of bases along DNA encodes genes, the units of biological inheritance — the bacterium *E. coli*, for example, has a genome of 4,639,221 base pairs coding for at least 4,288 proteins.

RNA is a polymer of ribonucleotides, usually single-stranded (though it may fold back on itself), pairing cytosine with guanine and uracil with adenine, and is synthesized from DNA by transcription. Three types of RNA carry out protein synthesis: messenger RNA (mRNA) carries the genetic message from DNA in the nucleus to the ribosomes; transfer RNA (tRNA),



small molecules of 75-90 nucleotides with one specific type for each amino acid, carries amino acids to the ribosome; and ribosomal RNA (rRNA), the major component of RNA in the cell, forms part of the ribosome's structure and machinery for linking amino acids into a protein.

Conjugated Molecules

When two molecules from different categories combine, the product is called a conjugated molecule. Carbohydrates combining with proteins form glycoproteins, and with lipids form glycolipids; both are important structural components of plasma membranes, and most cellular secretions are glycoproteins. Lipids combining with proteins form lipoproteins, which provide the basic structural framework of cell membranes. Nucleic acids have a strong affinity for basic proteins, combining to form nucleoproteins such as the nucleohistones found in chromosomes; besides their structural role, these conjugated proteins are important in regulating gene expression.

Important Definitions

Term	Definition
Metabolism	The sum of all chemical reactions taking place within a cell, made up of anabolic (building) and catabolic (breaking-down) reactions.
Monosaccharide	A simple sugar, such as glucose or ribose, that cannot be hydrolysed into a simpler sugar.
Polysaccharide	A complex carbohydrate formed of many monosaccharide units joined by glycosidic bonds, e.g. starch, glycogen or cellulose.
Fatty acid	A straight or branched carbon chain with a carboxyl (-COOH) group, which may be saturated or unsaturated; a building block of lipids.
Peptide bond	The covalent C-N bond formed between the carboxyl group of one amino acid and the amino group of another, releasing water.
Nucleotide	The basic subunit of a nucleic acid, made of a pentose sugar, a nitrogenous base and a phosphoric acid group.
Nucleoside	A compound formed by a nitrogenous base joined to a pentose sugar, without a phosphate group.
Conjugated molecule	A compound formed when two molecules of different categories combine, e.g. a glycoprotein (carbohydrate + protein).

Key Facts

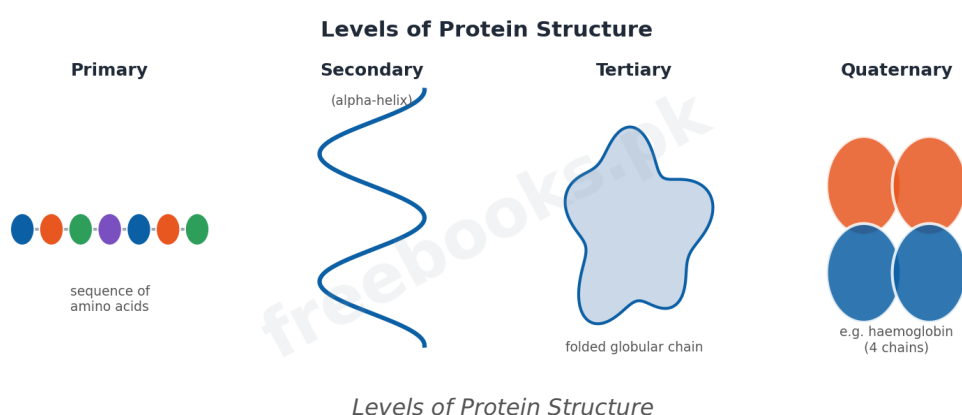
Item	Fact
General formula of carbohydrates	$C_x(H_2O)_y$, where x is 3 or more.
Photosynthesis (glucose formation)	$6CO_2 + 12H_2O \xrightarrow{\text{(light, chlorophyll)}} C_6H_{12}O_6 + 6O_2 + 6H_2O$



Item	Fact
Normal blood glucose	About 0.08% in human blood.
Sucrose formula	C ₁₂ H ₂₂ O ₁₁ -- hydrolyses to glucose + fructose.
DNA base pairing (Chargaff's rule)	Adenine = Thymine; Guanine = Cytosine.
Hydrogen bonds in base pairs	A-T pair: 2 hydrogen bonds. G-C pair: 3 hydrogen bonds.
DNA double helix geometry	About 10 base pairs per turn; one turn spans about 34 Angstrom units.
Insulin / Haemoglobin structure	Insulin: 51 amino acids in 2 chains (Sanger). Haemoglobin: 4 chains - 2 alpha (141 aa) + 2 beta (146 aa).

Diagrams & Illustrations

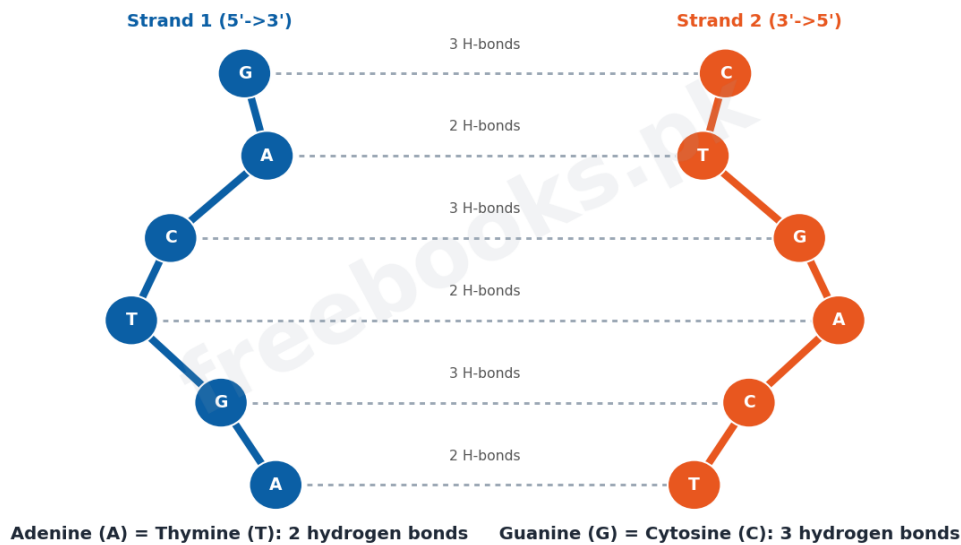
Levels of Protein Structure: a diagram comparing the primary (amino acid sequence), secondary (alpha-helix / beta-sheet), tertiary (folded globular chain) and quaternary (multiple chains, e.g. haemoglobin) levels of protein organization.



DNA Double Helix and Base Pairing: a diagram of the DNA double helix showing the two antiparallel strands and complementary base pairing, adenine with thymine (2 hydrogen bonds) and guanine with cytosine (3 hydrogen bonds).



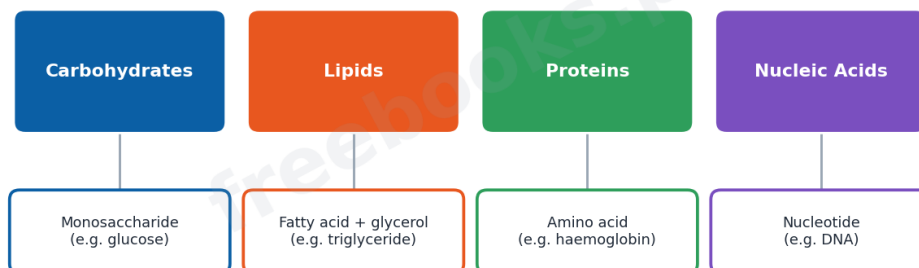
DNA Double Helix and Base Pairing



DNA Double Helix and Base Pairing

Major Classes of Biological Molecules: a summary chart of the four major classes of biological molecules - carbohydrates, lipids, proteins and nucleic acids - with their basic monomer unit and a common example of each.

Major Classes of Biological Molecules



Major Classes of Biological Molecules

Short Questions & Answers

Q1. Differentiate between monosaccharides and polysaccharides.

Ans. Monosaccharides are simple, sweet, water-soluble sugars that cannot be hydrolysed further (e.g. glucose), while polysaccharides are large, usually tasteless, only sparingly soluble molecules made of many monosaccharide units joined by glycosidic bonds (e.g. starch, cellulose).

Q2. Why do lipids store more energy than an equal mass of carbohydrate?

Ans. Lipids have a much higher proportion of C-H bonds and very little oxygen compared with carbohydrates, so oxidising the same mass of lipid releases roughly double the energy released from carbohydrate.



Q3. What is a peptide bond, and how is it formed?

Ans. A peptide bond is the C-N covalent bond linking two amino acids; it forms when the carboxyl group of one amino acid reacts with the amino group of another, releasing a molecule of water.

Q4. Differentiate between the primary and secondary structure of a protein.

Ans. Primary structure is simply the number and specific sequence of amino acids in the polypeptide chain, while secondary structure is the regular local folding of that chain, such as an alpha-helix or beta-pleated sheet, held together by hydrogen bonds.

Q5. State Chargaff's rule for DNA base composition.

Ans. In DNA from any organism, the amount of adenine is always approximately equal to the amount of thymine, and the amount of guanine is always approximately equal to the amount of cytosine.

Q6. Differentiate between mRNA and tRNA.

Ans. Messenger RNA (mRNA) carries the genetic message from DNA in the nucleus to the ribosomes, while transfer RNA (tRNA) is a small molecule that picks up specific amino acids and carries them to the ribosome to be linked into a protein.

Long Questions & Answers

Q1: Describe the classification of carbohydrates with examples of each group.

Carbohydrates are classified into three groups based on the number of sugar units they yield on hydrolysis. Monosaccharides are simple sugars such as glyceraldehyde, ribose and glucose that cannot be broken down into simpler sugars; they are sweet, water-soluble, and named by their carbon number (trioses, tetroses, pentoses, hexoses, heptoses), with glucose, a hexose, being the most important biologically since it is the main product of photosynthesis and the normal sugar of blood. Oligosaccharides yield two to ten monosaccharides on hydrolysis; the most important are disaccharides such as sucrose (glucose + fructose), maltose and lactose, joined by a glycosidic bond. Polysaccharides are the largest and most complex group, formed of many monosaccharide units and usually insoluble or only sparingly soluble; starch (amylose and amylopectin) is the main plant storage carbohydrate, glycogen is the equivalent storage carbohydrate in animals, and cellulose, the most abundant carbohydrate in nature, forms the rigid cell walls of plants and is digestible only by organisms with cellulase-producing gut microbes. Together these three groups supply energy, provide structural support, and combine with other molecules to form conjugated compounds such as glycoproteins.

Q2: Describe the four levels of protein structure.

A protein's specific shape and function depend on four levels of organization. The primary structure is the exact number and sequence of amino acids joined by peptide bonds along the polypeptide chain; this sequence, determined ultimately by the DNA that codes for the protein, is so specific that even one wrongly placed amino acid, as in sickle-cell



haemoglobin, can seriously disrupt the protein's function. The secondary structure describes regular, repeating local folding patterns held together by hydrogen bonds between nearby parts of the chain, most commonly the coiled alpha-helix (about 3.6 amino acids per turn) or the folded-back beta-pleated sheet. The tertiary structure is the overall three-dimensional folding of the whole polypeptide chain into a compact globular shape, stabilized by ionic bonds, hydrogen bonds and disulphide bridges, typically with hydrophobic amino acids folded into the interior and hydrophilic ones exposed on the surface in an aqueous environment. The quaternary structure applies only to proteins built from more than one polypeptide chain, describing how these separate tertiary-folded chains associate together through hydrophobic interactions and hydrogen and ionic bonds; haemoglobin, with its two alpha and two beta chains, is the classic example. Together these four levels explain why proteins as different as fibrous keratin and globular haemoglobin can be built from the same basic units — amino acids — arranged and folded in entirely different ways.

Q3: Describe the structure of DNA as proposed by Watson and Crick.

DNA (deoxyribonucleic acid) is a polymer of deoxyribonucleotides, each made of a deoxyribose sugar, a phosphate group, and one of four nitrogenous bases: the purines adenine and guanine, and the pyrimidines cytosine and thymine. In 1951 Erwin Chargaff analysed the base composition of DNA from many organisms and found that the amount of adenine always closely equals the amount of thymine, and guanine always closely equals cytosine, a pattern that strongly hinted at a pairing relationship between bases. Using X-ray diffraction images produced by Maurice Wilkins and Rosalind Franklin, James Watson and Francis Crick built a scale model showing that DNA consists of two polynucleotide strands wound around each other in a double helix, running antiparallel to one another (coiled in opposite directions). The two strands are held together by hydrogen bonds between complementary base pairs on the inside of the helix: adenine always pairs with thymine through two hydrogen bonds, and guanine always pairs with cytosine through three hydrogen bonds, which explains Chargaff's ratios. The helix is very regular, with about 10 base pairs in each complete turn spanning roughly 34 Angstrom units. Because the sequence of bases along one strand automatically determines the sequence on the other (through this base-pairing rule), each strand can act as a template, and the linear order of hundreds of bases at a time forms functional units called genes, which store all the hereditary information needed to build and run a cell.

Q4: Explain the different types of lipids and their biological importance.

Lipids are a chemically diverse group of compounds, united mainly by being insoluble in water but soluble in organic solvents, and they serve several biological roles: storing about twice as much energy per gram as carbohydrates, forming the structural basis of cell membranes, and providing insulation and waterproofing. Acylglycerols, especially triacylglycerols (triglycerides), are esters of glycerol and fatty acids and are the main energy-storage lipids in the body; the fatty acids that make them up may be saturated (no double bonds, generally forming solid fats) or unsaturated (one or more double bonds, generally forming liquid oils). Waxes are mixtures of long-chain alkanes, alcohols and esters that coat leaves, fruits, insect exoskeletons and animal fur to reduce water loss and resist abrasion. Phospholipids, built from glycerol, fatty acids, phosphoric acid and often a



nitrogenous base such as choline, are the main structural lipids of cell membranes because one end of the molecule is water-attracting and the other is water-repelling. Terpenoids, built from repeating isoprenoid units, give rise to important biological compounds such as steroids and carotenoids. Taken together, this range of lipid types allows the same broad chemical class to serve as fuel, as membrane material, and as protective coating across very different organisms.

Q5: Describe the three main types of RNA and their functions in protein synthesis.

Protein synthesis depends on three types of RNA, all transcribed from DNA in the nucleus before moving into the cytoplasm to do their specific jobs. Messenger RNA (mRNA) is a single strand of variable length, matched to the size of the gene and protein it codes for (a protein of 1,000 amino acids needs an mRNA of about 3,000 nucleotides); it carries the genetic message copied from DNA out to the ribosomes, where it specifies the order in which amino acids must be joined. Transfer RNA (tRNA) molecules are small, only 75 to 90 nucleotides long, and there is at least one specific type of tRNA for each of the roughly 20 amino acids used in proteins; each tRNA picks up its matching amino acid and carries it to the ribosome, positioning it correctly according to the mRNA sequence. Ribosomal RNA (rRNA) makes up the largest share of a cell's total RNA and is tightly combined with ribosomal proteins to form the physical machinery of the ribosome itself, on whose surface mRNA and tRNA interact so that the genetic information in a gene is finally translated into a specific, functional protein.

MCQs with Answers

1. Biochemistry is best described as the study of:

(a) fossils and evolution (b) chemical components and processes in living organisms (c) classification of organisms (d) distribution of organisms

Correct Answer: (b) chemical components and processes in living organisms.

Biochemistry studies the chemical compounds and chemical processes of living things.

2. Reactions in which simple substances combine to form complex substances, using energy, are called:

(a) catabolic reactions (b) anabolic reactions (c) hydrolysis reactions (d) ionization reactions

Correct Answer: (b) anabolic reactions. Anabolic reactions build complex molecules from simpler ones and require energy.

3. Carbon is described as tetravalent because it:

(a) has 4 electron shells (b) forms four covalent bonds (c) occurs in 4 forms in nature (d) has 4 isotopes

Correct Answer: (b) forms four covalent bonds. A carbon atom forms four covalent bonds, arranged tetrahedrally, giving stable molecules.

4. The general formula of a carbohydrate is usually written as:



(a) $C_xH_{2y}O_y$ (b) $C_x(H_2O)_y$ (c) $C_xN_yO_y$ (d) $C_x(H_2N)_y$

Correct Answer: (b) $C_x(H_2O)_y$. Carbohydrates are "hydrated carbons" with general formula $C_x(H_2O)_y$.

5. Which polysaccharide is the main carbohydrate storage form in animals?

(a) Starch (b) Cellulose (c) Glycogen (d) Sucrose

Correct Answer: (c) Glycogen. Glycogen, sometimes called animal starch, is stored mainly in liver and muscle.

6. Compared to a carbohydrate of equal mass, a lipid stores approximately:

(a) the same energy (b) half the energy (c) double the energy (d) four times the energy

Correct Answer: (c) double the energy. Lipids have more C-H bonds and less oxygen, so they store roughly double the energy.

7. The bond joining two amino acids in a protein is called a:

(a) glycosidic bond (b) peptide bond (c) phosphodiester bond (d) hydrogen bond

Correct Answer: (b) peptide bond. Amino acids join through peptide bonds, releasing a water molecule.

8. According to Chargaff's rule, in a DNA molecule the amount of adenine equals the amount of:

(a) guanine (b) cytosine (c) thymine (d) uracil

Correct Answer: (c) thymine. Adenine pairs with thymine; guanine pairs with cytosine (Chargaff's rule).

9. How many hydrogen bonds hold a guanine-cytosine base pair together in DNA?

(a) 1 (b) 2 (c) 3 (d) 4

Correct Answer: (c) 3. G-C pairs are held by three hydrogen bonds, versus two for an A-T pair.

10. Which type of RNA carries amino acids to the ribosome during protein synthesis?

(a) mRNA (b) tRNA (c) rRNA (d) hnRNA

Correct Answer: (b) tRNA. Transfer RNA (tRNA) picks up specific amino acids and delivers them to the ribosome.

Quick Revision Summary

- Metabolism = anabolism (builds, uses energy) + catabolism (breaks down, releases energy).
- Carbon's tetravalency and ability to form C-C chains/rings explain the huge variety of organic molecules; water's polarity makes it the solvent and temperature-stabilizer of life.
- Carbohydrates: monosaccharides (e.g. glucose) → oligosaccharides/disaccharides (e.g. sucrose) → polysaccharides (starch, glycogen, cellulose).
- Lipids (acylglycerols, waxes, phospholipids, terpenoids) store about double the energy of carbohydrates and build membranes.



- Proteins are polymers of amino acids joined by peptide bonds; 4 structure levels: primary (sequence), secondary (helix/sheet), tertiary (3-D fold), quaternary (multi-chain, e.g. haemoglobin).
- DNA: double helix (Watson & Crick), antiparallel strands, A-T (2 H-bonds) and G-C (3 H-bonds) pairing (Chargaff). RNA types: mRNA (message), tRNA (amino acid carrier), rRNA (ribosome structure).
- Conjugated molecules: glycoprotein/glycolipid (carbohydrate + protein/lipid), lipoprotein (lipid + protein), nucleoprotein (nucleic acid + protein). Notes by freebooks.pk.

Exam Tips

- Learn the three carbohydrate classes and one named example of each — a very common short-question and MCQ topic.
 - Be ready to list all four levels of protein structure in order, with what stabilizes each one (hydrogen bonds, disulphide bonds, etc.).
 - Memorise Chargaff's rule and the 2 vs 3 hydrogen-bond difference between A-T and G-C pairs; it is repeatedly tested.
 - Know the three types of RNA and one specific function of each (mRNA = message, tRNA = amino-acid carrier, rRNA = ribosome structure).
 - Practise naming conjugated molecules from their two components (e.g. carbohydrate + lipid = glycolipid).
 - For "why do lipids store more energy" style questions, always mention the higher C-H / lower oxygen content, not just "lipids have more energy".
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FSc Part-I Biology — Punjab Board

CHAPTER 3

Enzymes

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Enzymes from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Enzymes are the biological catalysts, almost all of them globular proteins, that make every metabolic reaction in a cell happen fast enough to sustain life. The chapter explains what enzymes are made of, how cofactors and coenzymes help some of them work, and the key characteristics that make enzymes such precise biological tools. These notes are prepared by freebooks.pk.

It then looks at how an enzyme actually catalyses a reaction at its active site, comparing the classic Lock and Key model with the modern Induced Fit model, and examines the four main factors — enzyme concentration, substrate concentration, temperature and pH — that control how fast an enzyme-catalysed reaction runs. The chapter closes with enzyme inhibitors, which is essential background for later chapters on metabolism and for understanding how drugs and poisons act on the body.

Learning Objectives

- Describe the composition of an enzyme, including the active site and, where present, its cofactor.
- Differentiate between a cofactor, prosthetic group, coenzyme, apoenzyme and holoenzyme.
- List the main characteristics of enzymes as biochemical catalysts.
- Explain the mechanism of enzyme action, including the binding site and catalytic site of the active site.
- Compare the Lock and Key model and the Induced Fit model of enzyme-substrate interaction.
- Explain how enzyme concentration, substrate concentration, temperature and pH each affect the rate of an enzyme-catalysed reaction.
- Differentiate between reversible and irreversible enzyme inhibitors, and between competitive and non-competitive inhibition.

Key Concepts

What Are Enzymes?

Enzymes are the most important group of biologically active proteins; they tremendously increase the efficiency (rate) of biochemical reactions and are specific for each type of reaction, so that without them reactions would proceed far too slowly to sustain life. An enzyme is composed of hundreds of amino acids joined together and coiled upon themselves into a globular structure, but its catalytic activity is restricted to a small region called the active site, to which the reactant — called the substrate — attaches; the rest of the bulky amino acid chain simply maintains the enzyme's overall globular shape.

Cofactors, Coenzymes and Related Terms

Some enzymes consist solely of protein, while others also need a non-protein part called a cofactor to function properly. A cofactor often acts as a bridge between the enzyme and its



substrate, sometimes contributing directly to the chemical reaction or supplying chemical energy; metal ions such as Mg^{2+} , Fe^{2+} , Cu^{2+} and Zn^{2+} commonly act as cofactors, and a detachable inorganic-ion cofactor is called an activator.

If the non-protein part is covalently bonded to the enzyme, it is called a prosthetic group; if it is only loosely attached, it is called a coenzyme. Coenzymes are closely related to vitamins, the essential raw materials from which they are made, and because coenzymes (like enzymes) can be reused repeatedly, only small quantities of vitamins are needed in the diet. An enzyme with its coenzyme or prosthetic group removed is called an apoenzyme, and adding the correct coenzyme back restores its activity; the complete, active combination of a polypeptide chain plus its cofactor is called a holoenzyme.

Characteristics of Enzymes

As biochemical catalysts, enzymes share several important characteristics: all enzymes are globular proteins; they increase the rate of a reaction without themselves being used up; their presence does not change the nature or properties of the end products; small amounts of an enzyme can accelerate large amounts of reaction; each enzyme is highly specific, usually catalysing only one reaction or a small group of related reactions; enzymes are sensitive to even minor changes in pH, temperature and substrate concentration; some enzymes need a cofactor to function properly; and all enzymes work by lowering the activation energy of a reaction. Enzymes may be dissolved freely in the cytoplasm or tightly bound to specific organelles — for example, the enzymes of photosynthesis are found in chloroplasts and those of cellular respiration in mitochondria, while some protein-synthesis enzymes are built into the ribosome itself. Some enzymes are potentially damaging if manufactured directly in their active form, so cells make them as inactive precursors instead; pepsin, a powerful protein-digesting enzyme, is produced as inactive pepsinogen and converted to its active form only inside the digestive tract, where it is actually needed.

Mechanism of Enzyme Action

An enzyme is a three-dimensional globular protein with a specific chemical composition and shape that allows it to recognize and react with one particular substrate, transform it into product(s), and then be released completely unchanged so it can be used again and again. In some pathways, such as respiration or photosynthesis, several enzymes act in a fixed order, forming an enzyme-to-enzyme chain in which the product of one step is handed directly to the enzyme catalysing the next step.

The active site itself is shaped by particular amino acids brought close together as the polypeptide chain coils and folds, and it consists of two distinct regions: the binding site, which recognizes and binds the correct substrate to form an enzyme-substrate (ES) complex, and the catalytic site, which is activated once binding occurs and actually carries out the chemical transformation of substrate into product. After catalysis the enzyme detaches from the product completely unchanged; enzymes require an aqueous medium to work, and most are not freely floating in the cytoplasm but attached in an orderly way to membrane systems such as those of mitochondria and chloroplasts.



Lock and Key Model vs Induced Fit Model

In 1890, Emil Fischer proposed the Lock and Key model to explain enzyme-substrate interaction: just as one specific key opens only one specific lock, a specific enzyme can transform only one particular substrate into product(s). In this model the active site is treated as a rigid structure that acts purely as a fixed template, with no change in shape before, during or after the reaction; later studies showed this model does not hold for every enzyme reaction.

Based on newer evidence, Koshland proposed a modified version in 1959 called the Induced Fit model. According to this model, when a substrate binds an enzyme it actually induces a change in the enzyme's structure, and this change in shape enables the enzyme to carry out its catalytic activity more effectively — making the active site flexible and responsive rather than a rigid, unchanging template.

Enzyme and Substrate Concentration

The rate of an enzyme-catalysed reaction depends on both how much enzyme and how much substrate are present. At an unlimited substrate concentration, the reaction rate depends directly on the amount of enzyme present — doubling the enzyme doubles the rate, because more active sites become available to convert substrate into product; beyond a certain enzyme concentration, however, the rate stops depending on this increase (some other factor becomes limiting).

At a low substrate concentration, the reaction rate is directly proportional to the amount of substrate available. But if enzyme concentration is held constant while substrate is increased, a point is reached where further increases in substrate no longer speed up the reaction, because at high substrate levels every active site of every enzyme molecule is already occupied.

Temperature and pH

The rate of an enzyme-controlled reaction generally rises with temperature up to a certain limit; every enzyme has a specific optimum temperature at which it works fastest, and for enzymes in the human body this optimum is 37 degrees Celsius. Heat provides activation energy and kinetic energy, making reacting molecules move and collide faster, but if heating continues past the optimum, it makes the atoms in the enzyme vibrate too violently, destroying the globular structure essential for activity; this loss of shape and function is called denaturation.

Every enzyme also works most effectively over a narrow range of pH known as its optimum pH — for example pepsin at about pH 2.0, salivary amylase at about pH 6.8, and pancreatic lipase at about pH 9.0. A slight shift in pH can alter the ionization of amino acids at the active site (and of the substrate itself), retarding or blocking enzyme activity, while extreme pH changes break the bonds that hold the enzyme's structure together, again causing denaturation.



Enzyme Inhibitors

An inhibitor is a chemical substance that reacts with an enzyme in place of its normal substrate but is not converted into product, so it blocks the active site temporarily or permanently; examples include poisons such as cyanide, certain antibiotics, anti-metabolites and some drugs. Inhibitors are divided into irreversible inhibitors, which permanently occupy the active site (often through covalent bonds) or destroy the enzyme's globular structure altogether, and reversible inhibitors, which form only weak linkages with the enzyme so that their effect can be reduced or removed by increasing substrate concentration.

Reversible inhibitors are further divided into two types. Competitive inhibitors resemble the substrate closely enough in structure to be accepted by the binding site, but they cannot activate the catalytic site, so no product is formed while they occupy the active site. Non-competitive inhibitors instead bind the enzyme at a site other than the active site, altering the enzyme's overall structure so that catalysis fails even when the genuine substrate does manage to bind the active site.

Important Definitions

Term	Definition
Enzyme	A biological catalyst, almost always a globular protein, that greatly increases the rate of a specific biochemical reaction without itself being used up.
Substrate	The specific reactant molecule that binds to an enzyme's active site and is converted into product.
Active site	The small region of an enzyme, made of specific amino acids, where the substrate binds and catalysis occurs.
Cofactor	A non-protein component, such as a metal ion, needed by some enzymes for proper functioning.
Coenzyme	A cofactor that is only loosely attached to an enzyme's protein part, often derived from a vitamin.
Holoenzyme	The complete, catalytically active enzyme, consisting of the polypeptide (apoenzyme) plus its cofactor.
Denaturation	The loss of an enzyme's normal globular shape and activity caused by extreme heat or pH.
Inhibitor	A substance that binds an enzyme in place of the substrate and blocks or reduces its catalytic activity.

Key Facts

Item	Fact
Optimum temperature (human enzymes)	37 degrees Celsius.
Optimum pH - Pepsin	About pH 2.0 (strongly acidic, stomach enzyme).



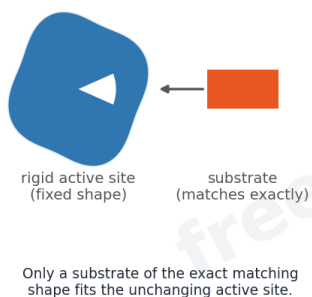
Item	Fact
Optimum pH - Salivary amylase	About pH 6.8 (near neutral).
Optimum pH - Pancreatic lipase	About pH 9.0 (alkaline).
Lock and Key model	Proposed by Emil Fischer, 1890 - rigid active site, fixed template.
Induced Fit model	Proposed by Koshland, 1959 - active site changes shape when substrate binds.
Effect of doubling enzyme concentration	Reaction rate doubles, at unlimited substrate concentration.
Types of inhibitors	Irreversible (permanent) vs Reversible (competitive or non-competitive).

Diagrams & Illustrations

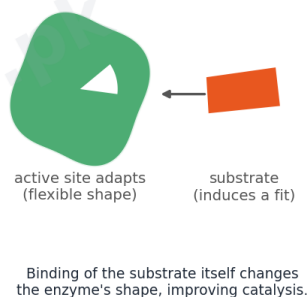
Enzyme Active Site: Lock and Key vs Induced Fit: a side-by-side comparison of the Lock and Key model (rigid active site matching only one substrate shape) and the Induced Fit model (active site changes shape as the substrate binds), showing the enzyme-substrate complex forming in each case.

Enzyme Active Site: Two Models

Lock and Key Model (Fischer, 1890)



Induced Fit Model (Koshland, 1959)

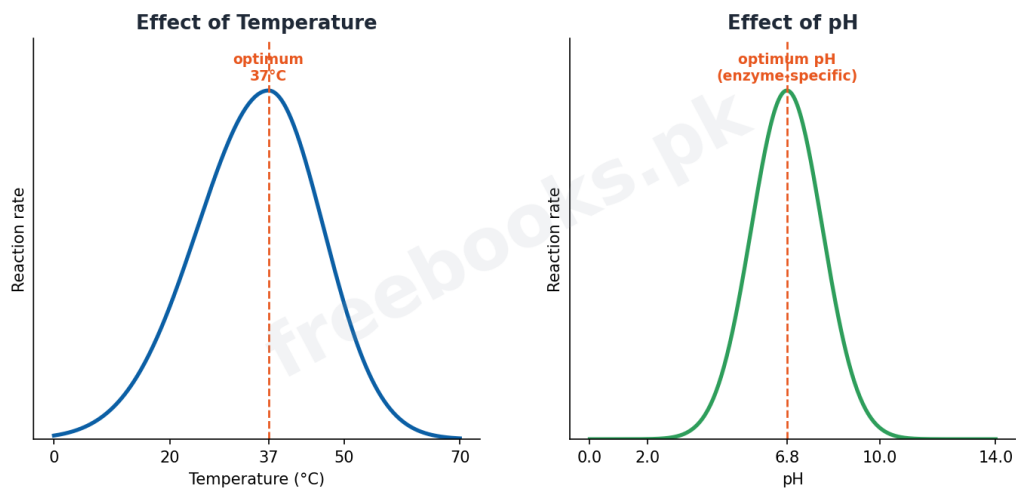


Enzyme Active Site: Lock and Key vs Induced Fit

Effect of Temperature and pH on Enzyme Activity: two curves showing enzyme reaction rate against temperature (rising to a peak at the optimum temperature of 37 degrees Celsius for human enzymes, then falling as the enzyme denatures) and against pH (a similar peak at each enzyme's own optimum pH).



Effect of Temperature and pH on Enzyme Activity

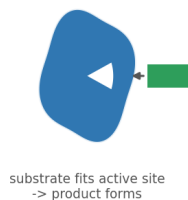


Effect of Temperature and pH on Enzyme Activity

Types of Enzyme Inhibition: a diagram comparing normal enzyme-substrate binding with competitive inhibition (an inhibitor occupies the active site instead of the substrate) and non-competitive inhibition (an inhibitor binds elsewhere on the enzyme and distorts the active site).

Types of Enzyme Inhibition

Normal Binding



Competitive Inhibition



Non-competitive Inhibition



Types of Enzyme Inhibition

Short Questions & Answers

Q1. What is a cofactor? Differentiate a prosthetic group from a coenzyme.

Ans. A cofactor is a non-protein part needed by some enzymes to function; if it is covalently bonded to the enzyme it is called a prosthetic group, while if it is only loosely attached it is called a coenzyme.

Q2. Differentiate between apoenzyme and holoenzyme.

Ans. An apoenzyme is the enzyme protein with its coenzyme or prosthetic group removed (and therefore inactive), while a holoenzyme is the complete, catalytically active combination of the polypeptide chain plus its cofactor.

Q3. Why is enzyme activity lost at very high temperature?



Ans. Excess heat makes the atoms of the enzyme vibrate too violently, breaking the bonds that hold its globular shape; this loss of structure, called denaturation, destroys the active site and stops catalysis.

Q4. Differentiate between competitive and non-competitive inhibitors.

Ans. A competitive inhibitor resembles the substrate and binds the active site itself, blocking the substrate from binding, while a non-competitive inhibitor binds at a different site on the enzyme and changes its shape so catalysis fails even if the substrate does bind the active site.

Q5. State two characteristics of enzymes.

Ans. Enzymes are globular proteins that speed up a reaction without being consumed, and each enzyme is highly specific, usually catalysing only one reaction or a small group of closely related reactions.

Q6. What is the Induced Fit model of enzyme action?

Ans. Proposed by Koshland in 1959, it states that an enzyme's active site is not rigid; when the substrate binds, it induces a change in the enzyme's shape that allows the enzyme to catalyse the reaction more effectively.

Long Questions & Answers

Q1: Describe in detail the mechanism of enzyme action.

An enzyme is a three-dimensional globular protein whose specific chemical composition and shape allow it to recognize and bind one particular substrate at a small region called the active site. The active site itself is made up of two distinct parts: the binding site, which recognizes and physically binds the correct substrate to form an enzyme-substrate (ES) complex, and the catalytic site, which becomes active once binding has occurred and carries out the actual chemical transformation of substrate into product. Once the reaction is complete, the enzyme detaches from the product completely unchanged and is free to bind a new substrate molecule, which is why small amounts of enzyme can process large amounts of substrate. In multi-step metabolic pathways such as respiration or photosynthesis, several enzymes may be arranged in a fixed sequence, forming an enzyme-to-enzyme chain in which the product released by one enzyme becomes the substrate handed directly to the next. Most enzymes require an aqueous medium and are not simply dissolved loose in the cytoplasm but are attached in an orderly way to specific membrane systems, such as the enzymes of respiration in the mitochondria and those of photosynthesis in the chloroplasts.

Q2: Explain the Lock and Key model and the Induced Fit model of enzyme action.

Two models have been proposed to explain how an enzyme recognizes and acts on its substrate. In 1890, Emil Fischer proposed the Lock and Key model, comparing the relationship between an enzyme and its substrate to a lock and its one matching key: a specific enzyme can transform only one particular substrate into product(s) because the active site is treated as a rigid, fixed-shape template that does not change before, during or



after the reaction. This model explained enzyme specificity well but could not account for all enzyme behaviour observed in later experiments. Building on new evidence, Koshland proposed the Induced Fit model in 1959, arguing that the active site is not rigid at all; instead, when the correct substrate approaches and binds, it actually induces a change in the shape of the enzyme's active site, and this induced change in structure enables the enzyme to carry out catalysis more effectively than a perfectly rigid template would allow. The Induced Fit model is now considered a more accurate general description of how enzymes and substrates interact, while the Lock and Key model remains a useful simple picture of enzyme specificity.

Q3: Describe the effect of enzyme concentration and substrate concentration on the rate of an enzyme-catalysed reaction.

When substrate is present in unlimited amount, the rate of an enzyme-catalysed reaction depends directly on the amount of enzyme present: doubling the enzyme concentration doubles the number of available active sites and therefore doubles the reaction rate, though beyond a certain enzyme concentration some other factor becomes limiting and the rate levels off. Conversely, when enzyme concentration is held constant, increasing substrate concentration initially increases the reaction rate in direct proportion, because more substrate molecules are available to occupy active sites at any given moment. However, once substrate concentration becomes high enough that every active site of every enzyme molecule is continuously occupied, adding still more substrate no longer increases the rate, since the enzyme molecules are already working at their maximum capacity; the reaction rate then plateaus regardless of further substrate increases.

Q4: Explain the effect of temperature and pH on enzyme activity.

Enzyme-controlled reactions generally speed up as temperature rises, because heat supplies both the activation energy needed to start the reaction and extra kinetic energy that makes molecules move and collide more often; each enzyme, however, has its own optimum temperature at which it works fastest, and for human-body enzymes this optimum is 37 degrees Celsius. Beyond the optimum, continued heating makes the atoms within the enzyme vibrate so violently that the bonds maintaining its globular shape break down, a process called denaturation, which destroys the active site and stops catalysis even though temperature is still rising. In the same way, every enzyme has a narrow optimum pH range at which it functions best — for example, pepsin works best around pH 2.0, salivary amylase around pH 6.8, and pancreatic lipase around pH 9.0 — because a shift in pH changes the ionization of amino acids in the active site (and sometimes of the substrate itself), which can slow or completely block binding and catalysis. Extreme pH changes, like extreme heat, break the bonds holding the enzyme's structure together and cause denaturation, permanently destroying enzyme activity.

Q5: Write a detailed note on enzyme inhibitors.

An inhibitor is a chemical substance that reacts with an enzyme in place of the normal substrate but is not converted into product, thereby blocking the active site temporarily or permanently; common examples include poisons such as cyanide, certain antibiotics, anti-



metabolites and some therapeutic drugs. Inhibitors fall into two broad categories. Irreversible inhibitors permanently reduce enzyme activity, either by forming covalent bonds that occupy the active site or by physically destroying the enzyme's globular structure, so the enzyme cannot recover its function. Reversible inhibitors, in contrast, form only weak, non-covalent linkages with the enzyme, so their inhibitory effect can be partly or completely overcome by increasing the substrate concentration; these are further divided into competitive inhibitors, which are structurally similar enough to the true substrate to be accepted at the binding site (blocking the substrate from binding and preventing any product from forming), and non-competitive inhibitors, which attach at a location other than the active site and distort the enzyme's overall shape so that catalysis fails even if the real substrate does manage to bind the active site. Understanding these categories of inhibition is essential for later topics such as drug action and metabolic regulation, since many medicines and toxins work precisely by inhibiting specific enzymes in the body.

MCQs with Answers

1. Enzymes are chemically classified as:

(a) carbohydrates (b) lipids (c) globular proteins (d) nucleic acids

Correct Answer: (c) globular proteins. All enzymes are globular proteins, though some need a non-protein cofactor.

2. A non-protein part of an enzyme that is only loosely attached is called a:

(a) prosthetic group (b) coenzyme (c) apoenzyme (d) holoenzyme

Correct Answer: (b) coenzyme. A loosely attached cofactor is a coenzyme; a covalently bonded one is a prosthetic group.

3. The Lock and Key model of enzyme action was proposed by:

(a) Koshland (b) Emil Fischer (c) Watson and Crick (d) Erwin Chargaff

Correct Answer: (b) Emil Fischer. Emil Fischer proposed the Lock and Key model in 1890.

4. The Induced Fit model of enzyme action was proposed by:

(a) Koshland (1959) (b) Emil Fischer (1890) (c) Sanger (1950s) (d) Miescher (1869)

Correct Answer: (a) Koshland (1959). Koshland proposed the Induced Fit model in 1959, based on new evidence.

5. The optimum temperature for most human body enzymes is:

(a) 20°C (b) 37°C (c) 50°C (d) 100°C

Correct Answer: (b) 37°C. Human enzymes work best at the normal body temperature of 37°C.

6. Pepsin, a stomach enzyme, works best at an optimum pH of about:

(a) 2.0 (b) 6.8 (c) 7.6 (d) 9.0

Correct Answer: (a) 2.0. Pepsin's optimum pH is strongly acidic, around 2.0, matching stomach conditions.

7. If enzyme concentration is doubled at an unlimited substrate concentration, the reaction rate:



(a) stays the same (b) is halved (c) doubles (d) becomes zero

Correct Answer: (c) doubles. More enzyme means more active sites, so the rate doubles when substrate is unlimited.

8. Loss of an enzyme's globular shape and activity due to extreme heat or pH is called:

(a) activation (b) denaturation (c) inhibition (d) hydrolysis

Correct Answer: (b) denaturation. This loss of structure and function is called denaturation.

9. An inhibitor that resembles the substrate and binds the active site itself is called a:

(a) non-competitive inhibitor (b) competitive inhibitor (c) irreversible inhibitor (d) cofactor

Correct Answer: (b) competitive inhibitor. Competitive inhibitors compete with the substrate for the active site due to structural similarity.

10. An enzyme with its coenzyme or prosthetic group removed is called a(n):

(a) holoenzyme (b) apoenzyme (c) isoenzyme (d) zymogen

Correct Answer: (b) apoenzyme. Without its cofactor, the inactive protein part of an enzyme is called an apoenzyme.

Quick Revision Summary

- Enzymes are globular protein catalysts; the active site (binding site + catalytic site) binds a specific substrate.
- Cofactor = non-protein helper; covalently bonded = prosthetic group, loosely attached = coenzyme; apoenzyme + cofactor = holoenzyme.
- 8 key characteristics: globular proteins, not consumed, don't change end products, work in small amounts, highly specific, sensitive to pH/temperature/substrate, may need cofactor, lower activation energy.
- Lock and Key model (Fischer, 1890): rigid active site. Induced Fit model (Koshland, 1959): active site changes shape on substrate binding.
- Rate depends on enzyme concentration and substrate concentration, each levelling off once the other becomes limiting.
- Optimum temperature for human enzymes = 37°C; each enzyme has its own optimum pH (e.g. pepsin ~2.0, pancreatic lipase ~9.0); extremes cause denaturation.
- Inhibitors: irreversible (permanent) vs reversible (competitive = active site, non-competitive = elsewhere on enzyme). Notes by freebooks.pk.

Exam Tips

- Memorise the 8 characteristics of enzymes as a list — a frequent "write a note" exam question.
- Be ready to name both enzyme-action models with their proposers and years: Fischer (1890, Lock and Key) and Koshland (1959, Induced Fit).



- Learn the exact optimum pH values for at least 3 named enzymes (pepsin, salivary amylase, pancreatic lipase) from the table.
- Practise sketching or describing the rate-vs-temperature and rate-vs-substrate-concentration curves, including why they plateau.
- Do not confuse competitive inhibition (blocks the active site) with non-competitive inhibition (binds elsewhere, distorts shape).
- Remember 37°C as the optimum temperature for human enzymes — a guaranteed MCQ.

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FSc Part-I Biology — Punjab Board

CHAPTER 4

The Cell

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers The Cell from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). The cell is the structural and functional unit of life — the smallest unit that can carry out all the activities of a living organism. The chapter traces how the Cell Theory emerged from Robert Hooke's first observations of cork in 1665 through Schwann, Schleiden and Virchow, and then works through the structure of a generalized eukaryotic cell: the plasma membrane, cytoplasm, and every major organelle. These notes are prepared by freebooks.pk.

It closes by comparing prokaryotic and eukaryotic cells, the most fundamental division in all of biology. Understanding the parts of a cell and how they work together is essential background for cell division, genetics, and every later chapter that deals with how organisms grow, reproduce and carry out their metabolism.

Learning Objectives

- State the Cell Theory and describe its historical development.
- Describe the structure and function of the plasma membrane, including the Fluid Mosaic Model.
- Describe the structure and function of the endoplasmic reticulum, ribosomes, Golgi apparatus and lysosomes.
- Describe peroxisomes, glyoxysomes, vacuoles, the cytoskeleton and centrioles.
- Describe the structure of mitochondria and explain why they are called the powerhouse of the cell.
- Describe the three types of plastids and the structure of the chloroplast.
- Describe the structure of the nucleus, including the nuclear membrane, nucleolus and chromosomes.
- Differentiate between prokaryotic and eukaryotic cells.

Key Concepts

Cell Theory: History and Modern Statement

The cell can be defined as the structural and functional unit of life — the smallest unit that can carry out all the activities of life, and the building block of complex multicellular organisms. Cell biology began with Robert Hooke (1665), who examined thin sections of cork under his own compound microscope and, in his book *Micrographia*, described the honeycomb-like compartments he called cells, though he thought of a cell as simply an empty space bounded by walls. In 1831 Robert Brown reported the presence of the nucleus, showing a cell was not empty, and in 1838-39 the botanist Schleiden and the zoologist Schwann, working independently, proposed the Cell Theory: that cells consist of a nucleus, cytoplasm and an outer plasma membrane (with a cell wall as an additional plant-only structure), and that all living organisms are composed of cells and cell products.

The theory was later extended by Rudolph Virchow (1855), who proposed that new cells arise only by the division of pre-existing cells ("omnis cellula e cellula"), a view supported



experimentally by Louis Pasteur (1862), who showed bacteria arise only from existing bacteria, disproving spontaneous generation. August Weismann (1880) added that all living cells share a common origin because of their basic similarities in structure and molecules. The modern Cell Theory states: all organisms are composed of one or more cells; all cells arise from pre-existing cells; and the cell is the basic structural and functional unit of all organisms. The development of microscopy has driven this understanding further — the naked eye can resolve points about 1.0 mm apart, a compound microscope improves this to about 2.0 micrometres (500 times better), and an electron microscope reaches a resolution of 2-4 Angstrom units, about 250,000 times better than the naked eye, revealing the fine internal structure of cell organelles.

The Plasma Membrane and Cell Wall

The plasma membrane (cell membrane) is the outermost boundary of the cell, chemically composed of about 60-80% protein and 20-40% lipid, plus a small amount of carbohydrate. Earlier models proposed a lipid bilayer sandwiched between two continuous protein layers (the unit membrane), but later evidence showed the protein is not continuous but embedded within the lipid layer in a mosaic pattern, leading to the now widely accepted Fluid Mosaic Model. The membrane is differentially (selectively) permeable, letting lipid-soluble and small neutral molecules such as gases, water and glucose cross more easily than charged ions; movement down a concentration gradient is passive, while movement against a gradient requires energy from ATP and is called active transport. Some animal cells also take in materials by endocytosis, which may be phagocytosis (engulfing solid particles) or pinocytosis (taking in liquid).

In most plant cells, an additional outer boundary, the cell wall, lies outside the plasma membrane, secreted by the cell's protoplasm and composed of a primary wall (cellulose with some pectin and hemicellulose), a secondary wall (thicker, rigid, with inorganic salts, silica, waxes, cutin and lignin), and the middle lamella between neighbouring cells. Unlike the plasma membrane, the cell wall does not block materials from passing through; its main role is to give the cell a definite, rigid shape. A bacterial cell wall is chemically different, built of peptidoglycan (murein) rather than cellulose, while fungal cell walls are made of chitin.

Cytoplasm and the Endomembrane System

The living contents of a eukaryotic cell are divided into the nucleus and the cytoplasm, which together form the protoplasm. The soluble part of the cytoplasm, the cytosol, is about 90% water and forms the ground substance in which cell organelles are suspended; it also serves as a storehouse of vital chemicals and a site for processes such as glycolysis. The endoplasmic reticulum (ER) is a network of membrane channels running through the cytoplasm, continuous in places with both the plasma membrane and the nuclear membrane; the rough ER (RER) is studded with ribosomes and synthesizes proteins for storage or export, while the smooth ER (SER) lacks ribosomes and instead handles lipid metabolism, detoxifies harmful drugs, and in muscle and nerve cells helps transmit impulses.



Ribosomes are tiny ribonucleoprotein granules, first studied by Palade (1955), made of roughly equal amounts of RNA and protein; a eukaryotic ribosome has a large 60S subunit and a small 40S subunit that join to form an 80S particle, and a group of ribosomes attached to one mRNA strand is called a polysome. New ribosomes are assembled in the nucleolus and exported to the cytoplasm. The Golgi apparatus, discovered by Golgi in 1898, is a stack of flattened membrane sacs (cisternae) that receives material budded from the SER at its forming face and releases finished, packaged secretory vesicles at its maturing face, modifying proteins and lipids by adding carbohydrate to form glycoproteins and glycolipids. Lysosomes, first isolated by De Duve (1949), are single-membrane sacs rich in hydrolytic enzymes that digest engulfed foreign material (phagocytosis) and worn-out cell parts (autophagy); several inherited storage diseases, such as Tay-Sachs disease, result from a missing lysosomal enzyme.

Other Cytoplasmic Organelles

Peroxisomes, isolated by De Duve and coworkers (1965), are single-membrane organelles about 0.5 micrometres across that contain hydrogen-peroxide-producing oxidases and catalase, found in both animal and plant cells. Glyoxysomes are similar plant-only organelles, abundant in germinating, lipid-rich seeds such as castor bean and soybean, where they run the glyoxylate cycle to convert stored fatty acids into carbohydrate for the growing seedling. Vacuoles occur in both animal and plant cells but are especially large in plant cells, where a single central vacuole can occupy most of the cell volume; bounded by a single membrane, they store water and cell products and generate the turgor pressure that supports plant tissues.

The cytosol also contains a cytoskeleton built of three fibre types: microtubules (long tubulin structures involved in spindle formation during mitosis, and in cilia, flagella and centrioles), microfilaments (slender actin structures responsible for cyclosis and amoeboid movement), and intermediate filaments (which maintain cell shape). Centrioles, found in animal cells and some lower plants, are paired cylindrical structures near the nucleus, each made of nine microtubule triplets arranged at right angles to its partner; they duplicate before cell division and help organize the spindle and, in some cells, the formation of cilia. Centrioles are absent in higher plants.

Mitochondria: The Powerhouse of the Cell

Mitochondria are bound by two membranes: a smooth outer membrane and an inner membrane that folds inward as cristae, projecting into the central mitochondrial matrix; small knob-like F₁ particles stud the inner surface of the cristae. The matrix contains enzymes, coenzymes and salts that carry out key metabolic pathways such as the Krebs cycle, aerobic respiration and fatty acid metabolism, converting the chemical energy of food into ATP, which the cell then uses on demand — this is why mitochondria are called the powerhouse of the cell. Mitochondria also contain their own DNA and ribosomes, meaning they can synthesize some of their own proteins and are self-replicating organelles; their number and size in a cell depend on how metabolically active that cell is.



Plastids: Chloroplasts, Chromoplasts and Leucoplasts

Plastids are membrane-bound, usually pigment-containing bodies found only in plant cells, of three main types. Chloroplasts, about 4-6 micrometres across, contain the green pigment chlorophyll (chemically similar to the haem of haemoglobin, but with magnesium instead of iron at its centre), which absorbs light energy for photosynthesis; under the electron microscope a chloroplast shows a double-membrane envelope, a fluid stroma (containing enzymes, ribosomes and a small circular DNA, where carbon dioxide is fixed into sugars), and stacks of flattened thylakoid membranes called grana (usually 50 or more thylakoids per granum), which is where light energy is trapped and ATP is generated; chloroplasts, like mitochondria, are self-replicating. Chromoplasts give flowers and ripe fruit their non-green colours, helping with pollination and seed dispersal, while leucoplasts are colourless plastids found in underground plant parts, where they store food.

The Nucleus: Membrane, Nucleolus and Chromosomes

The nucleus, first reported by Robert Brown in 1831, controls the life and activities of the cell; it is usually central in animal cells but pushed to the periphery in plant cells by the large vacuole. It is surrounded by a nuclear envelope made of two membranes, continuous with the ER at points, with nuclear pores where the two membranes meet, allowing regulated exchange of material between nucleus and cytoplasm (undifferentiated cells such as eggs may have about 30,000 pores per nucleus, while differentiated cells such as red blood cells have only 3 or 4). Inside, the nucleolus is a densely stained, non-membrane-bound body where ribosomal RNA is synthesized and ribosomal subunits are assembled before export through the nuclear pores.

In a non-dividing cell, hereditary material exists as a diffuse chromatin network within the nucleoplasm; during cell division, this chromatin condenses into visible, darkly staining chromosomes, each initially made of two identical chromatids joined at a centromere (the point of attachment for spindle fibres during division). A chromosome is built of DNA and protein and carries genes, the units that control cell activities and pass hereditary information to the next generation. The chromosome number is constant within a species: human body cells are diploid with 46 chromosomes, while human sperm and egg cells are haploid with 23; other examples include 8 in the fruit fly *Drosophila*, 16 in onion, 48 in potato and 14 in the garden pea.

Prokaryotic and Eukaryotic Cells

Cells are divided into two fundamental types based mainly on the structure of their nucleus. Eukaryotic cells (found in animals, plants, fungi and protists) have a well-defined nucleus in which the DNA is enclosed by a double nuclear membrane, along with membrane-bound organelles such as mitochondria, endoplasmic reticulum, Golgi apparatus and (in plants) chloroplasts. Prokaryotic cells (bacteria and blue-green algae) lack a nuclear membrane, so their DNA lies directly in the cytoplasm, and they also lack most of these membrane-bound organelles; prokaryotic ribosomes are smaller (70S) than eukaryotic ribosomes (80S), and since prokaryotes lack mitosis, they instead divide by binary fission. The most distinctive feature of the prokaryotic cell is its cell wall, built of peptidoglycan (murein) rather than the



cellulose found in plant cell walls, and it was long thought (due to their simpler structure) that prokaryotic cells represent an earlier evolutionary stage than eukaryotic cells.

Important Definitions

Term	Definition
Cell	The structural and functional unit of life; the smallest unit that can carry out all the activities of a living organism.
Fluid Mosaic Model	The currently accepted model of the plasma membrane, in which proteins are embedded in a mosaic pattern within a fluid lipid bilayer, rather than forming continuous outer layers.
Cytosol	The soluble, water-based part of the cytoplasm (about 90% water) in which cell organelles are suspended.
Polysome	A group of ribosomes attached to and translating the same strand of messenger RNA.
Mitochondrion	A double-membraned organelle that generates ATP through aerobic respiration; called the powerhouse of the cell.
Chloroplast	A plant-cell plastid containing chlorophyll, in which photosynthesis takes place.
Chromosome	A thread-like structure of DNA and protein, visible during cell division, that carries an organism's genes.
Prokaryotic cell	A cell, such as a bacterium, that lacks a nuclear membrane, so its DNA lies directly in the cytoplasm.

Key Facts

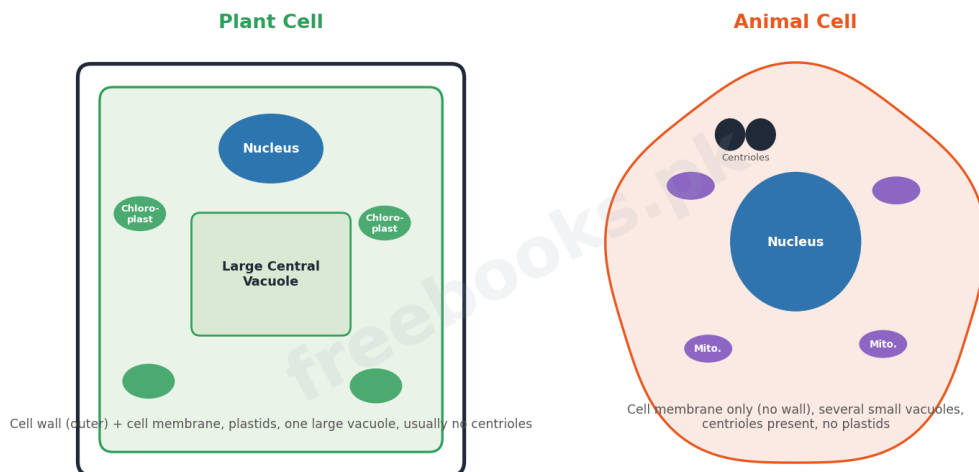
Item	Fact
Cell discovery	Robert Hooke, 1665 - observed cork cells, published in Micrographia.
Cell Theory proposed	Schleiden and Schwann, 1838-39 (independently).
"Omnis cellula e cellula"	Rudolph Virchow, 1855 - new cells arise only from pre-existing cells.
Microscope resolution	Naked eye: ~1.0 mm. Compound microscope: ~2.0 micrometres. Electron microscope: 2-4 Angstrom.
Ribosome sedimentation	Eukaryotic: 80S (60S + 40S subunits). Prokaryotic: 70S.
Human chromosome number	Body cells (diploid): 46. Sperm/egg cells (haploid): 23.
Golgi apparatus discovery	Camillo Golgi, 1898.
Lysosome / Peroxisome discovery	De Duve: lysosomes (1949), peroxisomes (1965, with coworkers).



Diagrams & Illustrations

Plant Cell vs Animal Cell: Key Differences: a side-by-side comparison chart of a generalized plant cell and animal cell, highlighting structures present only in plant cells (cell wall, large central vacuole, plastids) versus structures typical of animal cells (centrioles, small scattered vacuoles).

Plant Cell vs Animal Cell: Key Differences



Plant Cell vs Animal Cell: Key Differences

The Endomembrane System (Secretory Pathway): a flow diagram showing how a protein moves through the endomembrane system: synthesized on the rough endoplasmic reticulum, packaged and modified in the Golgi apparatus, then released as a secretory vesicle or stored in a lysosome.

The Endomembrane System (Secretory Pathway)



The Endomembrane System (Secretory Pathway)

Prokaryotic vs Eukaryotic Cell: a comparison chart of prokaryotic and eukaryotic cells across key features: nuclear membrane, ribosome size (70S vs 80S), membrane-bound organelles, and cell wall composition.



Prokaryotic vs Eukaryotic Cell

Feature	Prokaryotic	Eukaryotic
Nuclear membrane	Absent - DNA free in cytoplasm	Present - double membrane
Ribosome size	70S	80S (60S + 40S)
Membrane-bound organelles	Absent (no mitochondria, ER, Golgi)	Present (mitochondria, ER, Golgi, etc.)
Cell wall	Peptidoglycan (murein)	Cellulose (plants) / chitin (fungi)
Cell division	Binary fission	Mitosis / meiosis
Example organisms	Bacteria, blue-green algae	Animals, plants, fungi, protists

Prokaryotic vs Eukaryotic Cell

Short Questions & Answers

Q1. State the modern Cell Theory in three points.

Ans. All organisms are composed of one or more cells; all cells arise from pre-existing cells; and the cell is the basic structural and functional unit of all organisms.

Q2. Differentiate rough and smooth endoplasmic reticulum.

Ans. Rough endoplasmic reticulum (RER) has attached ribosomes and synthesizes proteins, while smooth endoplasmic reticulum (SER) lacks ribosomes and instead handles lipid metabolism, detoxification and impulse transmission in some cells.

Q3. What is the function of lysosomes? Name their discoverer.

Ans. Lysosomes digest engulfed foreign material and worn-out cell parts using hydrolytic enzymes; they were first isolated by De Duve in 1949.

Q4. Differentiate microtubules, microfilaments and intermediate filaments.

Ans. Microtubules are tubulin structures involved in spindle formation and organelles like cilia and centrioles; microfilaments are actin structures responsible for cell movement; intermediate filaments maintain cell shape.

Q5. State two differences between prokaryotic and eukaryotic cells.

Ans. Eukaryotic cells have a membrane-bound nucleus and 80S ribosomes, while prokaryotic cells have no nuclear membrane (DNA lies free in the cytoplasm) and smaller 70S ribosomes.

Q6. Why are mitochondria called the powerhouse of the cell?

Ans. Mitochondria carry out the Krebs cycle and aerobic respiration in their matrix, converting the chemical energy of food into ATP, which supplies energy for all cellular activities.



Long Questions & Answers

Q1: Describe the Cell Theory and discuss its historical emergence.

The Cell Theory developed gradually over two centuries. Robert Hooke first observed and named cells in 1665 while examining cork under a microscope, though he believed a cell was simply an empty space bounded by walls. Robert Brown's discovery of the nucleus in 1831 showed cells were not empty, and in 1838-39 Schleiden and Schwann, working independently, proposed that cells consist of a nucleus, cytoplasm and outer membrane, with a cell wall as an additional plant structure, and that all living organisms are made of cells and cell products. Rudolph Virchow extended the theory in 1855 with the idea that new cells arise only from pre-existing cells ("omnis cellula e cellula"), directly opposing the idea of spontaneous generation; Louis Pasteur supplied experimental proof of this in 1862 by showing bacteria arise only from existing bacteria. August Weismann later added that all living cells share a common origin, given their fundamental similarities in structure and chemistry. Together these contributions produced the modern Cell Theory: all organisms are composed of one or more cells, all cells arise from pre-existing cells, and the cell is the basic structural and functional unit of every organism — one of the most important unifying ideas in all of biology.

Q2: Describe the structure and function of the plasma membrane, including the Fluid Mosaic Model.

The plasma membrane is the outermost boundary of the cell (covered by a cell wall in most plant cells), chemically made of roughly 60-80% protein, 20-40% lipid, and a small amount of carbohydrate. Early models proposed that the membrane was a lipid bilayer sandwiched between two continuous protein layers, called the unit membrane; however, later evidence showed the protein is not continuous but embedded within the lipid bilayer in a scattered, mosaic arrangement, leading to the currently accepted Fluid Mosaic Model. Functionally, the plasma membrane is differentially (selectively) permeable: it acts as a barrier between the cell and its environment, allowing lipid-soluble molecules, gases, water and glucose to cross relatively freely, while restricting charged ions. Movement down a concentration gradient occurs passively, while movement against a gradient (from low to high concentration) requires energy supplied by ATP and is called active transport. In some animal cells, the membrane also folds inward to take in material by endocytosis — phagocytosis for solid particles or pinocytosis for liquids — and in neurons it transmits nerve impulses along the cell.

Q3: Compare the structure and function of mitochondria and chloroplasts.

Both mitochondria and chloroplasts are double-membrane-bound, self-replicating organelles that contain their own DNA and ribosomes, allowing them to synthesize some of their own proteins — a similarity that supports the idea that both organelles originated from ancient free-living bacteria. Structurally, a mitochondrion has a smooth outer membrane and a folded inner membrane (cristae) projecting into the central matrix, with small F1 particles on the cristae surface; the matrix carries out the Krebs cycle, aerobic respiration and fatty acid



metabolism, converting food energy into ATP, which is why mitochondria are called the cell's powerhouse. A chloroplast, found only in plant cells, has a double-membrane envelope surrounding a fluid stroma (containing enzymes, ribosomes, and its own small circular DNA, where carbon dioxide is fixed into sugar) and stacks of thylakoid membranes called grana, which hold the green pigment chlorophyll and are the site where light energy is trapped and used to generate ATP during photosynthesis. In short, mitochondria release the chemical energy stored in food as usable ATP in almost all eukaryotic cells, while chloroplasts capture light energy and convert it into chemical energy stored in sugars, but only in photosynthetic plant cells.

Q4: Describe the structure of the nucleus, including the nuclear membrane, nucleolus and chromosomes.

The nucleus, discovered by Robert Brown in 1831, is usually the most prominent structure in a cell and controls all of its life and activities; it sits centrally in most animal cells but is pushed to one side in plant cells by the large central vacuole. It is enclosed by a nuclear envelope made of two membranes, which is continuous with the endoplasmic reticulum at certain points and perforated by nuclear pores where the outer and inner membranes meet, allowing regulated exchange of material with the cytoplasm; undifferentiated cells such as eggs may have around 30,000 pores, while highly differentiated cells such as red blood cells have only 3 or 4. Within the nucleus, the nucleolus is a darkly staining region without its own membrane, where ribosomal RNA is synthesized and ribosomal subunits are assembled before being exported through the nuclear pores to the cytoplasm. The nucleus also contains chromatin, a diffuse network of DNA and protein in a non-dividing cell, which condenses into visible, deeply staining chromosomes when the cell divides; each chromosome is initially made of two identical sister chromatids joined at a centromere, the point where spindle fibres attach, and carries the genes that direct the cell's activities and are passed on to the next generation. The number of chromosomes is constant within a species — 46 in human body cells (diploid) and 23 in human sperm and egg cells (haploid) — and this constancy across generations is essential to accurate heredity.

Q5: Differentiate between prokaryotic and eukaryotic cells in detail.

Prokaryotic and eukaryotic cells differ mainly in the organization of their genetic material and internal organelles. In eukaryotic cells (found in animals, plants, fungi and protists), the DNA is organized into chromosomes enclosed within a distinct nucleus bounded by a double nuclear membrane, and the cytoplasm contains a variety of membrane-bound organelles, including mitochondria, endoplasmic reticulum, a Golgi apparatus, and, in plants, chloroplasts; eukaryotic ribosomes sediment at 80S (made of 60S and 40S subunits), and cell division typically occurs by mitosis. In prokaryotic cells (bacteria and blue-green algae), there is no nuclear membrane at all, so the DNA lies directly and freely within the cytoplasm; most of the membrane-bound organelles found in eukaryotes, such as mitochondria, ER, Golgi apparatus and chloroplasts, are absent, ribosomes are smaller at 70S, and since mitosis is missing, prokaryotic cells instead divide by simple binary fission. The most distinctive structural feature separating the two is the cell wall: eukaryotic plant cell walls are built mainly of cellulose, whereas the prokaryotic cell wall is built of peptidoglycan



(murein), an entirely different polysaccharide-amino acid complex. Because of their comparatively simple structure, prokaryotic cells were long considered to represent an earlier stage in the evolution of life than the more complex eukaryotic cells.

MCQs with Answers

1. The cell was first observed and named by:

(a) Robert Brown (b) Robert Hooke (c) Schwann and Schleiden (d) Rudolph Virchow

Correct Answer: (b) Robert Hooke. Robert Hooke observed cork cells in 1665 and described them in Micrographia.

2. The Cell Theory was proposed independently by:

(a) Hooke and Brown (b) Schleiden and Schwann (c) Virchow and Pasteur (d) Watson and Crick

Correct Answer: (b) Schleiden and Schwann. Schleiden (botanist) and Schwann (zoologist) proposed the Cell Theory in 1838-39.

3. "Omnis cellula e cellula" (all cells from pre-existing cells) was proposed by:

(a) Louis Pasteur (b) Robert Hooke (c) Rudolph Virchow (d) August Weismann

Correct Answer: (c) Rudolph Virchow. Rudolph Virchow proposed this idea in 1855.

4. The currently accepted model of the plasma membrane is called the:

(a) Unit Membrane Model (b) Fluid Mosaic Model (c) Lock and Key Model (d) Endomembrane Model

Correct Answer: (b) Fluid Mosaic Model. The Fluid Mosaic Model describes proteins embedded in a mosaic pattern within the fluid lipid bilayer.

5. A eukaryotic ribosome, formed of 60S and 40S subunits, sediments as a complete particle at:

(a) 70S (b) 80S (c) 100S (d) 40S

Correct Answer: (b) 80S. The 60S and 40S subunits combine to form the 80S eukaryotic ribosome.

6. The Golgi apparatus was discovered in 1898 by:

(a) De Duve (b) Camillo Golgi (c) Palade (d) Robert Brown

Correct Answer: (b) Camillo Golgi. Camillo Golgi discovered the organelle that bears his name in 1898.

7. Lysosomes were first isolated as a separate organelle by:

(a) De Duve (1949) (b) Golgi (1898) (c) Hooke (1665) (d) Weismann (1880)

Correct Answer: (a) De Duve (1949). De Duve isolated lysosomes in 1949.

8. Mitochondria are called the powerhouse of the cell because they:

(a) store genetic material (b) produce ATP through respiration (c) synthesize proteins only (d) digest foreign particles

Correct Answer: (b) produce ATP through respiration. Mitochondria convert food energy into ATP through aerobic respiration.

9. A normal human body cell contains how many chromosomes?



(a) 23 (b) 44 (c) 46 (d) 48

Correct Answer: (c) 46. Human body (somatic) cells are diploid with 46 chromosomes; sperm and egg cells have 23.

10. Which feature is characteristic of prokaryotic cells but not eukaryotic cells?

(a) 80S ribosomes (b) Membrane-bound nucleus (c) Cell division by binary fission (d) Presence of mitochondria

Correct Answer: (c) Cell division by binary fission. Prokaryotes lack mitosis and instead divide by binary fission.

Quick Revision Summary

- Modern Cell Theory: all organisms are made of cells; all cells arise from pre-existing cells; the cell is the basic structural/functional unit.
- Plasma membrane = Fluid Mosaic Model (proteins embedded in a fluid lipid bilayer); selectively permeable; active transport needs ATP.
- Endomembrane system: RER (protein synthesis) -> Golgi apparatus (modifies/packages) -> lysosomes/secretory vesicles.
- Cytoskeleton: microtubules (spindle, cilia), microfilaments (movement), intermediate filaments (shape); centrioles = 9 microtubule triplets.
- Mitochondria = powerhouse (ATP via Krebs cycle/respiration); chloroplasts = photosynthesis (grana, stroma); both have own DNA/ribosomes.
- Nucleus: double membrane with pores, nucleolus (rRNA/ribosome assembly), chromatin -> chromosomes (DNA + protein, centromere) during division.
- Human: 46 chromosomes (diploid, body cells), 23 (haploid, sperm/egg). Eukaryotes: 80S ribosomes, membrane-bound nucleus/organelles. Prokaryotes: 70S ribosomes, no nuclear membrane, binary fission. Notes by freebooks.pk.

Exam Tips

- Learn the three-point modern Cell Theory word for word — a very common "state the cell theory" question.
- Be ready to name each organelle's discoverer and year (Hooke 1665, Schwann/Schleiden 1838-39, Virchow 1855, Golgi 1898, De Duve 1949/1965) — frequently tested.
- Practise comparing mitochondria and chloroplasts side by side (structure and function) — a classic long question.
- Memorise chromosome numbers for at least 3 organisms (human 46, Drosophila 8, onion 16, pea 14).
- Know the prokaryote vs eukaryote differences as a clear table: nucleus, ribosome size, organelles, cell wall, division method.
- Don't confuse rough ER (protein synthesis) with smooth ER (lipid metabolism/detoxification) — a frequent short-question pair.



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CHAPTER 5

Variety of Life

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Variety of Life from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). With well over a million known species of animals and plants, biologists need a logical system to organize this diversity — the chapter builds the taxonomic hierarchy from species up to kingdom, explains Linnaeus's binomial nomenclature, and traces how classification systems evolved from two kingdoms to Whittaker's influential five-kingdom system. These notes are prepared by freebooks.pk.

The second half of the chapter turns to viruses — non-cellular infectious particles that sit at the boundary of what we call life. It covers their discovery, structure, the lytic and lysogenic life cycles of bacteriophages, retroviruses such as HIV, and major viral diseases including smallpox and hepatitis, giving essential background for the immunology and microbiology topics that follow in later chapters.

Learning Objectives

- Define species and describe the taxonomic hierarchy from species to kingdom.
- Explain binomial nomenclature and its rules, with examples.
- Trace the development of classification systems from two kingdoms to Whittaker's five-kingdom system.
- Describe the characteristics and structure of viruses, including the virion, capsid and envelope.
- Describe the lytic and lysogenic cycles of a bacteriophage.
- Explain what retroviruses are and how HIV causes AIDS.
- Describe major viral diseases, including smallpox and the different types of viral hepatitis.

Key Concepts

Principles of Classification and Taxonomic Hierarchy

With well over a million known species of animals and half a million of plants, biologists need a meaningful system of classification based on relationship and similarity in form and structure, not arbitrary traits such as colour or height. A species is defined as a group of natural populations that can interbreed freely among themselves and produce fertile offspring, but are reproductively isolated from all other such groups in nature; each species has its own distinct structural, ecological and behavioural characteristics and does not exchange genes with other species, though interbreeding cannot be used as a criterion for species recognition in organisms that reproduce mainly asexually.

Species are grouped into a hierarchy of increasingly general categories (taxa): a genus contains one or more related species, a family contains related genera, an order contains related families, a class contains related orders, a phylum (or division, for plants, algae and fungi) contains related classes, and a kingdom contains related phyla. Members of a lower category resemble one another more closely than members of a higher one — for example,



corn (*Zea mays*) belongs to kingdom Plantae, division Anthophyta, class Angiospermae, order Poales, family Poaceae, genus *Zea* and species *mays*.

Binomial Nomenclature

Common names of plants and animals vary by region and language and often cause confusion — the same plant may have several common names, and a single common name (such as "blue bell" or "blackbird") may refer to several unrelated organisms. During the 18th century, the Swedish botanist Carolus Linnaeus (1707-1778) devised a scientific naming system, publishing his list of plant names in 1753 and his list of animal names in 1758, much of which is still used today.

Linnaeus's system, giving every species a two-word scientific name derived from Latin, is called binomial nomenclature. The first word is the genus (generic name) and always begins with a capital letter; the second word is the specific name and begins with a lowercase letter — for example, onion is *Allium cepa*, amaltas is *Cassia fistula*, and man is *Homo sapiens*. Potato (*Solanum tuberosum*) and brinjal (*Solanum melongena*) share the same generic name, reflecting their close relationship. Every species has only one scientific name worldwide, and while early classification was based on morphology (appearance), it has since been refined using cytology, physiology, genetics and molecular biology.

Two to Five Kingdom Classification Systems

For centuries, living things were split into just two kingdoms: Plantae (autotrophs, which make their own food from simple inorganic material) and Animalia (heterotrophs, which depend on autotrophs or decaying matter for food), with bacteria placed among the plants. This system broke down for organisms such as *Euglena*, which has both plant-like (chlorophyll) and animal-like (no cell wall) features, and it ignored the fundamental difference between prokaryotic and eukaryotic cells. In 1866 Ernst Haeckel proposed a third kingdom, Protista, for organisms like *Euglena* and bacteria, and in 1937 Edouard Chatton coined the terms prokaryotic (before a nucleus) and eukaryotic (true nucleus) to distinguish bacteria and blue-green algae from plant and animal cells. Fungi (such as bread mould, yeast and mushrooms) were also difficult to classify, since although they resemble plants, they are heterotrophs that obtain food by decomposing and absorbing organic material and have chitin, not cellulose, in their cell walls.

In 1969 Robert Whittaker proposed the five-kingdom system, based on three levels of cellular organization (prokaryotic unicellular, eukaryotic unicellular, eukaryotic multicellular) and three modes of nutrition (photosynthesis, absorption, ingestion): Monera (prokaryotic unicellular organisms such as bacteria), Protista (mainly eukaryotic unicellular organisms such as *Euglena* and *Amoeba*), Plantae (eukaryotic multicellular autotrophs), Fungi (eukaryotic multicellular absorptive decomposers) and Animalia (eukaryotic multicellular organisms that ingest and digest food). In 1988, Lynn Margulis and Karlene Schwartz modified Whittaker's system by also considering cytology, genetics and organelles of symbiotic origin such as mitochondria and chloroplasts, naming the five kingdoms Prokaryotae (Monera), Protoctista (Protista), Plantae, Fungi and Animalia.



Viruses: Discovery and Characteristics

The modern concept of a virus emerged gradually. Edward Jenner's 1796 cowpox vaccination against smallpox was the first effective prevention of a viral disease, though the cause was unknown at the time. In 1884 Charles Chamberland found that an agent causing rabies could pass through filters that trapped bacteria, and in 1892 Ivanowski showed that a similarly filterable agent caused tobacco mosaic disease in plants. In 1935 Stanley successfully crystallized the tobacco mosaic virus, revealing that these particles contained only nucleic acid and protein. Bacteriophages (viruses that infect bacteria) were discovered independently by Twort (1915) and D'Herelle (1917), who named them "bacteria eaters" after observing that infected bacterial colonies underwent lysis.

Viruses are extremely small (ranging from about 20 nanometres in parvoviruses to 250 nanometres in poxviruses, 10 to 1000 times smaller than most bacteria), so small they can only be seen with an electron microscope and can pass through filters that trap bacteria. They cannot be grown on artificial media and can reproduce only inside living host cells (animal, plant or microbial), making them obligate intracellular parasites; they lack the metabolic machinery to synthesize their own nucleic acid and protein and instead hijack the host cell's biosynthetic machinery, a process called replication. Viruses are generally resistant to common antibiotics such as penicillin and streptomycin, since these drugs target bacterial structures that viruses do not have.

Structure of Viruses

The complete, mature, infectious virus particle is called a virion. At its centre is the genome, a core of nucleic acid (either DNA or RNA), surrounded by a protein coat called the capsid, which is built of protein subunits called capsomeres and gives the virion its shape (for example, the herpes virus capsid has 162 capsomeres, while the adenovirus capsid has 252). In some animal viruses, the nucleic acid plus capsid (together called the nucleocapsid) is further wrapped in an envelope derived from the host cell membrane; viruses without an envelope are called naked virions. Viruses may be polyhedral (many-sided), helical (spiral), enveloped or complex in shape; bacteriophages, for example, occur in icosahedral (20-faced) or helical forms, often with a distinct head and tail.

The most recently discovered and least understood infectious agents are prions (identified in 1983), which appear to be infectious proteins with no nucleic acid at all, unlike every other organism, which stores its genetic information in DNA or RNA; prions are linked to mad cow disease and certain rare brain infections in humans.

Life Cycle of Bacteriophages

Much of the classical research on bacteriophages used T-phages that infect *Escherichia coli*, especially T2 and T4, whose structure (studied by electron microscopy) resembles a tadpole with a DNA-filled hexagonal head and a complex tail ending in tail fibres used for attachment. Infection begins with attachment (adsorption) of the tail fibres to a specific receptor site on the bacterial cell wall, followed by penetration, in which the tail releases the



enzyme lysozyme to dissolve part of the cell wall so the tail core can inject the phage's DNA into the cell, leaving the empty protein coat outside.

Once inside, the viral DNA can follow one of two paths. In the lytic cycle, the viral DNA immediately takes over the host's biosynthetic machinery, directing the synthesis of new phage components; within about 25 minutes roughly 200 new bacteriophages are assembled and the bacterial cell bursts (lysis), releasing the new phages to infect other bacteria — a phage that causes this is called a lytic (virulent) phage. Alternatively, in lysogeny, the viral DNA becomes incorporated into the bacterial chromosome as a prophage, and the bacterium continues to live and reproduce normally, passing the prophage on to all its daughter cells; the prophage may later detach and enter the lytic cycle, a process called induction, and lysogenic bacteria are resistant to infection by the same or related phages. A phage that causes lysogeny is called a temperate (lysogenic) phage.

Retroviruses, HIV and AIDS

Retroviruses (oncoviruses) are single-stranded RNA tumour viruses, spherical, about 100 nanometres across, enveloped by host plasma membrane, and associated with tumour formation in several animal species. Most retroviruses can only infect host cells bearing the specific receptor they recognize. Their defining feature is a unique enzyme, reverse transcriptase, which converts the single-stranded RNA genome into double-stranded DNA; this viral DNA can then be incorporated into the host genome as a provirus and passed on to daughter cells, which in some cases converts normal cells into cancer cells.

The most familiar retrovirus is the human immunodeficiency virus (HIV), which causes acquired immune deficiency syndrome (AIDS). First recognized in the early 1980s and identified as the causal agent in 1984, HIV mainly infects helper T-lymphocytes, key cells of the immune system; as HIV infection progresses, the loss of helper T-lymphocytes causes the immune system to fail, leaving the infected person vulnerable to other infections and diseases. HIV is transmitted through intimate sexual contact, contact with blood, and breast feeding; prevention relies on avoiding direct contact with these routes of transmission and using sterile needles and syringes, and experimental vaccine trials in humans began in the early 2000s.

Viral Diseases: Smallpox and Hepatitis

Smallpox, caused by an enveloped DNA poxvirus, is an ancient disease producing fluid-filled skin lesions that become pitted scars; it was declared eradicated worldwide by the World Health Organization in 1980 following mass immunization. Other important viral diseases include herpes simplex (a DNA virus causing lesions of the mouth, lips and skin), influenza (an enveloped RNA virus causing widespread epidemics), mumps and measles (large enveloped RNA paramyxoviruses, both highly contagious in childhood), and polio (caused by poliovirus, one of the smallest known viruses, mainly affecting children).

Hepatitis is inflammation of the liver, usually from viral infection, causing jaundice, abdominal pain, liver enlargement and fatigue, and it can become chronic or lead to liver cancer. Hepatitis A (a non-enveloped RNA virus) spreads through contact with infected faeces and causes a relatively mild, short illness; Hepatitis B (a DNA virus, common across



Asia and Africa) spreads through blood, breast milk, saliva and sexual contact, and can become chronic, though a genetically engineered vaccine is available; Hepatitis C (an enveloped RNA virus) spreads mainly through blood and often becomes chronic liver disease, with no vaccine currently available; Hepatitis D, E (spread through faeces) and the less-understood Hepatitis F and G complete the known forms. Good hygiene, routine vaccination where available, and screening of donated blood, organs and tissue all help control the spread of viral hepatitis.

Important Definitions

Term	Definition
Species	A group of natural populations that can interbreed freely and produce fertile offspring, but is reproductively isolated from other such groups.
Binomial nomenclature	The scientific naming system, devised by Linnaeus, that gives every species a two-part Latin name: genus followed by specific epithet.
Kingdom	The broadest taxonomic category; in the five-kingdom system: Monera, Protista, Fungi, Plantae and Animalia.
Virus	A non-cellular infectious particle of DNA or RNA, usually enclosed in a protein coat, that can reproduce only inside a living host cell.
Virion	The complete, mature, infectious virus particle, consisting of nucleic acid enclosed in a capsid (and sometimes an envelope).
Capsid	The protein coat of a virus, built of subunits called capsomeres, that encloses and protects the viral genome.
Bacteriophage	A virus that infects bacteria, replicating via either the lytic or the lysogenic cycle.
Retrovirus	An RNA virus, such as HIV, that uses the enzyme reverse transcriptase to convert its RNA genome into DNA inside the host cell.

Key Facts

Item	Fact
Binomial nomenclature founder	Carolus Linnaeus (1707-1778) - plant names published 1753, animal names 1758.
Five-kingdom system	Proposed by Robert Whittaker, 1969.
Modified five-kingdom system	Lynn Margulis and Karlene Schwartz, 1988 (added symbiotic organelles).
Virus size range	About 20 nm (parvoviruses) to 250 nm (poxviruses).
First viral disease prevention	Edward Jenner's cowpox vaccination against smallpox, 1796.
Tobacco mosaic virus crystallized	Stanley, 1935 - showed viruses are nucleic acid + protein.
Bacteriophage discovery	Twort (1915) and D'Herelle (1917), independently.

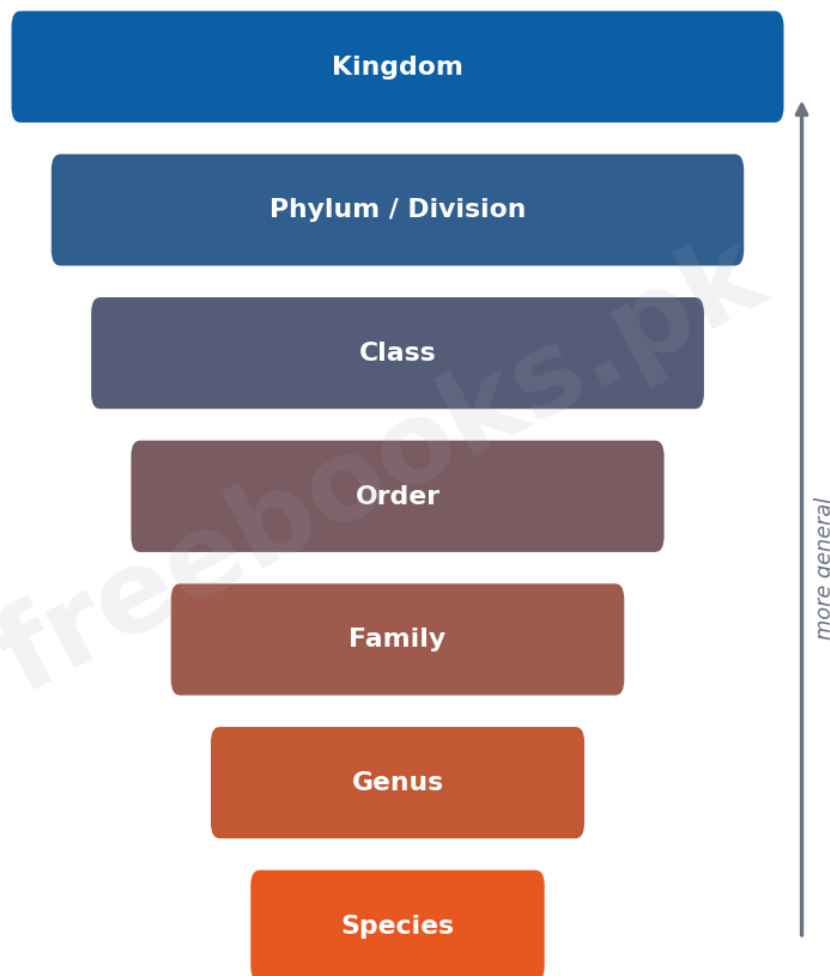


Item	Fact
Smallpox eradication	Declared eradicated worldwide by WHO in 1980.

Diagrams & Illustrations

Taxonomic Hierarchy: Species to Kingdom: a step diagram showing the classification hierarchy from the most specific to the most general level: species, genus, family, order, class, phylum/division, kingdom.

Taxonomic Hierarchy



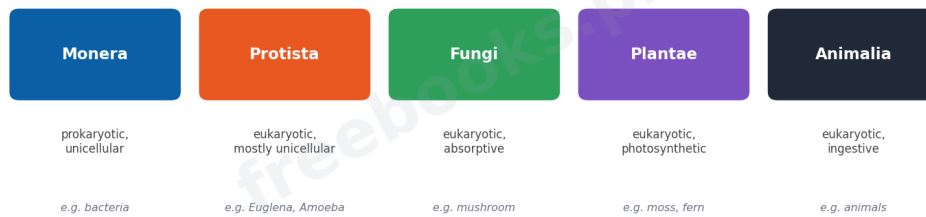
e.g. Corn (Zea mays): Plantae -> Anthophyta -> Angiospermae -> Poales -> Poaceae -> Zea -> mays

Taxonomic Hierarchy: Species to Kingdom

Whittaker's Five Kingdom Classification: a chart of the five kingdoms proposed by Whittaker - Monera, Protista, Fungi, Plantae and Animalia - each labelled with its cell type and mode of nutrition.



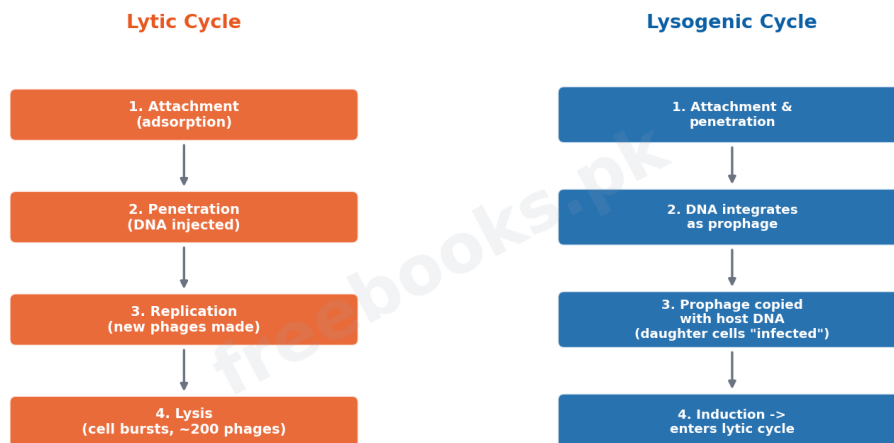
Whittaker's Five Kingdom Classification (1969)



Whittaker's Five Kingdom Classification

Lytic vs Lysogenic Cycle of a Bacteriophage: a diagram comparing the lytic cycle (attachment, injection, replication, lysis releasing new phages) with the lysogenic cycle (viral DNA incorporated as a prophage, replicated harmlessly with the host chromosome until induction triggers the lytic cycle).

Lytic vs Lysogenic Cycle of a Bacteriophage



Lytic vs Lysogenic Cycle of a Bacteriophage

Short Questions & Answers

Q1. Define species and state why interbreeding cannot always be used as a criterion.

Ans. A species is a group of natural populations that can interbreed freely and produce fertile offspring but are reproductively isolated from other such groups; this criterion cannot be applied to predominantly asexually reproducing organisms, which do not interbreed at all.

Q2. What is binomial nomenclature? Give an example.

Ans. Binomial nomenclature, devised by Linnaeus, gives every species a two-part Latin name: a capitalized genus name followed by a lowercase specific name, for example Homo sapiens for man.

Q3. Differentiate the lytic and lysogenic cycles of a bacteriophage.

Ans. In the lytic cycle, viral DNA immediately takes over the host cell to produce new phages and bursts the cell (lysis), while in the lysogenic cycle, viral DNA is incorporated into



the bacterial chromosome as a harmless prophage that is copied along with the host's DNA until induction triggers the lytic cycle.

Q4. What is a virion? Name its two main parts.

Ans. A virion is the complete, mature, infectious virus particle, made of a nucleic acid genome (DNA or RNA) enclosed in a protein coat called the capsid.

Q5. Differentiate prions from viruses.

Ans. Viruses contain nucleic acid (DNA or RNA) enclosed in a protein coat, whereas prions are infectious agents made only of protein, with no nucleic acid at all.

Q6. What is a retrovirus? Name the enzyme unique to retroviruses.

Ans. A retrovirus is an RNA virus, such as HIV, that uses the enzyme reverse transcriptase to convert its RNA genome into DNA, which can then integrate into the host's chromosome.

Long Questions & Answers

Q1: Describe the taxonomic hierarchy from species to kingdom with an example.

Classification organizes living things into a hierarchy of increasingly general categories, based on relationship and similarity rather than arbitrary features. The species is the basic unit: a group of natural populations that interbreed freely and produce fertile offspring while remaining reproductively isolated from other such groups. Closely related species are grouped into a genus; related genera form a family; related families form an order; related orders form a class; related classes form a phylum (or division, for plants, algae and fungi); and related phyla form a kingdom, the broadest category. Members of a lower category resemble one another more closely than members of a higher one. Corn (*Zea mays*) illustrates the full hierarchy: kingdom Plantae, division Anthophyta, class Angiospermae, order Poales, family Poaceae, genus *Zea*, species *mays*. This nested system lets biologists organize well over a million known species in a way that reflects genuine evolutionary relationships rather than superficial traits such as colour or size.

Q2: Describe the five kingdom classification system proposed by Whittaker.

Before 1969, classification struggled to accommodate organisms that did not fit neatly into the traditional two kingdoms of Plantae and Animalia — for example *Euglena*, which has both plant-like and animal-like features, and bacteria, whose prokaryotic cells differ fundamentally from eukaryotic plant and animal cells. In 1969, Robert Whittaker proposed a five-kingdom system based on three levels of cellular organization (prokaryotic unicellular, eukaryotic unicellular, eukaryotic multicellular) combined with three modes of nutrition (photosynthesis, absorption and ingestion). The five kingdoms are Monera, prokaryotic unicellular organisms such as bacteria; Protista, mainly eukaryotic unicellular organisms such as *Euglena* and *Amoeba* (this kingdom became a home for all eukaryotes that did not fit the other three kingdoms); Plantae, eukaryotic multicellular autotrophs that photosynthesize, such as mosses, ferns and flowering plants; Fungi, eukaryotic multicellular heterotrophs that absorb nutrients after external digestion, such as mushrooms; and Animalia, eukaryotic multicellular heterotrophs that ingest and internally digest food. In 1988, Lynn Margulis and Karlene



Schwartz refined this system by also considering cytology, genetics and organelles of symbiotic origin, such as mitochondria and chloroplasts, renaming the kingdoms Prokaryotae (Monera), Protoctista (Protista), Plantae, Fungi and Animalia — a system still widely used alongside newer molecular classification schemes.

Q3: Describe the structure of a bacteriophage and its lytic life cycle.

A typical T-phage such as T4, which infects *Escherichia coli*, has a tadpole-like structure with a hexagonal, DNA-filled head attached to a more complex tail: an inner protein tube (core) surrounded by a contractile sheath, a collar at one end and an end plate at the other, from which tail fibres extend for attaching to the host. Infection begins with attachment (adsorption), in which the tail fibres bind weakly to a specific receptor site on the bacterial cell wall. During penetration, the tail releases the enzyme lysozyme to dissolve part of the cell wall, the sheath contracts, and the tail core is forced through the wall and membrane so the phage can inject its DNA into the bacterium, leaving the empty protein coat outside — much like a syringe injecting its contents. Once inside, the viral DNA immediately takes over the host's biosynthetic machinery, directing the cell to manufacture new viral DNA and protein components. Within about 25 minutes of infection, roughly 200 new bacteriophages have been assembled, and the bacterial cell bursts open (lysis), releasing the new phages to infect further bacteria and begin the cycle again; a phage that causes this outcome is called a lytic or virulent phage.

Q4: Explain HIV and how it causes AIDS.

HIV (human immunodeficiency virus) is a retrovirus, an enveloped, single-stranded RNA virus about 100 nanometres across, first identified as the cause of AIDS in 1984 and formally named in 1986. Like other retroviruses, HIV carries the enzyme reverse transcriptase, which converts its RNA genome into double-stranded DNA once inside a host cell; this viral DNA can then integrate into the host cell's own chromosome as a provirus, where it may persist and be passed on as the cell divides. HIV specifically targets cells bearing the receptor it recognizes, mainly helper T-lymphocytes, key coordinating cells of the immune system, as well as certain cells of the central nervous system. As HIV infection progresses, it steadily destroys helper T-lymphocytes, which weakens and eventually causes the collapse of the immune system; without functioning immune defences, the infected person becomes vulnerable to infections and cancers that a healthy immune system would normally control, a condition known as acquired immune deficiency syndrome (AIDS). HIV is transmitted through intimate sexual contact, contact with infected blood (including shared needles and blood transfusion), and from mother to child via breast feeding, so prevention centres on avoiding these specific routes of exposure and using sterile medical equipment.

Q5: Write a note on viral hepatitis.

Hepatitis is inflammation of the liver, most often caused by viral infection, and produces symptoms such as jaundice, abdominal pain, liver enlargement and fatigue; it may be mild or become chronic, sometimes progressing to liver cancer. Several distinct viruses cause hepatitis. Hepatitis A, a non-enveloped RNA virus, spreads through contact with faeces from infected individuals and typically causes a milder, shorter illness; a vaccine is available.



Hepatitis B, caused by a DNA virus especially common across Asia, China, the Philippines, Africa and the Middle East, spreads through blood, breast milk, saliva and sexual contact, and although many patients recover completely and gain immunity, some develop chronic infection with a risk of long-term liver damage; a genetically engineered vaccine is available for Hepatitis B. Hepatitis C, an enveloped RNA virus, is transmitted mainly through blood and, while generally less severe in its acute stage than A or B, often becomes chronic liver disease, and currently has no vaccine. Hepatitis D (delta hepatitis) and Hepatitis E (spread through faeces) are less common, while Hepatitis F and G are caused by viruses that remain poorly characterized. Because several of these viruses spread through blood and body fluids, control relies on good hygiene, routine vaccination where a vaccine exists, and careful screening of donated blood, organs and tissue.

MCQs with Answers

1. Binomial nomenclature was devised by:

(a) Robert Whittaker (b) Carolus Linnaeus (c) Ernst Haeckel (d) Edouard Chatton

Correct Answer: (b) Carolus Linnaeus. Carolus Linnaeus devised binomial nomenclature, publishing plant names in 1753 and animal names in 1758.

2. The five-kingdom classification system was proposed in 1969 by:

(a) Lynn Margulis (b) Ernst Haeckel (c) Robert Whittaker (d) Louis Pasteur

Correct Answer: (c) Robert Whittaker. Robert Whittaker proposed the five-kingdom system in 1969.

3. Which scientist coined the terms 'prokaryotic' and 'eukaryotic'?

(a) Edouard Chatton (1937) (b) Robert Hooke (1665) (c) Carl Linnaeus (1753) (d) Rudolph Virchow (1855)

Correct Answer: (a) Edouard Chatton (1937). Edouard Chatton introduced these terms in 1937 to distinguish cell types.

4. Viruses range in size from about:

(a) 2 to 20 nm (b) 20 to 250 nm (c) 1 to 10 micrometres (d) 10 to 100 micrometres

Correct Answer: (b) 20 to 250 nm. Viruses range from about 20 nm (parvoviruses) to 250 nm (poxviruses).

5. The tobacco mosaic virus was first crystallized in 1935 by:

(a) Ivanowski (b) Stanley (c) Twort (d) D'Herelle

Correct Answer: (b) Stanley. Stanley crystallized the tobacco mosaic virus in 1935, showing it was made of nucleic acid and protein.

6. The protein coat of a virus is called the:

(a) genome (b) envelope (c) capsid (d) provirus

Correct Answer: (c) capsid. The capsid, built of capsomeres, is the protein coat enclosing the viral genome.

7. A phage whose DNA integrates harmlessly into the bacterial chromosome is called a:



(a) lytic phage (b) virulent phage (c) temperate (lysogenic) phage (d) naked virion

Correct Answer: (c) temperate (lysogenic) phage. A temperate or lysogenic phage integrates as a prophage rather than immediately lysing the host.

8. The enzyme unique to retroviruses, which converts RNA into DNA, is:

(a) DNA polymerase (b) reverse transcriptase (c) lysozyme (d) restriction enzyme

Correct Answer: (b) reverse transcriptase. Reverse transcriptase converts a retrovirus's RNA genome into DNA.

9. HIV mainly infects which type of cell in the human body?

(a) Red blood cells (b) Helper T-lymphocytes (c) Skin cells (d) Muscle cells

Correct Answer: (b) Helper T-lymphocytes. HIV targets helper T-lymphocytes, weakening the immune system and causing AIDS.

10. Smallpox was declared eradicated worldwide by the WHO in:

(a) 1935 (b) 1969 (c) 1980 (d) 2001

Correct Answer: (c) 1980. The World Health Organization declared smallpox eradicated in 1980.

Quick Revision Summary

- Taxonomic hierarchy (specific to general): species -> genus -> family -> order -> class -> phylum/division -> kingdom.
- Binomial nomenclature (Linnaeus): two-part Latin name, Genus + species, e.g. *Homo sapiens*.
- Classification history: 2 kingdoms -> Haeckel's Protista (1866) -> Chatton's prokaryote/eukaryote (1937) -> Whittaker's 5 kingdoms (1969: Monera, Protista, Fungi, Plantae, Animalia) -> Margulis & Schwartz refinement (1988).
- Viruses: non-cellular, DNA or RNA + protein capsid (+ sometimes envelope); obligate intracellular parasites; discovered via filterable agents (Chamberland 1884, Ivanowski 1892, Stanley 1935).
- Bacteriophage cycles: lytic (immediate replication + lysis, ~200 phages/~25 min) vs lysogenic (prophage integrated, passed to daughter cells until induction).
- Retroviruses (e.g. HIV) use reverse transcriptase to convert RNA to DNA; HIV destroys helper T-lymphocytes, causing AIDS.
- Viral diseases: smallpox (eradicated 1980), influenza, mumps/measles, polio, Hepatitis A-G (different viruses, transmission routes and severity). Notes by freebooks.pk.

Exam Tips

- Memorise the taxonomic hierarchy order (species to kingdom) — a guaranteed fill-in-the-blank or MCQ.
- Know Linnaeus's two publication years (1753 plants, 1758 animals) and the binomial nomenclature rules (capital genus, lowercase species).
- Be ready to list all five Whittaker kingdoms with their nutrition mode (photosynthesis / absorption / ingestion).



- Practise the difference between lytic and lysogenic cycles as a clear step-by-step comparison — a frequent long question.
- Remember key names/years: Jenner (1796, vaccination), Stanley (1935, TMV crystallized), Twort/D'Herelle (1915/1917, bacteriophages), WHO (1980, smallpox eradicated).
- For Hepatitis questions, know at least the transmission route and DNA/RNA nature of Hepatitis A, B and C specifically.

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CHAPTER 6

Kingdom Prokaryotae (Monera)

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Kingdom Prokaryotae (Monera) from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It traces the discovery of bacteria from Leeuwenhoek's first "animalcules" through Pasteur and Koch's germ theory of disease, then works through bacterial size, shape, and every major structural feature, from flagella and pili to the nucleoid, plasmids and endospores. These notes are prepared by freebooks.pk.

The chapter also covers bacterial nutrition, respiration, growth and reproduction, their enormous ecological, economic and medical importance, and the physical, chemical and medical methods used to control them, including antibiotics and their misuse. It closes with cyanobacteria (blue-green algae) and the genus *Nostoc*, an important photosynthetic prokaryote in its own right.

Learning Objectives

- Describe the discovery of bacteria and state Koch's postulates.
- Describe the size and the three main shapes of bacteria, with their arrangements.
- Describe bacterial cell structure: flagella, pili, capsule, cell wall and the Gram staining difference.
- Describe the nucleoid, plasmids, ribosomes and storage structures of a bacterial cell.
- Differentiate autotrophic and heterotrophic nutrition and aerobic and anaerobic respiration in bacteria.
- Describe binary fission and the four phases of the bacterial growth curve.
- Describe the ecological, economic and medical importance of bacteria and the methods used to control them.
- Describe the general characteristics of cyanobacteria, with reference to *Nostoc*.

Key Concepts

Discovery and Occurrence of Bacteria

Kingdom Prokaryotae consists of organisms with prokaryotic cells (Greek pro, "before", and karyon, "nucleus"), divided by microbiologists into eubacteria ("true bacteria") and the much smaller group of archaeobacteria ("ancient bacteria"). Bacteria could only be discovered once the microscope was invented; the Dutch scientist Antonie van Leeuwenhoek (1673) was the first to observe and accurately describe bacteria and protozoa, which he called "animalcules", first in rainwater and later in saliva and other substances. Louis Pasteur later confirmed the importance of these tiny organisms, developing vaccines for anthrax, fowl cholera and rabies, pioneering the pasteurization process, and proving that microorganisms can cause disease. Robert Koch formulated the germ theory of disease through four postulates still used to establish whether an organism causes a specific disease: it must always be found with the disease; it can be isolated and grown in pure culture; the pure culture must reproduce the disease in a susceptible animal; and the organism must be recoverable in pure culture from that experimentally infected animal.



Bacteria are found almost everywhere — in air, soil, water, food, decaying matter, and in and on plants, animals and humans — with some contributing to the normal (natural) flora of an environment and others restricted to extreme habitats such as hot springs or highly saline or acidic environments.

Size and Shape of Bacteria

Bacteria range enormously in size, from about 0.1 to 600 micrometres in a single dimension. The smallest, such as some *Mycoplasma* species, are only about 0.1-0.2 micrometres across, similar to the largest viruses, while *Escherichia coli*, an average-sized bacillus, measures about 1.1-1.5 by 2.0-6.0 micrometres; some spirochetes reach 500 micrometres, and the recently discovered *Epulopiscium fishelsoni* can grow to 600 by 80 micrometres, larger than many eukaryotic cells.

Bacteria are classified by general shape into three main categories: cocci (spherical or oval), bacilli (rod-shaped), and spiral forms, though some bacteria are pleomorphic and can take a variety of shapes. Cocci form different arrangements depending on their plane(s) of division: division in one plane gives a diplococcus (pairs) or streptococcus (chains) arrangement, division in two planes gives a tetrad (a square of 4 cocci), division in three planes gives a sarcina (a cube of 8 cocci), and division in random planes gives a staphylococcus (irregular, grape-like clusters, as in *Staphylococcus aureus*). Bacilli divide in one plane only, giving a single bacillus, a chain (streptobacillus), or pairs (diplobacilli), as seen in *Escherichia coli*. Spiral bacteria occur as a vibrio (curved, comma-shaped), a spirillum (thick, rigid spiral) or a spirochete (thin, flexible spiral).

Bacterial Cell Structure: Appendages and Cell Envelope

Flagella are thin, hair-like appendages made of the protein flagellin, anchored in a basal body beneath the cell membrane; bacteria are classified by their flagellar arrangement as atrichous (no flagella), monotrichous (one polar flagellum), lophotrichous (a tuft at one pole), amphitrichous (a tuft at each pole) or peritrichous (flagella all over the cell). Flagella provide motility and allow chemotaxis, movement toward or away from chemical signals. Pili are smaller, hollow, non-helical appendages made of the protein pilin, found mainly on Gram-negative bacteria; unlike flagella they are not used for movement but instead help bacteria attach to surfaces or, in the case of specialized sex pili, transfer genetic material during conjugation.

The layers external to the cell protoplasm together form the cell envelope: the capsule (a thick, gummy, tightly bound layer of polysaccharide and/or protein that increases pathogenicity), slime (a looser, soluble layer that also increases pathogenicity and resists phagocytosis), and the rigid cell wall, which determines the cell's shape and protects it from osmotic lysis (absent only in mycoplasmas). Using the Gram stain technique developed by Christian Gram, bacteria are classified as Gram-positive (retain the purple primary dye, thicker single-layer wall rich in peptidoglycan, about 20-80 nm thick) or Gram-negative (retain the pink secondary dye, thinner wall with an additional outer membrane of lipopolysaccharides and lipoproteins, about 8-11 nm thick, and much less peptidoglycan).



Archaeobacteria cell walls differ from both, lacking peptidoglycan altogether and being made instead of proteins, glycoproteins and polysaccharides.

Internal Structure: Nucleoid, Plasmids and Storage Structures

Beneath the cell wall lies the delicate plasma membrane, which regulates transport and carries respiratory enzymes; unlike eukaryotic membranes, bacterial membranes lack sterols such as cholesterol. The cytoplasmic matrix is a gel-like substance lacking membrane-bound organelles or a cytoskeleton, within which the nucleoid (also called the chromatin body or nuclear region) is found: a single, circular, double-stranded DNA molecule tightly folded near the centre of the cell, making bacteria haploid (they lack the discrete chromosomes and nuclear membrane of eukaryotes). Many bacteria also carry plasmids, smaller circular DNA molecules that are self-replicating and not essential for normal growth but often carry genes for drug resistance; plasmids are important vectors in genetic engineering.

Bacterial ribosomes, smaller than eukaryotic ribosomes, are the site of protein synthesis and may be free or loosely attached to the plasma membrane. Mesosomes are membrane invaginations involved in DNA replication, cell division and enzyme export. Bacteria store surplus nutrients such as glycogen, sulphur, fat or phosphate as granules when conditions allow. Under adverse conditions, certain bacteria form spores (dormant, resistant bodies, either exospores or endospores) or cysts (dormant, thick-walled but not heat-resistant forms), both of which can germinate into normal vegetative cells once favourable conditions return.

Nutrition and Respiration in Bacteria

Most bacteria are heterotrophic, unable to make their own organic compounds and living either as saprophytes (obtaining food from dead organic matter such as humus in soil) or as parasites (fully dependent on a host). Some bacteria are autotrophic, synthesizing their own organic compounds from inorganic substances, and are divided into photosynthetic autotrophs (which contain a form of chlorophyll dispersed in the cytoplasm rather than in chloroplasts, and use hydrogen sulphide instead of water as a hydrogen source, releasing sulphur instead of oxygen) and chemosynthetic autotrophs (such as nitrifying bacteria, which oxidize inorganic compounds like ammonia, nitrate or sulphur to release energy).

Respiration in bacteria may be aerobic (requiring free oxygen), anaerobic (not requiring oxygen), facultative (able to grow with or without oxygen), or microaerophilic (requiring only a low oxygen concentration).

Growth, Reproduction and Importance of Bacteria

Bacteria reproduce asexually by binary fission: the parent cell enlarges, its single chromosome duplicates, the plasma membrane pinches inward, and the cell wall grows inward to split the cell into two daughter cells; the time between successive divisions is called the generation time. Population growth follows a characteristic bacterial growth curve with four phases: the lag phase (little growth, cells preparing to divide), the log phase (rapid, exponential division), the stationary phase (death rate equals reproduction rate) and the death or decline phase (death rate exceeds reproduction rate). Although bacteria lack true



sexual reproduction and mitosis, some exchange genetic material between a donor and recipient cell through conjugation, often using specialized sex pili, producing new genetic combinations that can help bacteria survive changing conditions.

Bacteria are ecologically vital, decomposing organic matter and driving the nitrogen, phosphorus, sulphur and carbon cycles; economically important in food, drug (antibiotics, vaccines) and biotechnology industries, while also causing spoilage of food and crop losses; and medically significant, with roughly 200 species known to cause human disease, alongside many others that normally inhabit the human body harmlessly.

Control of Bacteria: Physical and Chemical Methods, Immunization

Controlling microorganisms is essential in the home, industry and medicine. Physical methods of sterilization (destruction of all life forms) use steam, dry heat, gas, filtration or radiation; moist heat kills microbes by coagulating their proteins, dry heat by oxidizing their chemical constituents, and heat-sensitive materials such as antibiotics can instead be sterilized by membrane filtration. Chemical methods use antiseptics (chemicals applied to living tissue to inhibit microbial growth), disinfectants (oxidizing or reducing agents such as halogens, phenols or alcohol, used on non-living surfaces), and chemotherapeutic agents and antibiotics (such as sulfonamides, tetracycline and penicillin), which destroy or inhibit microbes within living tissue.

Immunization and vaccination are key preventive measures. Pasteur discovered, while working with chicken cholera, that bacteria left to grow old in culture become attenuated (less virulent) yet can still stimulate a host to produce protective antibodies; he named the attenuated culture a vaccine (from the Latin vacca, "cow") and the process vaccination, honouring Edward Jenner, who had successfully vaccinated a boy against smallpox in 1796 using material from cowpox lesions. Antibiotics (Greek anti, "against", and bios, "life") are chemotherapeutic substances, naturally produced by certain bacteria, actinomycetes and fungi (and now also synthesized in the laboratory), used to treat infectious disease; however, their widespread and improper use has led to increasing drug resistance in microorganisms, and misuse can cause serious side effects, such as allergic reactions to penicillin, hearing loss from streptomycin, and permanent tooth discoloration in children from tetracycline.

Cyanobacteria and Nostoc

Cyanobacteria, formerly called blue-green algae, are the largest and most diverse group of photosynthetic bacteria and are true prokaryotes, 1-10 micrometres across, occurring as single cells, colonies, or filaments (trichomes) surrounded by a mucilaginous sheath; they have a Gram-negative type cell wall, lack flagella, and often move using gas vesicles or gliding motility. Their photosynthetic system closely resembles that of eukaryotes, using chlorophyll a and photosystem II to carry out oxygenic photosynthesis (releasing oxygen, using water as an electron donor), assisted by the accessory pigment phycocyanin housed in structures called phycobilisomes; they store food as glycogen and reproduce by binary fission or fragmentation. Cyanobacteria are ecologically valuable: they help reclaim alkaline soils, fix atmospheric nitrogen using specialized cells called heterocysts, release oxygen through photosynthesis, serve as pollution indicators, form symbiotic partnerships with fungi



(as the photosynthetic partner in most lichens) and with nitrogen-fixing associations in some flowering plants, though some species also form toxic, foul-smelling water blooms.

Nostoc is a common terrestrial cyanobacterium, widely distributed on alkaline soils and moist rocks, forming a jelly-like mass of unbranched, beaded trichomes of mostly spherical cells. At intervals along the trichome, larger, thick-walled heterocysts occur, and the trichome tends to break near these heterocysts to form hormogonia (fragments that grow into new filaments), the main means of asexual reproduction; Nostoc also forms akinetes, thick-walled resting cells that store food and germinate into new vegetative cells when conditions become favourable again.

Important Definitions

Term	Definition
Prokaryote	An organism, such as a bacterium, whose cell lacks a nuclear membrane, so its DNA lies free in the cytoplasm.
Cocci	Spherical or oval bacteria, which may occur singly or in arrangements such as diplococcus, streptococcus, tetrad, sarcina or staphylococcus.
Plasmid	A small, circular, self-replicating DNA molecule in bacteria, separate from the main chromosome, often carrying drug-resistance genes.
Nucleoid	The irregular, dense region of a bacterial cell where its single circular DNA molecule is concentrated, without a surrounding membrane.
Binary fission	The asexual method of bacterial reproduction in which a cell enlarges, duplicates its chromosome, and divides into two identical daughter cells.
Vaccine	A preparation of attenuated or killed pathogens (or their components) used to stimulate immunity without causing disease.
Antibiotic	A chemical substance, produced by microorganisms or synthetically, that inhibits or destroys other microorganisms.
Heterocyst	A specialized, thick-walled cell in certain cyanobacteria (e.g. Nostoc) responsible for fixing atmospheric nitrogen.

Key Facts

Item	Fact
Bacteria discovered / named	Antonie van Leeuwenhoek, 1673 - called them "animalcules".
Koch's postulates	4 rules linking a specific microorganism to a specific disease.
Bacterial size range	About 0.1 to 600 micrometres; E. coli approx. 1.1-1.5 x 2.0-6.0 micrometres.
Gram-positive cell wall	~50% peptidoglycan (dry weight), 20-80 nm thick, no outer membrane.
Gram-negative cell wall	~10% peptidoglycan, 8-11 nm thick, has an outer membrane (lipopolysaccharides/lipoproteins).

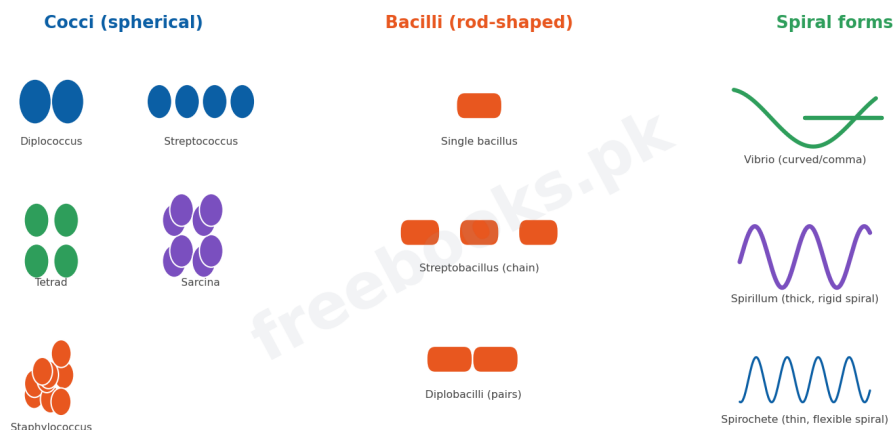


Item	Fact
Bacterial growth curve	Lag -> Log (exponential) -> Stationary -> Death/Decline phase.
Vaccination history	Edward Jenner, 1796 (smallpox/cowpox); term "vaccine" coined by Pasteur from Latin vacca (cow).
Cyanobacteria pigment	Chlorophyll a + phycocyanin (blue accessory pigment); oxygenic photosynthesis; store glycogen.

Diagrams & Illustrations

Shapes and Arrangements of Bacteria: a chart of the three main bacterial shapes - cocci (with diplococcus, streptococcus, tetrad, sarcina, staphylococcus arrangements), bacilli (single, diplobacilli, streptobacillus) and spiral forms (vibrio, spirillum, spirochete).

Shapes and Arrangements of Bacteria

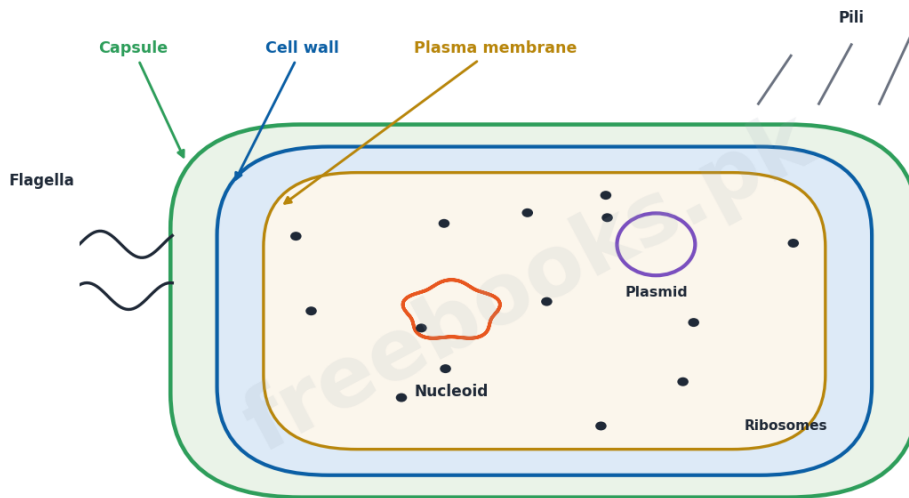


Shapes and Arrangements of Bacteria

Structure of a Generalized Bacterial Cell: a labelled diagram of a generalized bacterial cell showing the cell wall, plasma membrane, nucleoid, plasmid, ribosomes, flagella, pili and capsule.



Structure of a Generalized Bacterial Cell

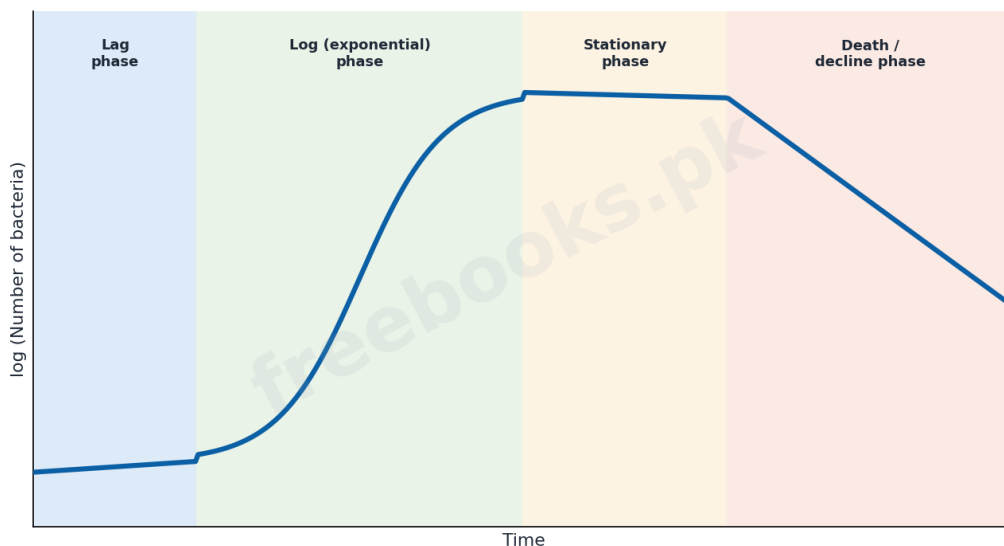


Prokaryotic cell: no nuclear membrane, no membrane-bound organelles; single circular DNA (nucleoid)

Structure of a Generalized Bacterial Cell

The Bacterial Growth Curve: a graph of bacterial population against time, showing the four phases of growth: lag phase, log (exponential) phase, stationary phase and death/decline phase.

The Bacterial Growth Curve



The Bacterial Growth Curve

Short Questions & Answers

Q1. State Koch's postulates.

Ans. Koch's four postulates state that a specific organism must always be found with a given disease, can be isolated and grown in pure culture, will reproduce the disease when



inoculated into a susceptible animal, and can be recovered in pure culture from that experimentally infected animal.

Q2. Differentiate Gram-positive and Gram-negative bacteria.

Ans. Gram-positive bacteria have a thick, single-layer cell wall rich in peptidoglycan and retain the purple primary stain, while Gram-negative bacteria have a thinner wall with much less peptidoglycan plus an additional outer membrane, and retain the pink secondary stain.

Q3. What is a plasmid? State one practical use.

Ans. A plasmid is a small, circular, self-replicating DNA molecule separate from the bacterial chromosome, often carrying drug-resistance genes; plasmids are widely used as vectors in genetic engineering.

Q4. Differentiate flagella and pili.

Ans. Flagella are longer appendages made of flagellin used for motility (and chemotaxis), while pili are shorter, hollow appendages made of pilin used mainly for attachment to surfaces or, as sex pili, for transferring genetic material during conjugation.

Q5. Name the four phases of the bacterial growth curve.

Ans. Lag phase (preparing to divide), log phase (rapid exponential growth), stationary phase (death rate equals reproduction rate), and death/decline phase (death rate exceeds reproduction rate).

Q6. Differentiate antiseptics and antibiotics.

Ans. Antiseptics are chemical substances applied to living tissue to inhibit microbial growth on contact, while antibiotics are chemotherapeutic substances, produced by microorganisms, that are taken to destroy or inhibit microbes from within the body.

Long Questions & Answers

Q1: Describe in detail the structure of the bacterial cell wall, emphasizing Gram-positive and Gram-negative properties.

The bacterial cell wall lies beneath the capsule or slime layer and external to the plasma membrane, giving the cell its shape and protecting it from osmotic lysis; it is absent only in mycoplasmas. Most bacterial cell walls contain a unique macromolecule, peptidoglycan, made of long glycan chains cross-linked by peptide fragments, along with other components such as teichoic acid, lipoproteins and lipopolysaccharides. Using the Gram stain technique developed by Christian Gram, bacteria are divided into two groups based on differences in this wall structure. Gram-positive bacteria have a single, comparatively thick wall layer (about 20-80 nm) made mostly of peptidoglycan (up to 50% of dry weight in some species) along with teichoic and lipoteichoic acids, no outer membrane, and are more permeable; they retain the purple crystal-violet-iodine complex during staining. Gram-negative bacteria, by contrast, have a thinner wall (about 8-11 nm) containing far less peptidoglycan (about 10% of dry weight), but possess an additional outer membrane built of lipopolysaccharides and lipoproteins, a periplasmic space present in all cells of this group, and are generally less permeable; they lose the purple stain and instead retain the pink counterstain. These structural differences are the fundamental reason the two groups respond differently to



Gram staining, and they also explain differences in antibiotic sensitivity and pathogenicity between the two groups.

Q2: Describe the shapes and arrangements of bacteria with examples.

Bacteria are classified by their general shape into three main categories, though some species are pleomorphic and can vary in shape. Cocci are spherical or oval cells whose arrangement depends on the plane(s) of division: division in a single plane produces either a diplococcus arrangement (pairs, as in *Diplococcus pneumoniae*) or a streptococcus arrangement (long chains); division in two planes produces a tetrad (a square of four cocci); division in three planes produces a sarcina (a cube of eight cocci); and division in random planes produces a staphylococcus arrangement (irregular, grape-like clusters, as in *Staphylococcus aureus*). Bacilli are rod-shaped bacteria that divide in only one plane, appearing as a single bacillus, a chain (streptobacillus), or in pairs (diplobacilli), as in *Escherichia coli* and *Bacillus subtilis*. Spiral bacteria are spirally coiled and occur in three forms: the vibrio, a curved or comma-shaped rod; the spirillum, a thick, rigid spiral; and the spirochete, a thin, flexible spiral, as seen in genera such as *Vibrio* and *Hyphomicrobium*. A few bacteria fall outside these three categories altogether, forming trichomes, sheaths, stalks, squares, stars, spindles, lobes or filaments.

Q3: Describe the growth and reproduction of bacteria.

Bacteria reproduce asexually through binary fission: the parent cell first enlarges and duplicates its single circular chromosome, the plasma membrane then pinches inward at the centre of the cell once the nuclear material has been evenly distributed to each half, and finally the cell wall grows inward to complete the separation into two genetically identical daughter cells. The time taken between one division and the next is called the generation time. As a bacterial population grows in a given environment, it passes through four recognizable phases, together called the bacterial growth curve: the lag phase, in which cells show little increase in number as they prepare for division; the log (exponential) phase, in which cells divide rapidly and population size increases exponentially; the stationary phase, in which the rate of new cell formation equals the rate of cell death, keeping the population roughly constant; and the death or decline phase, in which the death rate exceeds the reproduction rate and the population falls. Although bacteria lack true sexual reproduction and mitosis, genetic material can still be exchanged between a donor and a recipient cell through conjugation, sometimes using specialized sex pili; this process creates new genetic combinations that can help bacteria adapt to a wider range of environmental conditions.

Q4: Discuss the methods used to control bacteria, and the problems that can arise from the misuse of antibiotics.

Controlling microorganisms is important in homes, industry and medicine, both to prevent disease and to stop spoilage of food and other products. Physical methods achieve sterilization, the destruction of all life forms, using steam, dry heat, gas, filtration or radiation; moist heat kills microbes by coagulating their proteins, dry heat by oxidizing their cell components, certain electromagnetic radiations below 300 nm (such as gamma rays) are used for sterilization, and heat-sensitive substances like antibiotics and hormones are



instead sterilized using membrane filters. Chemical methods include antiseptics (applied to living tissue to inhibit microbial growth), disinfectants such as halogens, phenols, hydrogen peroxide, potassium permanganate, alcohol and formaldehyde (used on non-living surfaces to inhibit vegetative cells), and chemotherapeutic agents and antibiotics such as sulfonamides, tetracycline and penicillin, which act within living tissue to destroy or inhibit microorganisms. Immunization and vaccination provide preventive protection, a principle discovered through Pasteur's chicken cholera experiments and Jenner's earlier smallpox vaccination, alongside broader public health measures such as water purification and sewage disposal. However, the massive and often careless use of antibiotics has led to widespread antibiotic resistance in microorganisms, making some infections harder to treat, and misuse can directly harm patients: penicillin misuse can trigger allergic reactions, streptomycin can damage the auditory nerve and cause deafness, and tetracycline can permanently discolour the teeth of young children — which is why antibiotics should always be taken exactly as prescribed, at regular intervals, for the full course advised by a physician.

Q5: Describe the general characteristics of cyanobacteria, with special reference to Nostoc.

Cyanobacteria, formerly known as blue-green algae, are true prokaryotes and the largest, most diverse group of photosynthetic bacteria, ranging from about 1 to 10 micrometres in diameter and occurring as single cells, colonies, or filaments (trichomes) wrapped in a mucilaginous sheath. They have a Gram-negative type cell wall, lack flagella, and move using gas vesicles or, in filamentous species, gliding motility. Their photosynthetic apparatus closely resembles that of eukaryotes, using chlorophyll a and photosystem II to carry out oxygenic photosynthesis (using water as the electron donor and releasing oxygen), assisted by the blue accessory pigment phycocyanin held in structures called phycobilisomes, with carbon dioxide fixed via the Calvin cycle and glycogen stored as reserve food; reproduction occurs by binary fission or fragmentation. Ecologically, cyanobacteria help reclaim alkaline soils, fix atmospheric nitrogen through specialized cells called heterocysts, enrich the environment with oxygen, serve as pollution indicators, and form symbiotic relationships, notably as the photosynthetic partner in most lichens. Nostoc is a widely distributed terrestrial and sub-aerial cyanobacterium, forming jelly-like masses on alkaline soils and moist rocks that contain numerous unbranched, beaded trichomes of mostly spherical cells. At intervals, larger, thick-walled heterocysts occur along each trichome; the trichome tends to break near these heterocysts, producing hormogonia (fragments that develop into new filaments) as the main means of asexual reproduction, while some cells also develop into thick-walled, food-storing akinetes that can survive unfavourable conditions and later germinate into new vegetative filaments.

MCQs with Answers

1. Bacteria were first observed and described (as "animalcules") by:

(a) Robert Koch (b) Antonie van Leeuwenhoek (c) Louis Pasteur (d) Christian Gram

Correct Answer: (b) Antonie van Leeuwenhoek. Leeuwenhoek first observed bacteria and protozoa in 1673, calling them animalcules.



2. Koch's postulates are used to:

(a) classify bacteria by shape (b) prove an organism causes a specific disease (c) stain Gram-positive bacteria (d) measure bacterial growth rate

Correct Answer: (b) prove an organism causes a specific disease. Koch's four postulates establish whether a microorganism is the causal agent of a disease.

3. An arrangement of cocci forming a cube of eight cells is called:

(a) tetrad (b) sarcina (c) staphylococcus (d) diplococcus

Correct Answer: (b) sarcina. Sarcina describes cocci arranged in a cube of eight cells, from division in three planes.

4. Gram-positive bacteria, when Gram-stained, appear:

(a) pink (b) purple (c) colourless (d) yellow

Correct Answer: (b) purple. Gram-positive bacteria retain the purple crystal violet-iodine complex.

5. A small, circular, self-replicating DNA molecule separate from the main bacterial chromosome is a:

(a) nucleoid (b) mesosome (c) plasmid (d) ribosome

Correct Answer: (c) plasmid. A plasmid is a separate, self-replicating circular DNA molecule, often carrying drug-resistance genes.

6. The asexual method of bacterial reproduction is called:

(a) conjugation (b) binary fission (c) budding (d) sporulation

Correct Answer: (b) binary fission. Bacteria reproduce asexually by binary fission, splitting one cell into two.

7. In the bacterial growth curve, rapid exponential division occurs during the:

(a) lag phase (b) log phase (c) stationary phase (d) death phase

Correct Answer: (b) log phase. The log (exponential) phase is when bacteria divide most rapidly.

8. The term "vaccine" comes from the Latin word for:

(a) poison (b) cow (c) disease (d) life

Correct Answer: (b) cow. Vaccine is derived from Latin vacca, meaning cow, referencing Jenner's cowpox-based smallpox vaccination.

9. Cyanobacteria carry out oxygenic photosynthesis using chlorophyll a and the accessory pigment:

(a) carotene (b) phycocyanin (c) xanthophyll (d) chlorophyll b

Correct Answer: (b) phycocyanin. Phycocyanin is the main accessory pigment in cyanobacteria, held in phycobilisomes.

10. The specialized cyanobacterial cell responsible for fixing atmospheric nitrogen is the:

(a) akinete (b) hormogonium (c) heterocyst (d) trichome

Correct Answer: (c) heterocyst. Heterocysts are the specialized cells where nitrogen fixation occurs in cyanobacteria like Nostoc.



Quick Revision Summary

- Bacteria discovered by Leeuwenhoek (1673, "animalcules"); Koch's 4 postulates prove an organism causes a disease; Pasteur developed vaccines, pasteurization, disproved spontaneous generation.
- Bacterial shapes: cocci (diplococcus, streptococcus, tetrad, sarcina, staphylococcus), bacilli (single, diplobacilli, streptobacillus), spiral (vibrio, spirillum, spirochete).
- Cell structure: flagella (motility, flagellin) and pili (attachment/conjugation, pilin) as appendages; capsule/slime + cell wall (Gram+ thick peptidoglycan, no outer membrane; Gram- thin peptidoglycan + outer membrane) as the envelope.
- Nucleoid = single circular DNA (haploid); plasmids = extra DNA, drug resistance, genetic engineering vectors; mesosomes, ribosomes, granules, spores/cysts for storage/survival.
- Nutrition: heterotrophic (saprophytic/parasitic) or autotrophic (photosynthetic/chemosynthetic). Respiration: aerobic, anaerobic, facultative, microaerophilic.
- Reproduction: binary fission; growth curve = lag -> log -> stationary -> death. Control: physical (heat, radiation, filtration) + chemical (antiseptics, disinfectants, antibiotics) + immunization/vaccination.
- Cyanobacteria (blue-green algae): true prokaryotes, chlorophyll a + phycocyanin, oxygenic photosynthesis, glycogen storage, heterocysts fix nitrogen; Nostoc reproduces via hormogonia and akinetes. Notes by freebooks.pk.

Exam Tips

- Learn the 4 Koch's postulates in order — a classic "write a note" and short-question topic.
- Be ready to name all 5 cocci arrangements (diplococcus, streptococcus, tetrad, sarcina, staphylococcus) with the plane of division for each.
- Memorise the Gram-positive vs Gram-negative wall differences as a clear table (peptidoglycan %, thickness, outer membrane, stain colour).
- Practise the 4 phases of the bacterial growth curve and what happens in each.
- Remember the Jenner/Pasteur vaccination story and where the words "vaccine"/"vaccination" come from.
- Know cyanobacteria's key features: chlorophyll a + phycocyanin, oxygenic photosynthesis, glycogen storage, and heterocysts for nitrogen fixation (linked to Nostoc).



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CHAPTER 7

Kingdom Protista

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Kingdom Protista (or Protoctista) from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Kingdom Protista is essentially defined by exclusion: it groups eukaryotic organisms that do not fit neatly into the Plantae, Fungi or Animalia kingdoms, and from which those three eukaryotic kingdoms are thought to have arisen. These notes are prepared by freebooks.pk.

The chapter traces the historical development of the kingdom concept from Hogg and Haeckel through Copeland, Whittaker, and Margulis and Schwartz, then works through the three major groups of protists: the animal-like protozoa (amoebae, zooflagellates, ciliates, foraminiferans/actinopods, and apicomplexans), the plant-like algae (euglenoids, dinoflagellates, diatoms, brown algae, red algae and green algae), and the fungus-like protists (slime molds and water molds/oomycetes), along with their ecological and economic importance.

Learning Objectives

- Explain why Kingdom Protista is difficult to characterize and describe its historical development.
- Describe the major groups of protozoa: amoebae, zooflagellates, ciliates, foraminiferans/actinopods and apicomplexans.
- Describe the general characteristics of algae and classify them into their six major phyla by pigment.
- Describe euglenoids, dinoflagellates, diatoms, brown algae, red algae and green algae with examples.
- State the economic and ecological importance of algae.
- Describe the structure and reproduction of slime molds (Myxomycota).
- Differentiate water molds (Oomycetes) from true fungi and describe their importance.

Key Concepts

Kingdom Protista: Definition, Diversity and Historical Perspective

Kingdom Protista consists of a vast assortment of primarily aquatic eukaryotic organisms whose diverse body forms, types of reproduction, modes of nutrition and lifestyles make them difficult to characterize; the kingdom is essentially defined by exclusion, since all its members have characteristics that exclude them from the other four kingdoms. All protists are eukaryotic and are thought to have evolved from prokaryotes; the other eukaryotic kingdoms (Plantae, Fungi and Animalia) arose from protists in various ways, which is part of why placing certain eukaryotic organisms in the correct kingdom is difficult. Protists are unicellular, colonial or simple multicellular organisms with eukaryotic cell organization, but unlike plants and animals they do not develop from a blastula or an embryo. Kingdom Protista contains four major groups of organisms: single-celled protozoans, unicellular algae, multicellular algae, and slime molds and oomycetes (fungus-like protists).



The concept of this kingdom developed gradually. In 1861, John Hogg proposed the kingdom Protoctista for microscopic organisms. In 1866, Ernst Haeckel suggested creating Kingdom Protista to include bacteria and other microorganisms such as Euglena, though he separated blue-green algae and bacteria (prokaryotes) into a group he called Monera within Protista. In 1938, Herbert Copeland elevated the prokaryotes to full kingdom status, separating them from Protista. In Robert Whittaker's five-kingdom system (1969), only unicellular eukaryotes were placed in Kingdom Protista; today the kingdom also includes colonial and simple multicellular eukaryotes. Margulis and Schwartz (1988) modified the five-kingdom system further, keeping Protista (or Protoctista) as one of the five kingdoms. Because of this diversity, most biologists regard the protist kingdom as polyphyletic, meaning its members probably do not share a single common ancestor; Margulis and Schwartz listed 27 phyla to accommodate this diverse assemblage.

Protozoa: Animal-like Protists

All protozoans are unicellular, and most ingest their food by endocytosis. Amoebae include all free-living freshwater, marine and soil amoebae as well as parasitic species; they lack flagella and move using specialized cytoplasmic projections called pseudopodia ("false feet"). The intestinal parasite *Entamoeba histolytica* causes amoebic dysentery in humans, while the giant amoeba *Pelomyxa palustris*, possibly the most primitive of all eukaryote-like forms, has multiple membrane-bound nuclei but lacks the other organelles found in typical eukaryotes and obtains energy from methanogenic bacteria living inside it.

Zooflagellates are mostly unicellular (a few colonial) organisms with spherical or elongated bodies and a single central nucleus, possessing one to many long, whip-like flagella for movement; they may be free-living, symbionts or parasites. Trichonympha are complex flagellates with many flagella that live symbiotically in the guts of termites and help digest wood, while Trypanosoma is a parasitic flagellate that causes African sleeping sickness, transmitted by the bite of an infected tsetse fly. Choanoflagellates are sessile flagellates attached by a stalk, with a single flagellum surrounded by a delicate collar, and are notable for their striking resemblance to the collar cells found in sponges. Ciliates are unicellular organisms with a flexible outer covering called a pellicle, giving them a definite but changeable shape; in Paramecium the cell surface is covered with thousands of short, hair-like cilia beating in coordinated waves for movement. Ciliates possess two kinds of nuclei: one or more small, diploid micronuclei involved in sexual processes, and a large, polyploid macronucleus that controls cell metabolism and growth; most ciliates reproduce sexually through conjugation, in which two individuals exchange genetic material. Foraminiferans and actinopods are marine protozoans that produce shells (tests) — calcium-based in foraminiferans and silica-based in actinopods — with pores through which sticky cytoplasmic projections extend to trap prey; foraminiferan shells accumulating on the ocean floor have formed vast limestone deposits over geological time. Apicomplexans are a large group of parasitic protozoa lacking specific locomotory structures but able to move by flexing; the apicomplexan Plasmodium causes malaria, entering the human bloodstream through the bite of an infected female Anopheles mosquito, multiplying first in liver cells and then in red blood cells, whose simultaneous bursting causes malaria's characteristic chills and fever.



The Algae: Plant-like Protists

Algae are photosynthetic protists that carry out an estimated 50 to 60 percent of all photosynthesis on Earth. They differ from true plants in that their sex organs are unicellular and their zygote is not protected by parental tissue, whereas a plant zygote develops into a multicellular, parentally protected embryo. Algae show a remarkable range of growth forms: some are unicellular, others filamentous (composed of distinct cells or coenocytes, multinucleate structures lacking cross-walls), and still others, such as seaweeds, are multicellular with intricate branching or leaf-like extensions; a body not differentiated into true roots, stems and leaves, and lacking xylem and phloem, is called a thallus. All algae contain chlorophyll a and carotenoids, but different algal phyla also possess distinctive additional pigments such as xanthophylls and phycoerythrin, and classification of algae into phyla is based largely on this pigment composition. Except for the red algae (Rhodophyta), all algal phyla have flagellated, motile cell stages at some point in their life cycle. Almost all algae are aquatic, restricted when actively growing to damp or wet habitats such as oceans, freshwater bodies, hot springs, polar ice, and moist soil, trees or rocks.

Algae are classified into six major phyla based on pigments, form and locomotion: Euglenophyta (euglenoids, unicellular, two unequal flagella, chlorophyll a and b plus carotenoids), Pyrrophyta (dinoflagellates, unicellular, two flagella, chlorophyll a and c plus fucoxanthin), Chrysophyta (diatoms, usually unicellular, usually non-motile, chlorophyll a and c plus fucoxanthin), Phaeophyta (brown algae, multicellular, flagellated reproductive cells, chlorophyll a and c plus fucoxanthin), Rhodophyta (red algae, uni- or multicellular, non-motile, chlorophyll a plus phycoerythrin), and Chlorophyta (green algae, unicellular to multicellular, mostly flagellated, chlorophyll a and b plus carotenoids).

Euglenoids and Dinoflagellates

Euglenoids have historically been classified with both the plant kingdom (as algae) and the animal kingdom (as protozoans), and molecular data suggest they are closely related to zooflagellates; they are plant-like in their pigments, but some photosynthetic euglenoids lose their chlorophyll when grown in darkness and switch to heterotrophic feeding by ingesting organic matter, while other species are permanently colourless and heterotrophic.

Dinoflagellates are among the most unusual protist phyla; most are unicellular, and their cells are often covered with shells of interlocking, silicate-impregnated cellulose plates. Ecologically, dinoflagellates are among the most important producers in marine ecosystems, second only to diatoms, and are known for occasional population explosions or blooms that colour the water orange, red or brown, known as red tides.

Diatoms, Brown Algae and Red Algae

The cell wall of each diatom consists of two overlapping shells, fitting together like a petri dish, with silica deposited in intricate glasslike patterns. Diatoms are major producers in both marine and freshwater ecosystems because of their extremely large numbers, making them very important in aquatic food chains. Brown algae (Phaeophyta) include the giants of the protist kingdom; all are multicellular, ranging from a few centimetres to about 75 metres in length, with the largest, the kelps, being tough and leathery and possessing leaf-like blades,



stem-like stipes and root-like anchoring holdfasts. Brown algae are common in cooler marine waters, especially along rocky intertidal coastlines.

Red algae (Rhodophyta) commonly have a multicellular body made of complex, delicate, feathery, interwoven filaments, though a few are flattened sheets of cells; most attach to rocks or other substrates by a basal holdfast. Some red algae incorporate calcium carbonate into their cell walls and, together with coral animals, contribute to building coral reefs.

Green Algae and the Importance of Algae

Green algae (Chlorophyta) have pigments, energy-reserve products and cell walls essentially identical to those of true plants: they are photosynthetic, containing chlorophyll a, chlorophyll b and carotenoids in their chloroplasts, store energy mainly as starch, and mostly possess cellulose cell walls. Because of these similarities, and supporting evidence from RNA sequencing, it is generally accepted that land plants arose from ancestral green algae and that green algae and plants form a single monophyletic lineage. Green algae display diverse forms, from the unicellular *Chlamydomonas* and *Chlorella* (a non-motile, easily cultured freshwater alga used in photosynthesis research and studied as an alternate food source), to desmids, the colonial *Volvox*, filamentous *Spirogyra* and sheet-like *Ulva*.

Algae are of great economic and environmental importance: edible species such as kelps can help address world food shortages, marine algae are a source of useful substances such as algin, agar, carrageenan and antiseptics, and as major producers of the aquatic ecosystem, algae play a fundamental role in food chains, supplying both food and oxygen to other organisms.

Fungus-like Protists: Slime Molds and Water Molds

Some protists superficially resemble fungi, being non-photosynthetic and, in some cases, having bodies formed of thread-like hyphae; however, they differ fundamentally from true fungi, since many fungus-like protists possess centrioles and produce cellulose as a major cell-wall component, whereas fungi lack centrioles and have chitin cell walls. The two major groups of fungus-like protists are slime molds (Myxomycota) and water molds (Oomycetes). The feeding stage of a slime mold is a plasmodium, a slimy, multinucleate mass of cytoplasm that can grow up to about 30 cm in diameter, streaming over damp, decaying logs and leaf litter and ingesting bacteria, yeasts, spores and decaying organic matter as it creeps along. Under unfavourable conditions, a slime mold forms resistant haploid spores by meiosis within stalked structures called sporangia; when conditions improve, these spores germinate into biflagellated or amoeboid reproductive (swarm) cells, which unite to form a diploid zygote that develops into a new multinucleate plasmodium, each nucleus being diploid. *Physarum polycephalum*, a plasmodial slime mold, is a model organism widely used to study growth and differentiation, cytoplasmic streaming, and cytoskeletal function.

Water molds (Oomycetes) show close structural relationships to fungi but are now regarded as a more ancient group; their cell walls contain cellulose rather than chitin, and their hyphae are aseptate (lacking cross-walls). Oomycetes include several notorious pathogens, most famously *Phytophthora infestans*, the cause of late blight of potatoes and of the Irish potato famine of the 1840s. Several rainy, cool Irish summers in that decade allowed the



water mold to multiply unchecked, rotting potato tubers in the fields; since potatoes were the staple food of Irish peasants, between roughly 250,000 and over a million people starved to death, and the famine triggered mass emigration from Ireland to countries such as the United States.

Important Definitions

Term	Definition
Protist	A eukaryotic organism, usually unicellular or simple multicellular, that does not fit into the Plantae, Fungi or Animalia kingdoms.
Pseudopodia	Temporary, false-foot-like cytoplasmic projections used by amoebae for movement and feeding.
Cilia	Numerous short, hair-like structures on the surface of ciliates (e.g. Paramecium) that beat in coordination to produce movement.
Conjugation	A sexual process in ciliates in which two individuals temporarily join and exchange genetic material.
Thallus	A simple algal or fungal body not differentiated into true roots, stems and leaves, and lacking xylem and phloem.
Plasmodium (slime mold)	The feeding stage of a slime mold: a slimy, multinucleate mass of cytoplasm that streams over damp surfaces.
Sporangium	A stalked structure in which a slime mold produces resistant haploid spores by meiosis under unfavourable conditions.
Coenocyte	A multinucleate cytoplasmic structure, as in some filamentous algae, that lacks internal cross-walls.

Key Facts

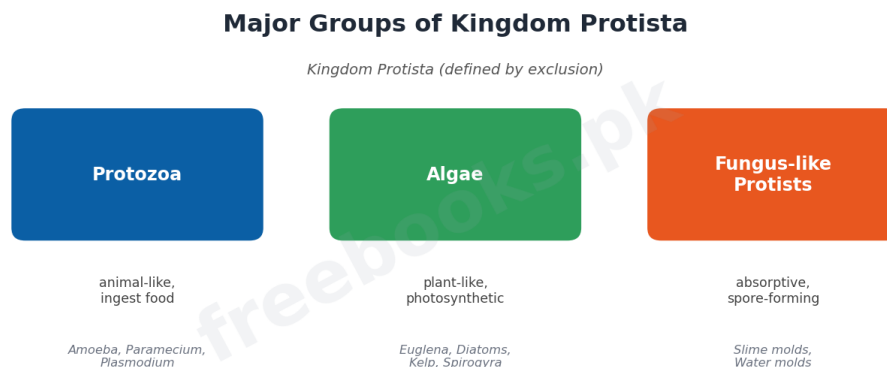
Item	Fact
Kingdom Protista proposed	Ernst Haeckel, 1866 (built on Hogg's 1861 "Protoctista").
Five Kingdom System	Robert Whittaker, 1969 - originally placed only unicellular eukaryotes in Protista.
Algae & global photosynthesis	Algae carry out about 50-60% of all photosynthesis on Earth.
Amoebic dysentery agent	Entamoeba histolytica (an amoeba).
Ciliate nuclei	Micronucleus (diploid, sexual reproduction) + Macronucleus (polyploid, metabolism/growth).
Malaria transmission	Plasmodium (Apicomplexa) via bite of infected female Anopheles mosquito.
Largest brown algae (kelps)	Can grow up to approx. 75 metres in length.



Item	Fact
Irish potato famine cause	Phytophthora infestans (water mold/Oomycete), 1840s Ireland.

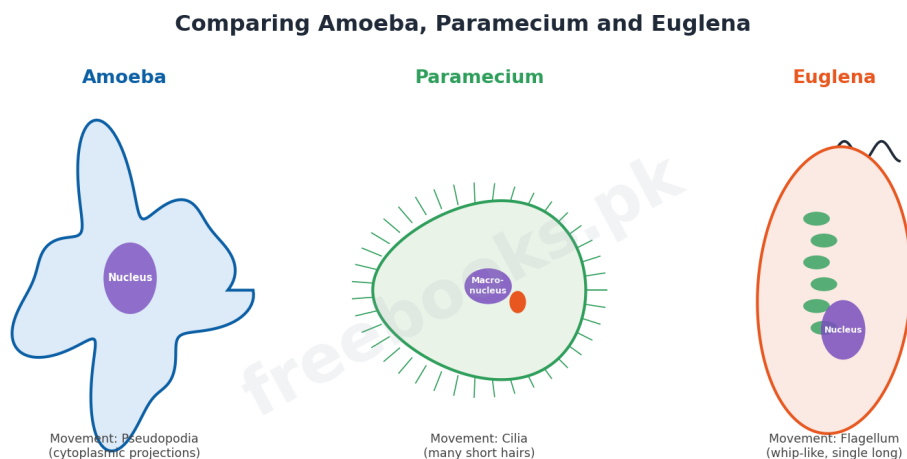
Diagrams & Illustrations

Major Groups of Kingdom Protista: an overview chart of the three major protist groups - Protozoa (animal-like), Algae (plant-like) and fungus-like protists - with representative examples of each.



Major Groups of Kingdom Protista

Comparing Amoeba, Paramecium and Euglena: a labelled comparison of three representative protists and their means of locomotion: Amoeba (pseudopodia), Paramecium (cilia) and Euglena (flagellum).



Comparing Amoeba, Paramecium and Euglena

The Six Phyla of Algae: a summary chart of the six algal phyla (Euglenophyta, Pyrrophyta, Chrysophyta, Phaeophyta, Rhodophyta, Chlorophyta) with their common names and key pigments.



The Six Phyla of Algae

Phylum	Common Name	Key Pigments
<i>Euglenophyta</i>	Euglenoids	Chl a, b + carotenoids
<i>Pyrrophyta</i>	Dinoflagellates	Chl a, c + fucoxanthin
<i>Chrysophyta</i>	Diatoms	Chl a, c + fucoxanthin
<i>Phaeophyta</i>	Brown algae	Chl a, c + fucoxanthin
<i>Rhodophyta</i>	Red algae	Chl a + phycoerythrin
<i>Chlorophyta</i>	Green algae	Chl a, b + carotenoids

The Six Phyla of Algae

Short Questions & Answers

Q1. What is a pseudopodium? Name an organism that uses it for movement.

Ans. A pseudopodium ("false foot") is a temporary cytoplasmic projection used for movement and feeding; Amoeba is a classic example of an organism that moves using pseudopodia.

Q2. Differentiate macronucleus and micronucleus in Paramecium.

Ans. The macronucleus is large and polyploid and controls cell metabolism and growth, while the micronucleus (or micronuclei) is small and diploid and functions in the sexual process of conjugation.

Q3. What is conjugation in ciliates?

Ans. Conjugation is a sexual process in which two ciliate individuals (e.g. Paramecium) come together temporarily and exchange genetic material through their micronuclei.

Q4. On what basis are algae classified into phyla?

Ans. Algae are classified into phyla largely on the basis of their pigment composition, along with differences in form and locomotion (e.g. flagellation).

Q5. What is a thallus?

Ans. A thallus is a simple plant/algal body that is not differentiated into true roots, stems and leaves and lacks vascular tissues (xylem and phloem).

Q6. Differentiate slime molds and water molds (oomycetes).

Ans. Slime molds (Myxomycota) form a multinucleate, creeping plasmodium and produce spores in stalked sporangia, while water molds (Oomycetes) have a hyphal, fungus-like structure with aseptate hyphae and cellulose (not chitin) cell walls, and include important plant pathogens such as *Phytophthora infestans*.



Long Questions & Answers

Q1: Discuss important features of protists. Why are protists so difficult to classify?

Kingdom Protista consists mainly of aquatic eukaryotic organisms showing enormous diversity in body form, reproduction, nutrition and lifestyle, which makes it difficult to give the kingdom a single positive definition; instead, it is essentially defined by exclusion, grouping organisms that do not belong to Plantae, Fungi or Animalia. All protists share a eukaryotic cell organization, distinguishing them from the prokaryotic kingdom Monera, but unlike plants and animals they do not develop from a blastula or embryo. The kingdom includes single-celled protozoans, unicellular and multicellular algae, and fungus-like slime molds and water molds — organisms as different in structure and lifestyle as Amoeba, giant kelp, and Plasmodium. Protists are difficult to classify because the other three eukaryotic kingdoms are believed to have evolutionarily arisen from various protist lineages, making it hard to draw sharp boundaries; because of this diversity, most biologists regard Protista as a polyphyletic group, probably not sharing a single common ancestor, with some biologists recognizing as many as 27 different phyla within it.

Q2: Describe protozoan diversity with reference to amoebae, zooflagellates, ciliates and apicomplexans.

Protozoa are unicellular, animal-like protists that mostly ingest food by endocytosis. Amoebae are free-living or parasitic organisms that lack flagella and move using pseudopodia; *Entamoeba histolytica*, an intestinal parasite, causes amoebic dysentery in humans. Zooflagellates are mostly unicellular organisms possessing one to many whip-like flagella for movement; examples include *Trichonympha*, which lives symbiotically in termite guts and helps digest wood, and *Trypanosoma*, which causes African sleeping sickness after transmission by the tsetse fly, while choanoflagellates are sessile, collared flagellates resembling sponge collar cells. Ciliates, such as *Paramecium*, are covered with numerous short cilia used for coordinated movement, and uniquely possess two types of nuclei — a diploid micronucleus for sexual reproduction (conjugation) and a polyploid macronucleus controlling metabolism and growth. Apicomplexans are parasitic protozoa lacking locomotory structures but capable of moving by flexing; *Plasmodium*, the apicomplexan that causes malaria, is transmitted by the female *Anopheles* mosquito and multiplies inside human liver cells and red blood cells, whose bursting produces the characteristic chills and fever of malaria. Foraminiferans and actinopods, closely related marine groups, produce calcium- or silica-based shells (tests) with pores for cytoplasmic projections that trap prey, and foraminiferan shells have historically formed vast limestone deposits.

Q3: Discuss the general characteristics of algae and describe their classification into six phyla.

Algae are photosynthetic protists responsible for an estimated 50-60% of all photosynthesis on Earth. They differ from true plants in having unicellular sex organs and an unprotected zygote, and they show a wide range of growth forms, from unicellular and filamentous



(including coenocytic) forms to large, complex multicellular bodies called thalli, which lack true roots, stems, leaves and vascular tissue. All algae contain chlorophyll a and carotenoids, but the presence of additional pigments differs between groups, and this pigment composition forms the main basis for classifying algae into six phyla: Euglenophyta (euglenoids, unicellular, two unequal flagella), Pyrrophyta (dinoflagellates, unicellular, two flagella, often armoured with cellulose plates), Chrysophyta (diatoms, mostly unicellular, glass-like silica shells), Phaeophyta (brown algae, multicellular, includes the giant kelps), Rhodophyta (red algae, uni- or multicellular, phycoerythrin pigment, contributors to coral reefs), and Chlorophyta (green algae, from unicellular *Chlamydomonas* to multicellular *Ulva*, considered ancestral to land plants). Almost all algae are aquatic, and except for the red algae, all have flagellated motile stages somewhere in their life cycle.

Q4: Green algae are considered ancestral organisms of green land plants. Discuss.

Green algae (Chlorophyta) are considered the ancestors of land plants because they share pigments, energy-reserve products and cell-wall composition that are essentially identical to those of true plants: both groups contain chlorophyll a and chlorophyll b along with carotenoids in their chloroplasts, both store surplus food mainly as starch, and both typically build their cell walls from cellulose. These shared biochemical and structural traits strongly suggest common ancestry rather than coincidence. This conclusion is further supported by molecular evidence: RNA sequencing data indicate that green algae and land plants form a single monophyletic lineage, meaning they share a common ancestor not shared by other algal groups. Because of this close relationship, green algae such as *Chlamydomonas*, desmids, *Volvox*, *Spirogyra* and *Ulva* are studied as useful models for understanding the evolutionary origins of the plant kingdom.

Q5: What features distinguish oomycetes from fungi? Describe the structure and reproduction of slime molds.

Although water molds (Oomycetes) superficially resemble true fungi in having hyphal, thread-like bodies and a non-photosynthetic lifestyle, several features distinguish them: oomycete cell walls are made of cellulose rather than the chitin found in fungal cell walls, oomycetes possess centrioles (which fungi lack), and their hyphae are aseptate, lacking the cross-walls found in most fungal hyphae. Oomycetes are now regarded as a more ancient group than true fungi and include notable plant pathogens such as *Phytophthora infestans*, which causes late blight of potatoes and was responsible for the devastating Irish potato famine of the 1840s. Slime molds (Myxomycota), the other major group of fungus-like protists, exist in a feeding stage called a plasmodium: a slimy, multinucleate mass of cytoplasm, sometimes growing up to 30 cm across, that streams over damp, decaying organic matter such as logs and leaf litter, ingesting bacteria, yeasts and spores as it moves. Under unfavourable conditions, the plasmodium forms resistant haploid spores through meiosis inside stalked sporangia; when favourable conditions return, these spores germinate into biflagellated or amoeboid swarm cells, which fuse to form a diploid zygote that develops into a new multinucleate plasmodium in which every nucleus is diploid. The model organism



Physarum polycephalum, a plasmodial slime mold, has been widely used to study cell growth, differentiation, cytoplasmic streaming and cytoskeletal function.

MCQs with Answers

1. Kingdom Protista was proposed by:

(a) John Hogg (b) Ernst Haeckel (c) Herbert Copeland (d) Robert Whittaker

Correct Answer: (b) Ernst Haeckel. Ernst Haeckel proposed Kingdom Protista in 1866, building on Hogg's earlier "Protoctista" concept.

2. Amoeba moves using:

(a) cilia (b) flagella (c) pseudopodia (d) setae

Correct Answer: (c) pseudopodia. Amoebae lack flagella and cilia; they move using cytoplasmic projections called pseudopodia.

3. Entamoeba histolytica causes:

(a) malaria (b) sleeping sickness (c) amoebic dysentery (d) late blight of potato

Correct Answer: (c) amoebic dysentery. Entamoeba histolytica is an intestinal parasite that causes amoebic dysentery in humans.

4. Malaria in humans is caused by:

(a) Trypanosoma (b) Plasmodium (c) Paramecium (d) Euglena

Correct Answer: (b) Plasmodium. Plasmodium, an apicomplexan protozoan, causes malaria and is transmitted by the female Anopheles mosquito.

5. In Paramecium, cell metabolism and growth are controlled by the:

(a) micronucleus (b) macronucleus (c) nucleolus (d) contractile vacuole

Correct Answer: (b) macronucleus. The large, polyploid macronucleus controls metabolism and growth, while the micronucleus is involved in sexual reproduction.

6. Algae are estimated to carry out what percentage of Earth's total photosynthesis?

(a) 10-20% (b) 30-40% (c) 50-60% (d) 80-90%

Correct Answer: (c) 50-60%. Algae are estimated to carry out about 50 to 60 percent of all photosynthesis on Earth.

7. Which algal phylum is exceptional in lacking flagellated motile cells in its life cycle?

(a) Chlorophyta (b) Phaeophyta (c) Rhodophyta (d) Pyrrophyta

Correct Answer: (c) Rhodophyta. Rhodophyta (red algae) is the one algal phylum in which flagellated motile stages are absent.

8. The largest protists, the kelps, belong to the phylum:

(a) Chrysophyta (b) Phaeophyta (c) Rhodophyta (d) Euglenophyta

Correct Answer: (b) Phaeophyta. Kelps are giant brown algae, belonging to phylum Phaeophyta, reaching up to about 75 metres in length.

9. The Irish potato famine of the 1840s was caused by:

(a) Plasmodium falciparum (b) Phytophthora infestans (c) Entamoeba histolytica (d) Trypanosoma brucei



Correct Answer: (b) Phytophthora infestans. Phytophthora infestans, a water mold (oomycete), caused late blight of potatoes and the Irish potato famine.

10. The feeding stage of a slime mold is called a:

(a) hypha (b) mycelium (c) plasmodium (d) thallus

Correct Answer: (c) plasmodium. The feeding stage of a slime mold is a multinucleate, creeping mass of cytoplasm called a plasmodium.

Quick Revision Summary

- Kingdom Protista is defined by exclusion; historical development: Hogg (1861) -> Haeckel (1866) -> Copeland (1938) -> Whittaker (1969) -> Margulis & Schwartz (1988). Mostly polyphyletic, aquatic, eukaryotic.
- Protozoa (animal-like): Amoebae (pseudopodia, Entamoeba histolytica), Zooflagellates (flagella, Trypanosoma, Trichonympha, choanoflagellates), Ciliates (cilia, macro+micronucleus, conjugation, Paramecium), Foraminifera/Actinopods (shells/tests), Apicomplexans (Plasmodium, malaria).
- Algae (plant-like): 50-60% of Earth's photosynthesis; classified into 6 phyla by pigment: Euglenophyta, Pyrrophyta (dinoflagellates), Chrysophyta (diatoms), Phaeophyta (brown algae/kelps), Rhodophyta (red algae), Chlorophyta (green algae, ancestor of land plants).
- Thallus = undifferentiated algal/plant body, no true roots/stems/leaves, no xylem/phloem. Coenocyte = multinucleate structure without cross-walls.
- Fungus-like protists: Slime molds (Myxomycota - plasmodium, sporangia, spores) and Water molds (Oomycetes - cellulose walls, aseptate hyphae, e.g. Phytophthora infestans, Irish potato famine).
- Algae economic importance: food (kelps), algin, agar, carrageenan, antiseptics; ecological importance: major aquatic producers, food chains, oxygen. Notes by freebooks.pk.

Exam Tips

- Remember Kingdom Protista is defined by exclusion — learn the historical sequence of scientists (Hogg, Haeckel, Copeland, Whittaker, Margulis & Schwartz) in order.
- Learn the 3 major protist groups (Protozoa, Algae, Fungus-like) with at least 2 examples each — a common short-question format.
- Memorise the 6 algal phyla with their common names and one distinguishing pigment/feature each.
- Be ready to compare macronucleus vs micronucleus, and slime molds vs water molds — classic "differentiate" questions.
- Know the Plasmodium malaria life cycle steps and the Phytophthora infestans/Irish potato famine story — frequently asked extensive questions.
- Practise linking green algae's shared traits with plants (pigments, starch storage, cellulose walls) to the "ancestor of land plants" argument.



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CHAPTER 8

Fungi

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Fungi, the Kingdom of Recyclers, from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Around 100,000 species of fungi are known, ranging from disastrous plant pathogens (rusts, smuts, molds) to prized delicacies (mushrooms, truffles, morels) and organisms of enormous commercial value such as *Penicillium* and yeasts. These notes are prepared by freebooks.pk.

The chapter explains why fungi occupy their own kingdom, separate from plants and animals, and works through the structure of the fungal body (mycelium and hyphae), fungal nutrition (saprotrophic, parasitic and predatory), the two key mutualistic associations of fungi (lichens and mycorrhizae), asexual and sexual reproduction, the classification of fungi into four major phyla, their adaptations to terrestrial life, and their far-reaching ecological and commercial importance.

Learning Objectives

- Discuss the taxonomic status of fungi and explain why they form a separate kingdom.
- Describe the fungal body plan: mycelium, hyphae, septate and coenocytic hyphae.
- Describe the modes of nutrition in fungi: saprotrophic, parasitic and predatory.
- Describe lichens and mycorrhizae as key mutualistic associations of fungi.
- Describe asexual reproduction (spores, conidia, fragmentation, budding) and sexual reproduction in fungi.
- Classify fungi into Zygomycota, Ascomycota, Basidiomycota and Deuteromycota with examples.
- Describe the land adaptations of fungi and their ecological and commercial importance.

Key Concepts

Taxonomic Status and Body Plan of Fungi

Approximately 100,000 species of fungi are known, and many more are estimated to exist; the group includes notorious pathogens such as rusts, smuts and molds, prized delicacies such as mushrooms, truffles and morels, and organisms of great commercial value such as *Penicillium* (source of the antibiotic penicillin) and yeasts (used in bakeries and breweries). The taxonomic status of fungi has changed from being treated as a group within the plant kingdom to forming their own separate kingdom, Fungi. Fungi resemble plants in having a cell wall, lacking centrioles, and being non-motile, but resemble animals more closely in being heterotrophic; unlike plants, fungi lack cellulose in their cell wall and instead contain chitin, the same chemical found in the external skeleton of arthropods, leading some mycologists to suspect fungi and animals share a common ancestor. However, fungi differ from animals too, being absorptive heterotrophs, non-motile, and possessing a cell wall; their DNA studies confirm they are distinct from plants, animals and protists, and they show a characteristic form of mitosis called nuclear mitosis, in which the nuclear envelope does not



break down but instead the mitotic spindle forms within the nucleus and the nuclear membrane constricts between the two clusters of daughter chromosomes.

The body of a fungus, called the mycelium, consists of long, slender, branched, thread-like filaments called hyphae (singular hypha), which spread extensively over the substratum's surface; their chitin walls resist decay better than the cellulose and lignin of plant cell walls. Hyphae may be septate, divided into individual cells by cross-walls called septa (which often have pores allowing cytoplasm to flow between cells), or non-septate (coenocytic), forming a single, elongated, multinucleated cell in which cytoplasm flows freely, distributing materials throughout. All parts of a growing fungus are metabolically active, and its extensive hyphal network provides an enormous surface area for absorption; hyphae may organize into complex reproductive structures such as mushrooms, puffballs and morels. Yeasts are unusual, non-hyphal, unicellular fungi. Fungal nuclei are haploid except for the transient diploid zygote formed during sexual reproduction; a single mycelium can produce up to a kilometre of new hyphae in a single day, and a circular clone of the pathogenic fungus *Armillaria* has been measured covering up to 15 hectares, making it a contender for the world's largest organism.

Nutrition in Fungi: Saprotrophs, Parasites and Predators

All fungi lack chlorophyll and are heterotrophs, obtaining food by direct absorption from their environment — hence they are called absorptive heterotrophs. Most fungi are saprotrophs (saprobes), decomposers that obtain food directly from dead organic matter by secreting digestive enzymes that break it down externally, after which the resulting organic molecules are absorbed back into the fungus; saprobic fungi anchor to the substrate using modified hyphae called rhizoids. Fungi are the principal decomposers of cellulose and lignin, the main components of plant cell walls, which most bacteria cannot break down, making saprobic fungi (alongside bacteria) major decomposers in the biosphere and central to nutrient recycling.

Some fungi are parasites, obtaining nutrients directly from a living host's cytoplasm using specialized hyphal tips called haustoria; these may be obligate parasites (which can grow only on a living host, such as most mildews and rusts) or facultative parasites (which can also grow on artificial culture media). Some fungi are active predators: the oyster mushroom (*Pleurotus ostreatus*) paralyzes and digests nematodes to obtain nitrogen while also breaking down wood for glucose, and species of *Arthrobotrys* trap soil nematodes using constricting hyphal rings before invading and digesting them.

Mutualistic Associations: Lichens and Mycorrhizae

Fungi form two key mutualistic symbiotic associations of benefit to both partners: lichens and mycorrhizae. Lichens are mutualistic associations between certain fungi (mostly Ascomycetes and imperfect fungi, with a few Basidiomycetes) and photoautotrophic partners — green algae, cyanobacteria, or sometimes both. Most of the visible lichen body is fungal tissue, with the algal partner living within the hyphae; the fungus protects the alga from strong light and desiccation, while the fungus obtains food from the alga's photosynthesis. Lichens can colonize harsh places, such as bare rocks, where neither partner could survive



alone, and are ecologically important as bioindicators of air pollution because of their high sensitivity to it.

Mycorrhizae are mutualistic associations between certain fungi and the roots of vascular plants, present in about 95% of all vascular plant species. Fungal hyphae dramatically increase the root's soil contact and absorptive surface area, helping the plant absorb phosphorus, zinc, copper and other nutrients, while the plant supplies organic carbon to the fungus; plants with this association typically grow better than those without it. There are two main types: endomycorrhizae, in which fungal hyphae penetrate the outer root cells, forming coils, swellings and minute branches while also extending into the surrounding soil, and ectomycorrhizae, in which hyphae surround and extend between root cells without penetrating their walls, commonly found in association with pines and firs.

Asexual Reproduction in Fungi

Most fungi (except imperfect fungi, in which sexual reproduction has never been observed) reproduce both asexually and sexually. Asexual reproduction occurs by spores, conidia, fragmentation, and budding. Spores are produced inside reproductive structures called sporangia, cut off from the hyphae by complete septa; they are haploid, non-motile, do not require water for dispersal, and are produced in enormous numbers, allowing wide dispersal by wind and causing the wide distribution of many fungi, including plant pathogens — when spores land in a suitable location, they germinate into new fungal hyphae. Conidia (singular conidium) are non-motile asexual spores cut off at the ends of modified hyphae called conidiophores, rather than inside sporangia, typically in chains or clusters; they may be produced in huge numbers, survive for weeks, and rapidly colonize new food sources.

Fragmentation is the simple breaking of a hyphal fungus's mycelium, with each fragment able to grow into a new mycelium. Unicellular yeasts reproduce asexually by budding, an asymmetric division producing a small outgrowth (bud) that may separate and grow into a new cell, or by simple, roughly equal cell division.

Sexual Reproduction in Fungi

Details of sexual reproduction vary among fungal groups, but the fusion of haploid nuclei followed by meiosis is common to all. During sexual reproduction, hyphae of two genetically different but compatible mating types come together, their cytoplasm fuses (plasmogamy), and this is eventually followed by fusion of the nuclei (karyogamy). In two of the three main sexually reproducing groups (Basidiomycetes and Ascomycetes), karyogamy does not occur immediately after plasmogamy; instead, the two genetically distinct haploid nuclei may coexist and divide together within the same hyphae for most of the fungus's life, producing a dikaryotic (or heterokaryotic) hypha or cell containing two nuclei of different genetic types.

Different fungal groups produce distinctive types of haploid sexual spores, such as basidiospores and ascospores, following meiosis in the zygote; these spores are typically produced within or upon characteristic fruiting bodies or structures, such as basidia/basidiocarps and asci/ascocarps.



Classification of Fungi: Four Major Phyla

Fungi are classified into four main phyla, based primarily on their sexual reproductive structures and methods of reproduction, though hyphal type and other characters also differ between the groups. In Zygomycota (Zygomycetes, or conjugating fungi), such as *Rhizopus* (black bread mold), the fusion of hyphae directly forms a temporary, dormant, thick-walled resistant zygospore; meiosis occurs on germination, producing haploid spores, and hyphae are coenocytic. Ascomycota (Ascomycetes or sac fungi) is the largest group, with over 60,000 species including yeasts, morels, truffles and powdery mildews; they produce haploid ascospores by meiosis inside sac-like structures called asci (typically 8 ascospores per ascus), often within macroscopic fruiting bodies called ascocarps, have septate hyphae with a lengthy dikaryotic phase, and reproduce asexually via wind-dispersed conidia. Yeasts, mostly Ascomycetes, are unicellular fungi that mainly reproduce asexually by budding but can also reproduce sexually; they ferment glucose to ethanol and carbon dioxide, giving them major economic importance, with *Saccharomyces cerevisiae* the most widely exploited species.

Basidiomycota (Basidiomycetes or club fungi) includes edible mushrooms, plant-pathogenic rusts and smuts, puffballs, and bracket fungi; they are named for their club-shaped sexual structure, the basidium, where nuclear fusion is followed by meiosis, producing four haploid basidiospores borne externally on each basidium. Their hyphae are septate, uninucleate during part of the life cycle and dikaryotic for the remaining, lengthy phase, with visible mushrooms formed entirely of dikaryotic mycelium; *Puccinia* species are common rust fungi (named for rusty, orange-red disease spots) and *Ustilago* species are common smut fungi (named for their black, sooty spore masses that replace grain kernels in crops like wheat). Deuteromycota (Deuteromycetes or imperfect fungi) is a heterogeneous group in which no sexual phase has ever been observed; most are related to Ascomycetes, though some resemble Zygomycota or Basidiomycota, and if sexual structures are later discovered in an imperfect fungus, it is reassigned to the appropriate phylum. Important genera include *Penicillium* (blue/green molds, reproducing via conidia in chains on branched conidiophores) and *Aspergillus*; despite lacking sexual reproduction, imperfect fungi can still exchange genetic material through a process called parasexuality.

Land Adaptations of Fungi

Although fungi grow best in moist habitats, they are found wherever organic matter is present, making them a highly successful group of land organisms. Their extensive, fast-spreading hyphal system penetrates the substrate and dramatically increases contact area for absorption, with cytoplasmic flow throughout the hyphae driving rapid growth and spread; their chitin-reinforced hyphal walls resist decay better than the cellulose and lignin of plant walls, and fungi can even break down lignin to obtain nutrients. Rhizoids anchor saprobic fungi to the substrate while also digesting and absorbing food.

Fungi are well adapted to land life due to their lack of flagellated cells, their efficient wind dispersal of non-motile spores and conidia, and thick-walled zygotes and other resistant structures; some hyphae are modified to allow reproduction without dependence on external water. Many fungi tolerate hyperosmotic conditions (such as concentrated salt or sugar



solutions in jams and jellies) and a wide pH and temperature range (roughly 2-9 pH; from below freezing to 50 degrees Celsius or more) better than bacteria — which is why molds such as *Penicillium* can grow on refrigerated oranges and jelly while bacteria generally cannot.

Importance of Fungi: Ecological and Commercial

Ecologically, fungi are vital decomposers and symbionts: alongside saprobic bacteria, they recycle inorganic nutrients through the ecosystem, without which essential nutrients would remain locked in dead organic matter and life would cease. Mycorrhizal fungi improve plant growth in about 95% of vascular plant species, lichens growing on rocks help break them down, contributing to ecological succession, lichens serve as sensitive bioindicators of air quality, and some fungi are used for bioremediation of environmental pollutants.

Commercially, fungi provide major economic gains: edible fungi include roughly 200 species of mushrooms, morels and truffles (though poisonous toadstools such as *Amanita* and jack-o'-lantern mushrooms must be avoided); yeasts are used in baking and brewing due to their fermenting ability, while *Penicillium* and *Aspergillus* species flavour cheeses and ferment soy products; fungi are also a source of drugs, including penicillin (discovered by Alexander Fleming in 1928 from *Penicillium notatum*), lovastatin, cyclosporine, and ergotine; and yeasts are heavily used in genetic research (the first eukaryote to have its genome fully sequenced, in 1996, was *Saccharomyces cerevisiae*). However, fungi also cause serious economic losses: plant diseases such as rusts, smuts, powdery mildews and root rots destroy crops; animal and human diseases such as ringworm, athlete's foot, candidiasis, histoplasmosis and aspergillosis are caused by various fungi; and saprobic fungi damage stored food, wood, fibre and leather, with 15-50% of the world's fruit lost annually to fungal attack, while some *Aspergillus* strains produce highly carcinogenic aflatoxins in improperly stored grain.

Important Definitions

Term	Definition
Mycelium	The body of a fungus, made up of a network of long, branched, thread-like filaments called hyphae.
Hypha	A single thread-like filament of fungal tissue; many hyphae together form the mycelium.
Septum	A cross-wall dividing a fungal hypha into individual cells; septa often have pores allowing cytoplasm to flow between cells.
Coenocytic hyphae	Non-septate hyphae forming a single, elongated, multinucleated cell without internal cross-walls.
Rhizoid	A modified, root-like hypha that anchors a saprobic fungus to its substrate and helps absorb digested food.
Dikaryotic (cell/hypha)	A fungal cell or hypha containing two genetically different haploid nuclei that coexist without immediately fusing.



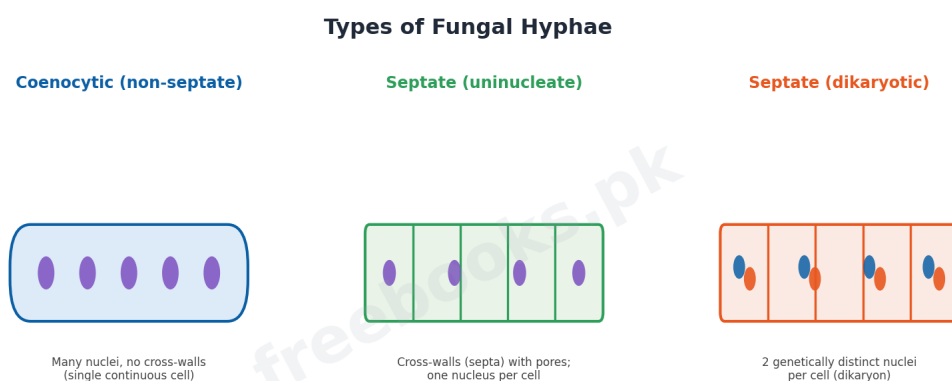
Term	Definition
Mycorrhizae	Mutualistic associations between certain fungi and the roots of vascular plants that aid nutrient and water absorption.
Ascus	A sac-like reproductive structure in Ascomycetes in which meiosis produces (typically 8) haploid ascospores.

Key Facts

Item	Fact
Known fungal species	Approximately 100,000 species described; many more estimated to exist.
Fungal cell wall	Chitin (not cellulose); shows nuclear mitosis (nuclear envelope does not fully break down).
Penicillin discovery	Alexander Fleming, 1928, from <i>Penicillium notatum</i> .
Four fungal phyla	Zygomycota, Ascomycota, Basidiomycota, Deuteromycota (Imperfect Fungi).
Ascomycota	Largest fungal group, 60,000+ species; ~8 ascospores per ascus.
Basidiomycota	4 basidiospores borne externally on each club-shaped basidium.
Mycorrhizae prevalence	Found in about 95% of all kinds of vascular plants.
Yeast genome milestone	<i>Saccharomyces cerevisiae</i> - first eukaryote with a fully sequenced genome (1996).

Diagrams & Illustrations

Types of Fungal Hyphae: a comparison of the three main hyphal types found in fungi - coenocytic (non-septate, multinucleate), septate uninucleate, and septate dikaryotic (with two genetically distinct nuclei per cell).

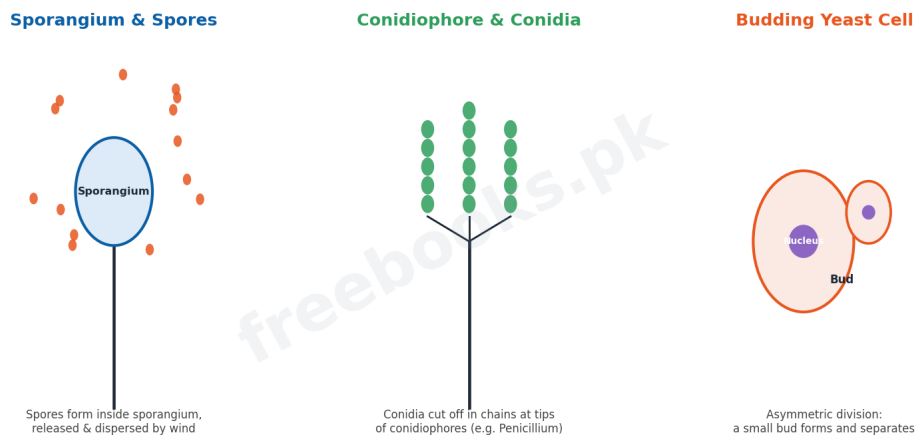


Types of Fungal Hyphae



Asexual Reproductive Structures in Fungi: a labelled comparison of three asexual reproduction structures in fungi - a sporangium releasing spores, a conidiophore bearing chains of conidia, and a budding yeast cell.

Asexual Reproductive Structures in Fungi



Asexual Reproductive Structures in Fungi

Classification of Fungi into Four Phyla: a summary chart of the four fungal phyla - Zygomycota, Ascomycota, Basidiomycota and Deuteromycota - with their sexual spore type and a typical example.

Classification of Fungi into Four Phyla

Phylum	Sexual Spores	Typical Example
Zygomycota	Zygospores	<i>Rhizopus</i>
Ascomycota	Ascospores (in asci)	Yeasts, morels
Basidiomycota	Basidiospores (on basidia)	Mushrooms, rusts
Deuteromycota	None observed	<i>Penicillium</i> , <i>Aspergillus</i>

Classification of Fungi into Four Phyla

Short Questions & Answers

Q1. What is a hypha? What is the advantage of having incomplete (porous) septa?

Ans. A hypha is a single, thread-like filament of fungal tissue that makes up the mycelium. Incomplete (porous) septa allow cytoplasm and nutrients to flow freely from cell to cell along the hypha, enabling rapid growth toward food and water when conditions are favourable.

Q2. What is the composition of the fungal cell wall, and how is this advantageous to fungi?

Ans. The fungal cell wall is composed mainly of chitin, the same tough polysaccharide found in the exoskeleton of arthropods; chitin is more resistant to decay than the cellulose and



lignin of plant cell walls, helping protect fungal hyphae as they grow through and digest organic substrates.

Q3. To which phylum do yeasts mostly belong? How do they differ from other fungi?

Ans. Most yeasts belong to Ascomycota, though yeasts are also found among Basidiomycota. Unlike most fungi, yeasts are unicellular and non-hyphal, and they typically reproduce asexually by budding rather than forming an extensive mycelium.

Q4. What are mycorrhizae?

Ans. Mycorrhizae are mutualistic associations between certain fungi and the roots of vascular plants, in which the fungus improves the plant's absorption of water and nutrients like phosphorus and zinc, while the plant supplies the fungus with organic carbon; about 95% of vascular plants form this association.

Q5. Differentiate ascus and basidium.

Ans. An ascus is a sac-like structure in Ascomycetes in which meiosis produces haploid ascospores (typically 8) enclosed within it, whereas a basidium is a club-shaped structure in Basidiomycetes on which four haploid basidiospores are borne externally, not enclosed.

Q6. Why is green mold more likely to contaminate a refrigerated orange than bacteria are?

Ans. Fungi such as *Penicillium* tolerate a wider range of temperature (including cold, refrigerator-level temperatures) and higher osmotic pressure than most bacteria, allowing molds to grow on refrigerated food where bacterial growth is inhibited.

Long Questions & Answers

Q1: Discuss the taxonomic status of fungi.

Fungi were once classified as a group within the plant kingdom because, like plants, they possess a cell wall, lack centrioles, and are non-motile. However, unlike plants, fungi are heterotrophic, lack chlorophyll, and their cell walls are made of chitin rather than cellulose, a compound also found in the exoskeletons of arthropods; this chitin composition, along with certain similarities in metabolism, has led some mycologists to hypothesize that fungi and animals may share a common ancestor. Yet fungi also differ clearly from animals: they possess a cell wall, are absorptive rather than ingestive heterotrophs, and are non-motile throughout their life cycle. Molecular (DNA) studies further confirm that fungi are genetically distinct from plants, animals and protists. Fungi additionally exhibit a unique form of cell division called nuclear mitosis, in which the nuclear envelope does not break down as it does in typical eukaryotic mitosis; instead, the mitotic spindle forms inside the nucleus, and the nuclear membrane constricts between the separating groups of chromosomes. Because of this combination of unique structural, biochemical, and genetic characteristics, fungi are now recognized as a wholly separate kingdom, Fungi, distinct from Plantae, Animalia and Protista.



Q2: Summarize the differentiating characteristics of the four main groups of fungi, giving two examples of each.

Fungi are classified into four phyla based mainly on their sexual reproductive structures. Zygomycota (Zygomycetes), such as *Rhizopus* (black bread mold) and *Pilobolus*, have coenocytic (non-septate) hyphae and reproduce sexually by forming a thick-walled resting zygospore directly from fused hyphae, with asexual non-motile spores formed in sporangia. Ascomycota (Ascomycetes or sac fungi), such as yeasts and morels, have septate hyphae with a lengthy dikaryotic phase, produce haploid ascospores (typically 8 per ascus) inside sac-like asci often within visible ascocarps, and reproduce asexually via conidia cut off from conidiophores. Basidiomycota (Basidiomycetes or club fungi), such as mushrooms and rust or smut fungi (e.g. *Puccinia*, *Ustilago*), also have septate hyphae with a long dikaryotic phase, and bear four haploid basidiospores externally on club-shaped basidia following nuclear fusion and meiosis, with asexual reproduction being uncommon in this group. Deuteromycota (Deuteromycetes or imperfect fungi), such as *Penicillium* and *Aspergillus*, show no observed sexual phase and reproduce only by conidia; if sexual structures are ever discovered in one of these fungi, it is reclassified into the appropriate phylum, and modern DNA sequencing now allows most imperfect fungi to be classified even without any sexual structures being found.

Q3: State the various features of fungi that adapt them to a terrestrial mode of life.

Fungi possess several structural and reproductive features that suit them to life on land. Their extensive, fast-spreading system of hyphae penetrates the substrate and dramatically increases the surface area available for absorption, while continuous cytoplasmic flow through the hyphae supports their rapid growth and spread. Their hyphal walls, reinforced with chitin, resist decay far better than the cellulose and lignin found in plant cell walls, and fungi can even break down lignin itself to obtain nutrients; modified hyphae called rhizoids anchor saprobic fungi to their substrate while simultaneously digesting and absorbing food. Fungi lack flagellated cells at any stage, and instead rely on non-motile spores and conidia that are efficiently dispersed over long distances by wind, along with thick-walled, resistant zygotes and other dormant structures that allow them to survive unfavourable periods; some hyphae are modified so that reproduction does not depend on external water. Fungi are also generally more tolerant than bacteria of hyperosmotic conditions, such as the concentrated sugar or salt found in jams and jellies, and can survive a wide range of temperature, from several degrees below freezing to 50 degrees Celsius or more, which is why molds like *Penicillium* can grow even on refrigerated food.

Q4: Discuss the ecological importance of saprotrophic fungi, lichens and mycorrhizae.

Saprotrophic fungi are, alongside bacteria, the principal decomposers in the biosphere; they break down dead organic matter, including cellulose and lignin that most bacteria cannot digest, recycling carbon, nitrogen, phosphorus and other essential nutrients back into the ecosystem. Without this decomposing activity, nutrients would remain locked up in dead



plant and animal material, becoming unavailable to living organisms, and ecosystems would eventually collapse. Lichens, mutualistic associations of fungi with algae or cyanobacteria, are ecologically significant as pioneer organisms: growing on bare rock, they gradually break it down, helping initiate ecological succession in barren habitats; because lichens are extremely sensitive to atmospheric pollutants, they are also widely used as bioindicators of air quality. Mycorrhizae, mutualistic associations between fungi and the roots of about 95% of vascular plant species, dramatically increase the root surface area available for absorbing water and minerals such as phosphorus, zinc and copper from the soil, resulting in markedly improved plant growth compared to plants lacking this association, while the fungus in turn receives organic carbon from its plant partner.

Q5: Fungal enzymes are useful on one hand and harmful on the other. Discuss.

Fungi secrete powerful extracellular enzymes capable of breaking down cellulose, lignin, and even cutin, and these enzymes underlie both fungi's great benefits and their significant harms. On the beneficial side, these enzymes allow saprotrophic fungi to decompose dead organic matter, recycling nutrients through ecosystems; fermenting enzymes in yeasts convert glucose to ethanol and carbon dioxide, underpinning the baking and brewing industries, while other fungal enzymes are exploited to flavour cheeses, ferment soy sauce and soy paste, and produce citric acid. Fungal enzymes and metabolic products are also the source of important drugs, including the antibiotic penicillin (from *Penicillium notatum*), the cholesterol-lowering drug lovastatin, the immunosuppressant cyclosporine, and ergotamine used for migraine relief. On the harmful side, the very same class of digestive enzymes allows fungi to attack living plants, breaking down cellulose, lignin and cutin in crop tissues and causing devastating diseases such as rusts, smuts, powdery mildews and root rots, historically contributing to famine and mass displacement of people. Saprotrophic enzymes that are ecologically beneficial in nature become economically damaging when they degrade stored food, timber, fibre and leather, destroying an estimated 15-50% of the world's fruit harvest each year, while some fungal enzymes and metabolic byproducts, such as the aflatoxins produced by certain *Aspergillus* strains on improperly stored grain, are highly carcinogenic and pose serious health risks.

MCQs with Answers

1. The fungal cell wall is primarily composed of:

(a) cellulose (b) chitin (c) lignin (d) peptidoglycan

Correct Answer: (b) chitin. Fungal cell walls are made mainly of chitin, unlike plant cell walls, which contain cellulose.

2. The characteristic type of mitosis seen in fungi, in which the nuclear envelope does not fully break down, is called:

(a) meiosis (b) amitosis (c) nuclear mitosis (d) binary fission

Correct Answer: (c) nuclear mitosis. Fungi show nuclear mitosis, in which the spindle forms inside the nucleus and the envelope constricts rather than disappearing.

3. Penicillin was first discovered in 1928 by:



(a) Robert Koch (b) Alexander Fleming (c) Louis Pasteur (d) Anton van Leeuwenhoek

Correct Answer: (b) Alexander Fleming. Alexander Fleming discovered penicillin in 1928 from the fungus *Penicillium notatum*.

4. Ascospores are produced inside a sac-like structure called the:

(a) basidium (b) ascus (c) conidium (d) sporangium

Correct Answer: (b) ascus. Ascospores (usually 8 per structure) are produced by meiosis inside a sac-like ascus in Ascomycetes.

5. A club-shaped structure that bears basidiospores externally is called a:

(a) ascus (b) conidiophore (c) basidium (d) zygosporangium

Correct Answer: (c) basidium. The basidium is the club-shaped sexual reproductive structure of Basidiomycetes, bearing basidiospores externally.

6. Rhizopus, the black bread mold, belongs to the phylum:

(a) Ascomycota (b) Basidiomycota (c) Zygomycota (d) Deuteromycota

Correct Answer: (c) Zygomycota. *Rhizopus* is a classic Zygomycete, forming a resistant zygosporangium from fused hyphae.

7. Fungi in which no sexual reproductive phase has ever been observed are grouped as:

(a) Zygomycota (b) Ascomycota (c) Basidiomycota (d) Deuteromycota

Correct Answer: (d) Deuteromycota. Deuteromycota (imperfect fungi) is a heterogeneous group lacking any observed sexual phase.

8. Mycorrhizae are mutualistic associations between fungi and:

(a) algae (b) cyanobacteria (c) roots of vascular plants (d) arthropod exoskeletons

Correct Answer: (c) roots of vascular plants. Mycorrhizae form between certain fungi and the roots of about 95% of vascular plant species.

9. A lichen is a mutualistic association between a fungus and:

(a) a green alga and/or cyanobacterium (b) a vascular plant root (c) an arthropod (d) a protozoan

Correct Answer: (a) a green alga and/or cyanobacterium. Lichens are associations between a fungus and a photoautotroph - a green alga, a cyanobacterium, or both.

10. Aflatoxins, highly carcinogenic mycotoxins found in improperly stored grain, are produced by:

(a) *Penicillium* (b) *Aspergillus* (c) *Rhizopus* (d) *Saccharomyces*

Correct Answer: (b) Aspergillus. Certain strains of *Aspergillus* produce aflatoxins, among the most carcinogenic mycotoxins known.

Quick Revision Summary

- Fungi = separate kingdom: heterotrophic, chitin cell wall, non-motile, nuclear mitosis; ~100,000 known species.
- Body = mycelium (network of hyphae); hyphae may be septate (with pores) or coenocytic (non-septate, multinucleate); dikaryotic cells have 2 genetically distinct nuclei.



- Nutrition: saprotrophic (decomposers, rhizoids), parasitic (obligate/facultative, haustoria), predatory (e.g. Arthrobotrys traps nematodes).
- Mutualisms: Lichens (fungus + alga/cyanobacterium, bioindicators) and Mycorrhizae (fungus + plant roots, ~95% of vascular plants; endo- vs ecto-mycorrhizae).
- Reproduction: Asexual (spores in sporangia, conidia on conidiophores, fragmentation, budding); Sexual (plasmogamy -> [dikaryotic stage] -> karyogamy -> meiosis -> ascospores/basidiospores).
- 4 Phyla: Zygomycota (zygospores, coenocytic, e.g. Rhizopus), Ascomycota (ascospores in asci, e.g. yeasts, morels), Basidiomycota (basidiospores on basidia, e.g. mushrooms, rusts, smuts), Deuteromycota (no sexual phase, e.g. Penicillium, Aspergillus).
- Importance: decomposers & nutrient recycling, mycorrhizae improve plant growth, source of food/antibiotics/drugs (penicillin, lovastatin, cyclosporine); also cause plant/animal diseases and food/wood spoilage. Notes by freebooks.pk.

Exam Tips

- Learn why fungi are neither plants nor animals — list the plant-like and animal-like traits separately, then the traits unique to fungi (chitin wall, nuclear mitosis, absorptive heterotrophy).
- Be ready to differentiate: septate vs coenocytic hyphae; ascus vs basidium; endomycorrhizae vs ectomycorrhizae; obligate vs facultative parasite; plasmogamy vs karyogamy.
- Memorise the 4 phyla with 1 key example + spore type each — a very common table-style exam question.
- Know the Penicillin discovery story (Fleming, 1928, Penicillium notatum) and other named drugs (lovastatin, cyclosporine, ergotamine).
- Practise the terrestrial adaptation list (chitin wall, wind-dispersed spores, no flagellated cells, tolerance of extreme pH/temperature/osmotic pressure).
- Revise both sides of fungal importance — economic gains (food, drugs, industry) vs economic losses (plant/animal disease, food spoilage, aflatoxins) — as this is a favourite "discuss" question.

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FSc Part-I Biology — Punjab Board

CHAPTER 9

Kingdom Plantae

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Kingdom Plantae from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Kingdom Plantae mainly includes eukaryotic, autotrophic, multicellular, non-motile organisms that develop from embryos and have cellulose cell walls, with about 360,000 known species. These notes are prepared by freebooks.pk.

The chapter divides Plantae into non-vascular Bryophyta and vascular Tracheophyta, and works through bryophyte structure and alternation of generations, the vascular plant subdivisions (Psilopsida, Lycopside, Sphenopsida and Pteropsida), the evolution of the leaf and of the seed habit, the gymnosperms and angiosperms (including double fertilization), and the classification of angiosperms into monocots and dicots along with several important angiosperm families and their economic importance.

Learning Objectives

- Describe the general characteristics of Kingdom Plantae and its broad classification into Bryophyta and Tracheophyta.
- Describe the structure, reproduction and classification of bryophytes and explain alternation of generations.
- Describe the vascular plant subdivisions Psilopsida, Lycopside and Sphenopsida.
- Describe the evolution of the leaf (microphylls and megaphylls) and the structure/ life cycle of ferns (*Adiantum*).
- Describe the evolution of the seed habit and the characteristics of gymnosperms and angiosperms.
- Explain double fertilization in angiosperms and its significance.
- Differentiate monocots from dicots and describe the economic importance of key angiosperm families.

Key Concepts

Kingdom Plantae: Overview and Classification

Biologists classify living organisms using a phylogenetic system of classification, one that reflects natural relationships and evolutionary origin among organisms. Kingdom Plantae mainly includes eukaryotic, autotrophic, multicellular, non-motile organisms that develop from embryos and possess a cellulose cell wall outer to the cell membrane; about 360,000 species of plants are known. For convenience, Plantae is divided into two broad categories: the non-vascular Bryophyta and the vascular Tracheophyta. Bryophyta comprises three subdivisions — Hepaticopsida (liverworts), Musci/Bryopsida (mosses) and Anthoceropsida (hornworts) — while Tracheophyta comprises Psilopsida (whisk ferns), Lycopside (club mosses), Sphenopsida (horsetails) and Pteropsida, which itself includes class Filicinae (ferns), class Gymnospermae (naked-seeded plants) and class Angiospermae (flowering plants).



Division Bryophyta: Structure, Reproduction and Classification

Bryophytes were the first plants to colonize land, likely evolving from green algae, but remain poorly adapted to terrestrial life and are mainly confined to damp, shady places; they are sometimes called the amphibians of the plant world because they still need water for reproduction. They lack specialized conducting tissues (xylem and phloem) and rely on diffusion and osmosis for transport, have only a thin cuticle (or none), and absorb water over their general body surface. Bryophytes show a regular alternation of heteromorphic generations: a dominant, free-living haploid gametophyte (thalloid in many liverworts, or differentiated into stem-, leaf- and rhizoid-like structures in mosses) produces a less conspicuous diploid sporophyte (consisting of foot, seta and capsule) that remains dependent on the gametophyte for nourishment. The sporophyte produces one kind of haploid spore (homosporous) by meiosis in sporangia; spores germinate into a new haploid gametophyte, which bears multicellular male antheridia (producing motile antherozoids) and female archegonia (each producing a single egg); fertilization occurs in water, and the resulting diploid zygote develops into an embryo and then a new sporophyte, remaining attached to and nourished by the gametophyte, since it lacks chloroplasts of its own.

Bryophytes show several adaptations to land life: a compact multicellular body with a cuticle to conserve water, specialized chambers for gas exchange, rhizoids for absorption and anchorage, heterogamy (non-motile eggs and motile sperm), protected multicellular sex organs, a retained and protected multicellular embryo, and alternation of generations for genetic variability. Bryophytes are classified into three subdivisions: Hepaticopsida (liverworts, e.g. *Marchantia*, *Porella* — about 900 species, simplest bryophytes, thalloid or falsely leafy gametophyte), Bryopsida (mosses, e.g. *Funaria*, *Polytrichum* — gametophyte differentiated into stem- and leaf-like structures, spores germinate into an algal-like protonema before forming new gametophyte plants), and Anthoceropsida (hornworts, e.g. *Anthoceros* — a more advanced group whose sporophyte has stomata, chloroplasts and a persistent meristematic growth zone, allowing it to photosynthesize and grow indefinitely, largely independent of the gametophyte).

Alternation of Generations

In liverworts, mosses and hornworts, two distinct multicellular generations regularly alternate: the dominant, conspicuous haploid gametophyte, which produces gametes (antherozoids and eggs) by mitosis, and the less conspicuous diploid sporophyte (differentiated into foot, seta and capsule/sporogonium), which produces haploid spores by meiosis from spore mother cells. A haploid antherozoid fuses with a haploid egg to form a diploid zygote (oospore), which develops into the sporophyte rather than directly into a gametophyte; the sporophyte's spores, upon germination, give rise to a new gametophyte rather than another sporophyte — this cyclical alternation of gametophyte and sporophyte generations is called alternation of generations. The gametophyte (haploid) phase runs from spore to gamete, while the sporophyte (diploid) phase runs from oospore to spore mother cell.

Alternation of generations is significant because meiotic division during spore formation reshuffles genes, producing spores (and hence gametophytes) with varied genetic



combinations; gametophytes with favourable genetic makeup survive better in their environment, while less-adapted ones are eliminated. Since no further reshuffling occurs during gamete formation (which is by mitosis), the new genetic combination created at fertilization (oospore) is passed to the sporophyte, which upon maturity again produces genetically varied spores. Over many generations, this natural process of variability and selection allows plant populations to become progressively better adapted to their environment.

Division Tracheophyta: Psilopsida, Lycopsidea and Sphenopsida

Tracheophytes are called vascular plants because they possess xylem and phloem; the evolution of roots, stems, leaves, vascular tissue, protected sporangia (leading to seeds), pollen tubes, flowers and fruit, and heteromorphic alternation of generations enabled vascular plants, and flowering plants especially, to dominate the land flora. Tracheophyta is subdivided into Psilopsida, Lycopsidea, Sphenopsida and Pteropsida. Psilopsida (e.g. the living genera *Psilotum* and *Tmesipteris*, and extinct genera like *Cooksonia*) are considered the earliest vascular plants; their rootless sporophytes have a dichotomously branched rhizome and leafless green aerial stem bearing sporangia at branch tips, and their thalloid, underground gametophyte lives in mycorrhizal symbiosis with a fungus.

Lycopsidea (club mosses, e.g. *Lycopodium*, *Selaginella*) have sporophytes differentiated into true roots, stems and small, single-veined leaves called microphylls, with sporangia developing on sporophylls that may form club-shaped strobili; *Lycopodium* is homosporous while *Selaginella* is heterosporous, producing microspores and megaspores, making it resemble seed plants in some respects. Sphenopsida (horsetails, e.g. *Equisetum*), also called arthropytes, have jointed, ridged stems, whorled leaves, and sporangia borne on sporangioophores aggregated into strobili.

Evolution of the Leaf and Class Filicineae (Ferns)

Early vascular land plants such as *Cooksonia* lacked true leaves or roots, having only dichotomously branched, leafless aerial stems and an anchoring rhizome. Lycopods were the first plants to evolve true leaves and roots, but their leaves (microphylls) are small, with a single undivided vein. Ferns and seed plants, by contrast, evolved megaphylls: large leaves with divided veins and an expanded blade, believed to have evolved from a dichotomous branching system in primitive psilopsids roughly 350 million years ago, over a further 15-20 million years, through three successive steps: overtopping (unequal growth of dichotomous branches in different planes), planation (arrangement of these unequal branches into one plane), and fusion/webbing (parenchyma filling the spaces between overtopped branches to form a flat leaf blade with dichotomously, and later reticulately, branched veins).

Class Filicineae (ferns) comprises seedless plants with foliar sporangia attached to leaves called fronds, whose immature fronds are coiled in a pattern called circinate vernation. *Adiantum* (maidenhair fern) illustrates the fern life cycle well: its dominant diploid sporophyte has a rhizome, adventitious roots and large compound fronds bearing sori (clusters of sporangia) on the underside of leaflet margins; each sporangium produces haploid spores by meiosis, dispersed when the annulus contracts in dry weather and



ruptures the thin-walled stomial cells. A spore germinates on moist soil into a small, heart-shaped, autotrophic gametophyte (prothallus) bearing both archegonia (near the notch) and antheridia (among the rhizoids); motile, spirally coiled antherozoids swim through water to fertilize the egg in the archegonium, forming an oospore that develops into a new, initially dependent but later independent, sporophyte.

Evolution of the Seed Habit

The evolution of the seed habit, one of the most significant events in land plant history, began roughly 390 million years ago, with the first complete seeds appearing about 365 million years ago in the late Devonian. A seed is technically a fertilized ovule, and an ovule is an integumented, indehiscent megasporangium. The evolution of the seed habit proceeded through six key steps: (1) evolution of heterospory, in which plants began producing distinct microspores (forming male microgametophytes) and megaspores (forming female megagametophytes), rather than a single spore type (homospory); (2) retention and germination of the megaspore within the megasporangium, rather than shedding it before germination; (3) development of protective integument layers around the megasporangium, forming the ovule; (4) reduction to a single functional megaspore per megasporangium, with the other three of the four products of meiosis aborting; (5) development of an embryo sac (the megaspore's female gametophyte) retained within the megasporangium; and (6) modification of the megasporangium's distal end to capture pollen, allowing pollen tubes to deliver male gametes directly to the embryo sac for fertilization without needing external water, after which the fertilized ovule develops into a seed and its integuments become the seed coat.

Class Gymnospermae and Class Angiospermae

Gymnosperms ("naked-seeded" plants) are a successful, worldwide group of heterosporous seed plants that form about one-third of the world's forests; their ovules lie exposed (naked) on the surface of fertile leaves called megasporophylls rather than being enclosed in an ovary. Important genera include *Cycas*, *Pinus*, *Taxus*, *Picea* and *Cedrus*. In *Pinus*, the dominant sporophyte bears separate male cones (with microsporophylls containing microsporangia that produce winged, wind-dispersed pollen grains) and female cones (with woody megasporophylls, each bearing two ovules/megasporangia); pollen lands directly on the ovule and forms a pollen tube delivering male gametes to the embryo sac, after which the fertilized ovule develops into a seed — an important evolutionary adaptation freeing gymnosperms from dependence on water for fertilization.

Angiosperms ("enclosed-seeded" plants) have fertile leaves (carpels) folded and fused at the margins to form an ovary, which develops into a fruit after fertilization; angiosperms make up about 235,000 of the 360,000 known plant species and are the most highly evolved seed plants, producing flowers, fruits and seeds. The diploid sporophyte produces flowers containing stamens (bearing anthers with microspore mother cells that form pollen/microgametophytes by meiosis) and carpels (with an ovary containing ovules, each with an integument and nucellus). After pollination, the pollen tube grows through the style into the ovule, delivering two male gametes to the seven-celled female gametophyte (embryo sac). One male gamete fuses with the egg to form a diploid zygote (developing into the embryo),



while the second fuses with the secondary (fusion) nucleus to form a triploid endosperm nucleus (developing into nutritive endosperm tissue) — this process, unique to angiosperms, is called double fertilization, and helps the plant economize food resources by producing endosperm only after successful fertilization. The ovule's integuments become the seed coat (testa and tegmen), and the ovary wall develops into the fruit.

Classification of Angiosperms and Important Families

Class Angiospermae is divided into two subclasses based on the number of cotyledons in the embryo: Monocotyledonae (one cotyledon; monocots) and Dicotyledonae (two cotyledons; dicots), which also differ in features such as leaf venation, vascular bundle arrangement, and floral parts in multiples of three versus four or five. Several important angiosperm families and their economic importance include: Rosaceae (rose family; ~100 genera, 2000 species; e.g. *Rosa*, *Malus*, *Fragaria* — important temperate fruits like apple, pear and strawberry, and ornamental roses); Solanaceae (potato/nightshade family; ~90 genera, 2000 species; e.g. *Solanum tuberosum*, *Nicotiana tabacum*, *Lycopersicon esculentum* — provides food crops like potato and tomato, tobacco, and medicinal alkaloids such as atropine); Fabaceae/Papilionaceae (pea family; ~400 genera, 9000 species; e.g. *Lathyrus*, *Arachis hypogaea*, *Cicer arietinum* — an important source of high-protein pulses, forage crops and timber, with characteristic papilionaceous flowers bearing a standard, wings and keel).

Caesalpiniaceae (cassia family; ~152 genera, 2300 species; e.g. *Tamarindus indica*, *Cassia fistula*, *Bauhinia variegata*) provides medicinal drugs (e.g. senna, a laxative), ornamentals and dyes; Mimosaceae (mimosa/acacia family; ~56 genera, 2800 species; e.g. *Acacia nilotica*, *Albizia lebbek*, *Mimosa pudica*) provides commercial timber, gum arabic and ornamentals; and Poaceae/Gramineae (grass family; ~600 genera, 10,000 species; e.g. *Triticum*, *Zea mays*, *Oryza sativa*, *Saccharum officinarum*) is economically the most important flowering plant family, providing the world's major cereal and fodder crops, sugar, building materials (bamboo) and fibres, with a characteristic spikelet inflorescence and a caryopsis (grain) fruit type.

Important Definitions

Term	Definition
Phylogenetic classification	A system of classification that groups organisms to reflect their natural evolutionary relationships and mode of origin.
Bryophyte	A non-vascular, flowerless land plant (liverwort, moss or hornwort) with a dominant gametophyte and a dependent sporophyte.
Alternation of generations	The regular alternation, in a plant life cycle, between a haploid, gamete-producing gametophyte and a diploid, spore-producing sporophyte.
Heterospory	The production of two distinct types of spores - smaller microspores and larger megaspores - by a plant sporophyte.
Megaphyll	A large leaf with divided veins and veinlets and an expanded blade, characteristic of ferns and seed plants.



Term	Definition
Ovule	An integumented, indehiscent megasporangium that develops into a seed after fertilization.
Double fertilization	A process unique to angiosperms in which one male gamete fuses with the egg (forming the zygote) and a second fuses with the secondary nucleus (forming the triploid endosperm).
Monocot / Dicot	The two subclasses of angiosperms, distinguished mainly by having one cotyledon (monocot) or two cotyledons (dicot) in the seed embryo.

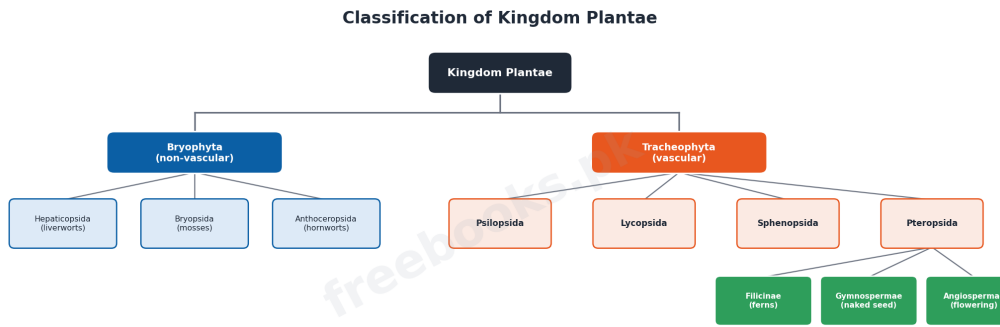
Key Facts

Item	Fact
Known plant species	About 360,000 species; angiosperms make up about 235,000 of these.
Bryophyte subdivisions	Hepaticopsida (liverworts), Bryopsida (mosses), Anthoceropsida (hornworts).
Bryophyte sporophyte parts	Foot, seta and capsule (sporogonium).
Seed evolution timeline	Seed habit began ~390 million years ago; first complete seeds ~365 million years ago (late Devonian).
Pinus pollen adaptation	Two wings on pollen grain aid long-distance wind dispersal.
Double fertilization result	Egg (n) + male gamete (n) → zygote (2n, embryo); secondary nucleus (2n) + male gamete (n) → endosperm (3n).
Angiosperm subclasses	Monocotyledonae (1 cotyledon) and Dicotyledonae (2 cotyledons).
Most economically important family	Poaceae (Gramineae) - cereals, fodder, sugar cane, bamboo; ~600 genera, 10,000 species.

Diagrams & Illustrations

Classification of Kingdom Plantae: a tree diagram showing Kingdom Plantae divided into Bryophyta (Hepaticopsida, Bryopsida, Anthoceropsida) and Tracheophyta (Psilopsida, Lycopside, Sphenopsida, Pteropsida with classes Filicinae, Gymnospermae, Angiospermae).

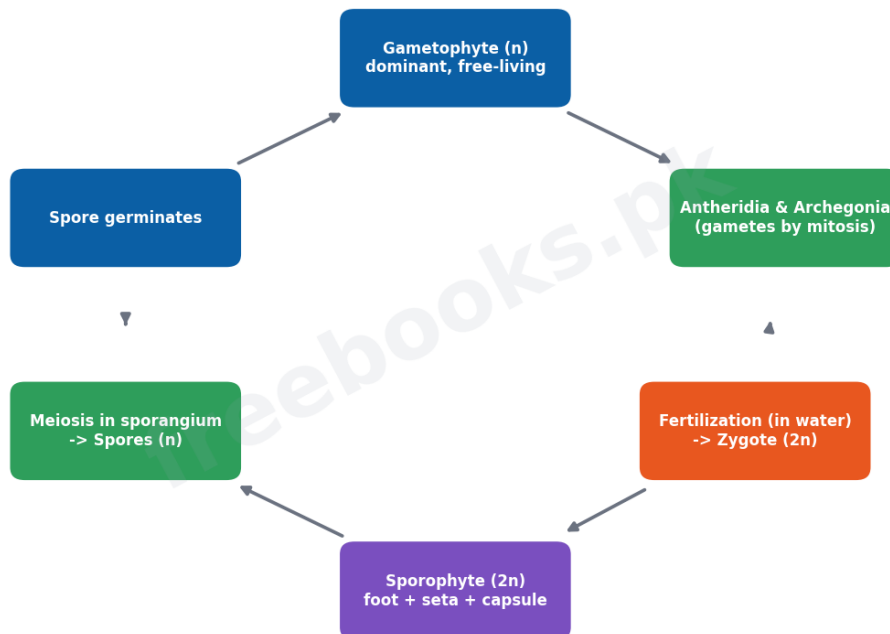




Classification of Kingdom Plantae

Alternation of Generations in a Bryophyte: a life-cycle diagram showing the haploid gametophyte producing gametes that fuse to form a diploid zygote, developing into a sporophyte that produces haploid spores by meiosis, which germinate into a new gametophyte.

Alternation of Generations (Bryophyte)



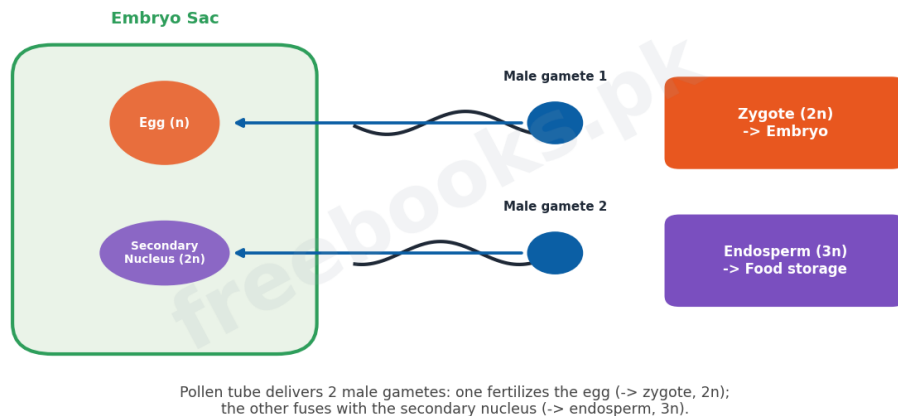
Haploid (n) phase: spore -> gametophyte -> gametes. Diploid (2n) phase: zygote -> sporophyte -> spore mother cell.

Alternation of Generations in a Bryophyte

Double Fertilization in Angiosperms: a diagram of double fertilization showing one male gamete fusing with the egg to form the diploid zygote, and a second male gamete fusing with the secondary nucleus to form the triploid endosperm nucleus.



Double Fertilization in Angiosperms



Double Fertilization in Angiosperms

Short Questions & Answers

Q1. How are ferns better adapted to life on land than liverworts and mosses?

Ans. Ferns have true vascular tissue (xylem and phloem) for efficient water and nutrient transport, true roots, stems and megaphyll leaves, and a dominant, independent sporophyte, whereas liverworts and mosses lack vascular tissue and have a dominant gametophyte that still depends on external water for fertilization.

Q2. Differentiate microphyll and megaphyll.

Ans. A microphyll is a small leaf with a single, undivided vein, found in lycopods, whereas a megaphyll is a large leaf with divided veins, veinlets and an expanded blade, characteristic of ferns and seed plants.

Q3. What is heterospory? Why is it significant in seed evolution?

Ans. Heterospory is the production of two distinct spore types - smaller microspores (forming male gametophytes) and larger megaspores (forming female gametophytes) - by a single sporophyte; it was the first essential step in the evolution of the seed habit, since retention of the megaspore within the megasporangium eventually led to the ovule and seed.

Q4. What is a seed? Define ovule and integument.

Ans. A seed is technically a fertilized ovule. An ovule is an integumented, indehiscent megasporangium, and integuments are the specialized protective layers surrounding the megasporangium that later become the seed coat.

Q5. What is double fertilization? State its significance.

Ans. Double fertilization is the angiosperm-specific process in which one male gamete fuses with the egg to form the diploid zygote (embryo), while a second male gamete fuses with the secondary nucleus to form the triploid endosperm nucleus (nutritive tissue); its significance



is that it economizes the plant's food resources by producing nutritive endosperm only after successful fertilization has occurred.

Q6. Differentiate monocots and dicots (any two characters).

Ans. Monocots have one cotyledon in the seed embryo and scattered vascular bundles in the stem, whereas dicots have two cotyledons and vascular bundles arranged in a ring; monocot leaves typically show parallel venation while dicot leaves show reticulate (net-like) venation.

Long Questions & Answers

Q1: Discuss alternation of generations, defining sporophyte and gametophyte, with reference to bryophytes.

Alternation of generations refers to the regular alternation, in the life cycle of plants such as bryophytes, between two distinct multicellular phases: the haploid gametophyte and the diploid sporophyte. The gametophyte is the gamete-producing generation; in bryophytes it is the dominant, conspicuous, free-living phase, producing motile male gametes (antherozoids) in antheridia and a single egg in each archegonium, both by mitosis. A haploid antherozoid fuses with a haploid egg (fertilization occurring in water) to form a diploid zygote or oospore, which develops — not into a new gametophyte, but into the sporophyte, a genetically and structurally distinct generation consisting of a foot, seta and capsule, that remains attached to and nutritionally dependent on the gametophyte. The sporophyte is the spore-producing generation: within its capsule, spore mother cells undergo meiosis to produce haploid spores, and these spores germinate not into another sporophyte but into a new gametophyte, completing the cycle. An adult animal is comparable only to the diploid sporophyte generation of a plant, since animals produce gametes directly by meiosis within a single diploid body, without ever passing through a free-living, multicellular haploid stage equivalent to the gametophyte; this is the key reproductive dissimilarity between plants and animals.

Q2: Describe the evolution of the leaf and its importance in vascular plants.

Early vascular land plants, such as *Cooksonia*, lacked true leaves or roots and consisted only of dichotomously branched, leafless green aerial stems and an anchoring underground rhizome. Lycopods were the first plants to evolve true leaves and roots, though their leaves (microphylls) remained small, with only a single, undivided vascular strand. The much larger, more complex megaphyll leaf — with divided veins, veinlets and an expanded blade — is thought to have evolved from a dichotomously branching stem system in primitive psilopsids roughly 350 million years ago, over a further 15 to 20 million years, through three successive evolutionary steps: overtopping, in which some branches of a dichotomously branching stem grew faster and larger than others in different planes; planation, in which these unequally overtopped branches became rearranged into a single plane; and fusion (webbing), in which parenchyma tissue filled the spaces between the overtopped, planated branches, forming a continuous, flattened leaf blade with a branching (and eventually



reticulate) venation pattern. The evolution of the megaphyll leaf was of enormous importance to vascular plants because its greatly expanded surface area dramatically increased the plant's capacity for photosynthesis, and megaphylls became the characteristic and highly successful leaf type of both ferns and all seed plants.

Q3: Discuss the evolution of seed habit and its significance.

The seed habit evolved through a defined sequence of six steps over tens of millions of years, beginning roughly 390 million years ago, with complete seeds appearing by about 365 million years ago. First, heterospory evolved: instead of producing a single spore type (homospory), some plant lineages began producing distinct microspores (forming male gametophytes) and larger megaspores (forming female gametophytes). Second, rather than being shed immediately, the megaspore began to be retained and to germinate within the megasporangium itself. Third, sporophytic tissue surrounding the megasporangium fused to form a protective integument, converting the megasporangium into an ovule (an integumented, indehiscent megasporangium). Fourth, of the four megaspores normally produced by meiosis of a megaspore mother cell, only one was retained as functional, the other three aborting, reducing competition for space and food. Fifth, the single surviving megaspore developed into a female gametophyte called the embryo sac, fully enclosed and protected within the megasporangium. Finally, the distal end of the now fully integumented, indehiscent megasporangium became modified to capture pollen, enabling pollen tubes to deliver male gametes directly to the embryo sac without needing external water for fertilization, after which the fertilized ovule became a seed with the integuments forming its seed coat. This sequence was of immense evolutionary significance: the resulting seed offered maximum protection to the developing embryo under harsh, variable terrestrial conditions, and freed reproduction almost entirely from a dependence on external water, enabling seed plants to permanently and successfully colonize the land.

Q4: Describe the process of double fertilization in angiosperms and explain its significance.

In an angiosperm, after pollination, the pollen grain germinates on the stigma to form a pollen tube, and the pollen's nucleus divides mitotically to produce two male gametes plus a tube nucleus; meanwhile, within the ovule, a megaspore develops into a seven-celled female gametophyte (embryo sac), one cell of which is the egg. The pollen tube grows down through the style, enters the ovule, and reaches the embryo sac, where it discharges its two male gametes. In double fertilization, one male gamete fuses with the egg cell to form a diploid ($2n$) zygote, which develops into the embryo, while the second male gamete simultaneously fuses with the diploid secondary (fusion) nucleus of the embryo sac to form a triploid ($3n$) endosperm nucleus, which develops into the nutritive endosperm tissue. This process, unique to flowering plants, is evolutionarily significant because it means that food-storing endosperm tissue is produced only after fertilization has actually taken place, allowing the plant to economize its food resources rather than pre-provisioning ovules that might never be fertilized; the endosperm formed then nourishes the developing embryo within the seed.



Q5: How do monocots and dicots structurally differ, and what is the economic importance of the Poaceae and Fabaceae families?

Monocotyledonous and dicotyledonous plants, the two subclasses of Angiospermae, differ in the number of cotyledons in their seed embryo (one in monocots, two in dicots) as well as in several other structural features: monocot leaves usually show parallel venation while dicot leaves show reticulate (net-like) venation; monocot stems have scattered vascular bundles while dicot stems have vascular bundles arranged in a ring around the periphery; and monocot floral parts typically occur in multiples of three, while dicot floral parts typically occur in multiples of four or five. The family Poaceae (Gramineae), a monocot family with about 600 genera and 10,000 species, is economically the most important family of flowering plants: it supplies the world's staple cereal crops (wheat, rice, corn, barley, oats), major fodder grasses for livestock, sugar (from sugarcane), building materials such as bamboo, and various fibres and oils. The family Fabaceae (Papilionaceae), a dicot family with about 400 genera and 9,000 species, is likewise of major economic importance, providing high-protein pulses (gram, pea, kidney bean) that are a key food source, important forage crops (alfalfa, clover), valuable timber trees (*Dalbergia sissoo*/Shisham), medicinal plants (*Glycyrrhiza glabra* for cough and cold), and characteristic papilionaceous (butterfly-shaped) flowers with a standard, wings and keel.

MCQs with Answers

1. Kingdom Plantae contains approximately how many known species?

- (a) 36,000 (b) 100,000 (c) 235,000 (d) 360,000

Correct Answer: (d) 360,000. About 360,000 species of plants are known, of which angiosperms make up about 235,000.

2. Bryophyta is divided into how many subdivisions?

- (a) 2 (b) 3 (c) 4 (d) 5

Correct Answer: (b) 3. Bryophyta has 3 subdivisions: Hepaticopsida (liverworts), Bryopsida (mosses) and Anthoceropsida (hornworts).

3. The sporophyte of a bryophyte consists of:

- (a) root, stem, leaf (b) foot, seta, capsule (c) rhizoid, thallus, cuticle (d) anther, ovary, stigma

Correct Answer: (b) foot, seta, capsule. The bryophyte sporophyte is differentiated into foot, seta and capsule (sporogonium).

4. The production of two distinct spore types (microspores and megaspores) is called:

- (a) homosporous (b) heterosporous (c) isosporous (d) sporogenesis

Correct Answer: (b) heterosporous. Heterosporous is the production of two spore types and was the first key step in seed evolution.

5. Technically, a seed may be defined as a:

- (a) fertilized ovule (b) unfertilized megaspore (c) mature pollen grain (d) young embryo sac



Correct Answer: (a) fertilized ovule. A seed is technically a fertilized ovule, which is itself an integumented, indehiscent megasporangium.

6. The term "Gymnospermae" literally means:

(a) enclosed seed (b) naked seed (c) no seed (d) double seed

Correct Answer: (b) naked seed. Gymnospermae means "naked seed" (gymno = naked, spermae = seed), reflecting their exposed ovules.

7. In double fertilization, the second male gamete fuses with the secondary nucleus to form the:

(a) zygote (b) embryo (c) endosperm nucleus (d) pollen tube

Correct Answer: (c) endosperm nucleus. The second male gamete fuses with the secondary (fusion) nucleus to form the triploid endosperm nucleus.

8. Class Angiospermae is divided into the subclasses Monocotyledonae and:

(a) Gymnospermae (b) Pteropsida (c) Dicotyledonae (d) Filicinae

Correct Answer: (c) Dicotyledonae. Angiosperms are divided into Monocotyledonae (1 cotyledon) and Dicotyledonae (2 cotyledons).

9. Which family is economically the most important among flowering plants, providing the world's major cereal crops?

(a) Rosaceae (b) Solanaceae (c) Poaceae (d) Mimosaceae

Correct Answer: (c) Poaceae. Poaceae (Gramineae), the grass family, is the most economically important flowering plant family.

10. Pinus pollen grains have two wings, which help in:

(a) water dispersal (b) insect attachment (c) wind dispersal over long distances (d) self-pollination only

Correct Answer: (c) wind dispersal over long distances. The two wings on Pinus pollen grains allow them to float in air and travel long distances by wind.

Quick Revision Summary

- Kingdom Plantae: eukaryotic, autotrophic, multicellular, non-motile, cellulose walls, ~360,000 species. Divided into Bryophyta (non-vascular) and Tracheophyta (vascular).
- Bryophyta: 3 subdivisions (Hepaticopsida, Bryopsida, Anthoceropsida); dominant gametophyte, dependent sporophyte (foot+seta+capsule); homosporous; need water for fertilization.
- Alternation of generations: haploid gametophyte (gamete-producing, mitosis) <-> diploid sporophyte (spore-producing, meiosis); provides genetic variability for natural selection.
- Tracheophyta subdivisions: Psilopsida (rootless, e.g. Psilotum), Lycopsidea (microphylls, e.g. Lycopodium/Selaginella), Sphenopsida (jointed stems, e.g. Equisetum), Pteropsida (Filicinae/Gymnospermae/Angiospermae).
- Leaf evolution: microphyll (1 vein, lycopods) vs megaphyll (divided veins, ferns/seed plants) via overtopping -> planation -> fusion/webbing.



- Seed evolution (6 steps): heterospory -> megaspore retention -> integument/ovule formation -> single functional megaspore -> embryo sac -> pollen capture modification.
- Gymnosperms = naked seed (e.g. Pinus, Cycas); Angiosperms = enclosed seed, double fertilization (zygote $2n$ + endosperm $3n$); Monocots (1 cotyledon) vs Dicots (2 cotyledons).
- Key angiosperm families: Rosaceae (fruits/ornamentals), Solanaceae (potato/tomato/tobacco), Fabaceae (pulses/forage), Caesalpiniaceae (senna/dyes), Mimosaceae (timber/gum), Poaceae (cereals - most economically important). Notes by freebooks.pk.

Exam Tips

- Learn the classification tree of Plantae (Bryophyta vs Tracheophyta with all subdivisions) — a very common diagram/fill-in-the-blank question.
 - Master alternation of generations: define gametophyte and sporophyte precisely, and know which is haploid/diploid and gamete-/spore-producing.
 - Memorise the 6 steps in the evolution of the seed habit in order — a classic extensive question.
 - Be ready to differentiate: microphyll/megaphyll, gymnosperm/angiosperm, monocot/dicot, homospory/heterospory.
 - Understand double fertilization clearly: which gamete forms the zygote ($2n$) and which forms the endosperm ($3n$).
 - Know at least 2-3 economically important plants and uses for each of the 6 angiosperm families listed (especially Poaceae and Fabaceae).
-

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FSc Part-I Biology — Punjab Board

CHAPTER 10

Kingdom Animalia

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Kingdom Animalia from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Kingdom Animalia (from the Latin anima, breath or soul) includes all multicellular, diploid, eukaryotic, ingestive heterotrophs that develop from two dissimilar haploid gametes, a large egg and a smaller sperm; virtually all biologists agree animals evolved from protoctists. These notes are prepared by freebooks.pk.

The chapter works through the basic body-organization concepts used to classify animals (Parazoa vs Eumetazoa, Radiata vs Bilateria, diploblastic vs triploblastic, acoelomate/pseudocoelomate/coelomate, and protostome vs deuterostome development), then surveys the major invertebrate phyla (Porifera, Cnidaria, Platyhelminthes, Nematoda, Annelida, Arthropoda, Mollusca, Echinodermata, Hemichordata) and the phylum Chordata, including the vertebrate classes Cyclostomata, Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves and Mammalia.

Learning Objectives

- Describe the general characteristics of Kingdom Animalia and its basic organizational groupings.
- Differentiate radial and bilateral symmetry, and diploblastic and triploblastic organization.
- Differentiate acoelomate, pseudocoelomate and coelomate body plans, and protostome and deuterostome development.
- Describe the general characteristics of Porifera, Cnidaria, Platyhelminthes and Nematoda.
- Describe the general characteristics and classification of Annelida, Arthropoda, Mollusca and Echinodermata.
- Describe the characteristics of phylum Chordata and the major classes of vertebrates.
- Describe the adaptations that allowed animals to transition from aquatic to terrestrial life.

Key Concepts

Kingdom Animalia: Basic Body Organization

Kingdom Animalia includes all multicellular, diploid, eukaryotic, ingestive heterotrophs that develop from two dissimilar haploid gametes (a large egg and smaller sperm). In Robert Whittaker's five-kingdom system followed in this book, the traditional single-celled Protozoa belong instead to Kingdom Protoctista, leaving Animalia composed of about 29 multicellular phyla. Multicellularity, though present in Fungi and Plantae too, has developed most impressively in animals, whose cells are joined by complex junctions controlling communication and material flow between cells. The simplest animals, subkingdom Parazoa (phylum Porifera), lack tissues organized into organs and have an indeterminate, asymmetrical shape. Subkingdom Eumetazoa includes all other animal phyla, which have tissues organized into organs and organ systems, and is further divided into grade Radiata



(radially symmetrical animals, e.g. phylum Cnidaria) and grade Bilateria (bilaterally symmetrical animals, comprising most remaining phyla).

Animals are also classified by the presence, absence or type of body cavity: Acoelomata (no body cavity), Pseudocoelomata (a false body cavity, the pseudocoel, not lined by mesoderm), and Coelomata (a true, mesoderm-lined coelom). In radial symmetry, any plane passing through the central axis divides the animal into near-mirror-image halves (e.g. sea anemone); in bilateral symmetry, only one plane divides the animal into two equal halves, with a distinct anterior/posterior end and dorsal/ventral surfaces (most Bilateria, though adult echinoderms have secondarily re-evolved radial symmetry as an adaptation to their lifestyle, even though their larvae are bilateral).

Protostomes and Deuterostomes; Diploblastic and Triploblastic Organization

Bilateria is further split into two developmental series. In Protostomes (Platyhelminthes, Nematoda, Annelida, Mollusca, Arthropoda), cleavage of the zygote is spiral and determinate (the fate of each blastomere is fixed early), the mouth develops from or near the blastopore, and the coelom forms by a splitting of the mesoderm (schizocoelous). In Deuterostomes (Echinodermata, Hemichordata, Chordata), cleavage is radial and indeterminate (any one blastomere can still form a complete embryo), the mouth forms at a distance from the blastopore while the blastopore itself becomes the anus, and the coelom develops as an outpouching of the archenteron (enterocoelous).

Diploblastic animals (grade Radiata, phylum Cnidaria) have a body built of just two germ layers, ectoderm and endoderm, separated by a jelly-like, largely non-cellular mesogloea; they show a lower degree of specialization, lack a central nervous system (having only a diffuse nerve net) and a special transport system, and possess a single gastrovascular cavity (enteron) with only one opening serving as both mouth and anus (a sac-type digestive system). Triploblastic animals (grade Bilateria) have three true germ layers — ectoderm, mesoderm and endoderm — showing much greater specialization into organs and organ systems (ectoderm forming the integument and nervous system, mesoderm forming muscular, skeletal and reproductive systems, endoderm forming the gut lining and digestive glands); most have a tube-type digestive system with a separate mouth and anus, and may be acoelomate, pseudocoelomate or coelomate.

Parazoa (Porifera) and Grade Radiata (Cnidaria)

Phylum Porifera (sponges; ~5,000 species, mostly marine) are pore-bearing, sessile, asymmetrical animals lacking true tissues; the body wall has an outer pinacoderm (pinacocytes) and inner choanoderm (flagellated choanocytes), enclosing a central spongocoel, with water entering through numerous ostia and leaving through the osculum. Choanocyte flagella draw in water carrying food (zooplankton, phytoplankton and mostly detrital particles), and a needle-like calcareous or siliceous skeleton of spicules (or, in bath sponges, protein spongin fibres) provides support. Sponges reproduce asexually by budding (external buds or internal gemmules) and sexually (mostly hermaphroditic, often protandrous), producing a swimming larva. Examples include Sycon, Leucosolenia,



Euplectella (Venus flower basket) and Spongilla (freshwater sponge); natural sponges remain commercially valuable for bathing, surgical fluid absorption and sound insulation.

Phylum Cnidaria (Coelenterata) are diploblastic, radially symmetrical, aquatic animals named for stinging cnidocyte cells bearing nematocysts, used for defence and capturing prey; their single gastrovascular cavity (enteron) opens through only one mouth surrounded by tentacles, and the nervous system is a diffuse nerve net without a brain. Cnidarians occur in two body forms: sessile, nutritive polyps (gastrozooids) and free-swimming, sexually reproducing medusae; many, such as Obelia, show alternation of generations between asexual polyp and sexual medusa stages, while others like Hydra exist only as polyps. Colonial cnidarians may show polymorphism, having more than two structurally and functionally distinct zooid types (e.g. Physalia, the Portuguese man-of-war, has up to five). Colonial corals (e.g. Madrepora) secrete a hard calcium carbonate exoskeleton that builds coral reefs and even small islands, found along coasts such as Florida, the West Indies, East Africa, Australia and the Coral Sea.

Acoelomate Platyhelminthes and Pseudocoelomate Nematoda

Phylum Platyhelminthes (flatworms) are soft, dorsoventrally flattened, triploblastic acoelomates with bilateral symmetry and an unsegmented body; mesoderm forms a loose packing tissue (mesenchyme/parenchyma) filling the space between ectoderm and endoderm rather than a true coelom. Most are endoparasites (e.g. Taenia solium, tapeworm; Fasciola hepatica, liver fluke; Schistosoma, blood fluke), though free-living forms like Dugesia (Planaria) exist in freshwater. They have a branching sac-type gut (reduced or absent in tapeworms), flame-cell excretory system, a well-developed nervous system with anterior sense organs, but no respiratory or circulatory system; reproduction is by fission (asexual) or as hermaphrodites (sexual). Parasitic flatworms show specific adaptations: a protective resistant cuticle instead of epidermis, adhesive suckers and hooks for attachment, degeneration of muscular and nervous systems, a simplified digestive system, complex reproductive systems producing huge numbers of eggs, and complex life cycles involving more than one host — as in Taenia, whose mature proglottids pass out in faeces, are ingested by an intermediate host (e.g. cattle) where the larva embeds in muscle, and infect humans who eat improperly cooked meat.

Phylum Nematoda (Aschelminthes; roundworms) are elongated, pointed-ended, triploblastic pseudocoelomates with bilateral symmetry and an unsegmented body; their pseudocoelom is derived from the embryonic blastocoel rather than from mesoderm splitting, and is filled with hydrostatic, protein-rich fluid. They have a complete alimentary canal (mouth and anus), a excretory system of longitudinal canals, a nerve ring with longitudinal cords, sensory papillae, but no circulatory or respiratory system (gas exchange occurs across the body surface); sexes are separate. Important parasitic nematodes include Ascaris lumbricoides (intestinal parasite of humans), Enterobius vermicularis (pinworm, causing intense anal itching), and Ancylostoma duodenale (hookworm, which attaches to intestinal villi, secretes an anticoagulant, and can cause severe anemia in children).



Coelomate Annelida and Arthropoda

Phylum Annelida (segmented worms) are triploblastic, coelomate, bilaterally symmetrical animals with a metamerically segmented body (repeating similar segments separated internally by septa, though the gut, blood vessels and nerve cord run continuously through them); examples include *Nereis* (marine), earthworms (soil-dwelling) and *Hirudo* (leech, a parasite). They have a complete, regionally specialized digestive tract, true coelom (formed by mesoderm splitting into parietal and visceral layers) serving as a hydrostatic skeleton, excretion via ciliated nephridia in each segment, a well-developed central nervous system (simple brain plus ventral nerve cord), and the first closed circulatory system among invertebrates; gas exchange occurs by diffusion across moist skin. Locomotion combines circular and longitudinal body-wall muscles acting against the hydrostatic (coelomic) skeleton, aided by chitinous chaetae/setae or parapodia; most annelids are hermaphroditic, though *Nereis* has separate sexes and produces a trochophore larva. Annelida includes class Polychaeta (parapodia, distinct head, mostly marine, e.g. *Nereis*), class Oligochaeta (setae, no distinct head, hermaphroditic, no larva, e.g. earthworms), and class Hirudinea (leeches, suckers, no locomotory organs, e.g. *Hirudo medicinalis*). Earthworms are called "nature's plough" for aerating and mixing the soil.

Phylum Arthropoda (jointed-legged animals) is the largest animal phylum, including insects, crustaceans, arachnids and myriapods; the segmented body bears jointed appendages modified for varied functions, covered by a waterproof, chitinous exoskeleton periodically shed through moulting (ecdysis). The coelom is reduced to a haemocoel (body cavity through which blood flows, part of an open circulatory system with a simple dorsal heart, colourless blood lacking haemoglobin), excretion is via Malpighian tubules (excreting solid uric acid), and gas exchange occurs mainly via a tracheal system with spiracles (or gills/book lungs in some). The nervous system has paired ganglia per segment connected to a ventral nerve cord, with compound eyes and antennae as major sense organs. Arthropod classes include Crustacea (aquatic, gills, carapace, two pairs of antennae, e.g. crabs, prawns), Insecta (largest class overall; head-thorax-abdomen body plan, 3 pairs of legs, often wings, metamorphosis, e.g. beetles, butterflies), Arachnida (cephalothorax and abdomen, 4 pairs of legs, chelicerae, book lungs, e.g. spiders, scorpions), and Myriapoda (many segments each with a pair of legs, e.g. centipedes, millipedes). Insects undergo metamorphosis (egg to larva to pupa to adult, or incomplete metamorphosis via a nymph); economically, harmful insects (mosquitoes, tsetse flies, locusts) transmit diseases like malaria and sleeping sickness and damage crops, while beneficial insects (honeybees, silkworms) provide honey, wax and silk.

Mollusca and Echinodermata

Phylum Mollusca is the second-largest invertebrate phylum (over 50,000 species), including snails, slugs, bivalves and cephalopods (the giant squid being the largest invertebrate); molluscs are triploblastic coelomates with bilateral symmetry, an unsegmented soft body differentiated into a head, muscular foot, and dorsal visceral mass, covered by a mantle that typically secretes a protective calcareous shell (reduced or lost in more active groups). Many possess a radula (rasping, tooth-bearing tongue) for feeding; the circulatory system (except in Cephalopoda) is open, using the blue respiratory pigment haemocyanin, gas exchange is mainly by gills, excretion by paired nephridia, and the nervous system has three pairs of



interconnected ganglia; sexes are usually separate, with a trochophore larva. Major classes include Gastropoda (asymmetrical, usually coiled single shell, e.g. garden snail *Helix*, slug *Limax*), Bivalvia/Pelecypoda (bilaterally symmetrical, two-part shell, plate-like gills, e.g. mussels, oysters), and Cephalopoda (bilaterally symmetrical, reduced/internal or absent shell, highly active and intelligent, e.g. squid *Loligo*, cuttlefish *Sepia*, octopus). Economically, molluscs provide food (clams, oysters, mussels), pearls, and shell products, though slugs and shipworms (*Teredo*) cause damage to gardens and ships.

Echinodermata and Hemichordata, and Phylum Chordata Overview

Phylum Echinodermata ("spiny-skinned" animals; over 5,000 species, exclusively marine) are triploblastic coelomates with a mesodermal (endoskeleton) calcareous skeleton, and are radially symmetrical as adults (though bilaterally symmetrical as larvae, a secondary adaptation to their sedentary/slow-moving lifestyle). Their most distinctive feature is a water vascular system of coelomic canals and tube feet, with water entering via a sieve-like madreporite; they have specialized digestive and reproductive organs but poorly developed respiratory, excretory, circulatory and nervous systems (no true brain, only a nerve ring), and show strong powers of regeneration. Examples include *Asterias* (starfish), sea urchins, sea cucumbers and brittle stars. Echinoderms show striking developmental and biochemical resemblances to chordates (radial cleavage, blastopore forming the anus, shared biochemistry like phosphocreatine) and close affinities with Hemichordata (e.g. *Balanoglossus*, *Saccoglossus*), a small phylum of soft, worm-like animals with a body divided into proboscis, collar and trunk, gill slits, and features transitional between invertebrates and chordates — hence sometimes called "prechordates".

Phylum Chordata is defined by three key features present at some life stage: a notochord (a semi-rigid, rod-like skeletal axis of vacuolated cells), a dorsal, hollow central nervous system, and paired pharyngeal gill slits (functional throughout life in forms like *Amphioxus* and fishes, only in embryos or larvae in others). Chordata is divided into Protochordata (lower chordates, lacking a vertebral column: subphylum Urochordata/tunicates, e.g. *Molgula*, with notochord only in the larva; and subphylum Cephalochordata, e.g. *Amphioxus*, with notochord persisting the whole body length throughout life) and subphylum Vertebrata (Craniata, higher chordates with a vertebral column replacing the notochord and a cranium enclosing the brain). Vertebrates are grouped into superclass Pisces (classes Cyclostomata, Chondrichthyes, Osteichthyes — strictly aquatic) and superclass Tetrapoda (classes Amphibia, Reptilia, Aves, Mammalia — four-limbed, mostly land-dwelling), and separately into anamniotes (no foetal membranes: Cyclostomata, Chondrichthyes, Osteichthyes, Amphibia) and amniotes (with foetal membranes: Reptilia, Aves, Mammalia).

Vertebrate Classes: Fishes, Amphibians, Reptiles, Birds and Mammals

Superclass Pisces includes class Cyclostomata (jawless, eel-like, cartilaginous, e.g. lamprey, hagfish — the most primitive living vertebrates), class Chondrichthyes (sharks and rays; entirely cartilaginous skeleton, placoid scales, 5-7 pairs of gills without an operculum, no swim bladder, e.g. sharks reaching 30-50 feet), and class Osteichthyes (bony fishes; bony skeleton, dermal scales, gills covered by an operculum, usually a swim bladder for buoyancy, two-chambered heart). Key adaptations to aquatic life include a streamlined body, a



hydrostatic swim bladder, paired and unpaired fins for balance and locomotion, and gills for gas exchange; the transition from water to land (pioneered by lobe-finned dipnoi fish in the Devonian) required skin for protection against drying, protective, food-storing shelled eggs, lungs in place of gills, circulatory changes, jointed limbs in place of fins, and more advanced sense organs.

Class Amphibia (frogs, toads, salamanders), the first vertebrates on land, remain structurally and reproductively tied to water: they have a mostly bony skeleton, four limbs (tetrapod, some legless), smooth, glandular, often poison-producing skin, gill respiration in larvae and lung/skin respiration in adults, a 3-chambered heart, external fertilization, a larval stage, and cold-blooded (poikilothermic), anamniotic biology with metamorphosis. Class Reptilia are fully terrestrial, with internal fertilization via a copulatory organ, leathery amniotic eggs (with amnion, allantois and chorion), dry scaly skin, an incompletely partitioned ventricle (fully partitioned in crocodiles), and are cold-blooded; reptiles flourished through the Mesozoic era and include today's lizards, snakes, tuatara and crocodiles. Class Aves (birds), believed to have evolved from reptiles (the fossil Archaeopteryx from the Jurassic shows both reptilian and avian traits), are warm-blooded (homeothermic) with a streamlined, feathered body, forelimbs modified into wings, a light, air-filled skeleton, a toothless horny beak, a muscular gizzard for grinding food, a 4-chambered heart, internal fertilization, and large yolky eggs. Class Mammalia, believed to have evolved from mammal-like reptiles (cotylosaurs) and dominant since the Cenozoic period, are named for nourishing young with milk from mammary glands; key features include hair, a muscular diaphragm, a single-boned lower jaw, three middle-ear bones (malleus, incus, stapes), a 4-chambered heart with a left aortic arch, non-nucleated red blood cells, and being warm-blooded and (mostly) viviparous. Mammals are divided into subclass Prototheria (egg-laying, e.g. duck-billed platypus, echidna — a reptile-mammal link), subclass Metatheria (pouched marsupials, e.g. kangaroo, opossum), and subclass Eutheria (placental mammals, including humans, whales and most familiar mammals).

Important Definitions

Term	Definition
Coelom	A true body cavity between the body wall and alimentary canal, completely lined by mesoderm and filled with coelomic fluid.
Pseudocoelom	A false body cavity, derived from the embryonic blastocoel rather than from mesoderm, not lined by coelomic epithelium (as in nematodes).
Radial symmetry	A body organization in which any plane passing through the central axis divides the animal into near-mirror-image halves (e.g. Cnidaria).
Bilateral symmetry	A body organization in which only one plane divides the animal into two equal, mirror-image halves, with distinct anterior/posterior and dorsal/ventral surfaces.
Metamorphosis	An abrupt change of form/structure during an animal's life cycle, e.g. egg to larva to pupa to adult in insects.
Notochord	



Term	Definition
	A semi-rigid, rod-like axis of vacuolated cells that supports and stiffens the body in all chordates at some life stage.
Polymorphism (Cnidaria)	The occurrence of more than two structurally and functionally distinct zooid types within a single colonial organism (e.g. Obelia, Physalia).
Amniote	A vertebrate (Reptilia, Aves, Mammalia) whose embryo develops within protective foetal membranes (amnion, chorion, allantois).

Key Facts

Item	Fact
Kingdom Animalia definition	Multicellular, diploid, eukaryotic, ingestive heterotrophs developing from a large egg and small sperm.
Parazoa vs Eumetazoa	Parazoa (Porifera) lack tissues/organs; Eumetazoa have tissues organized into organs and organ systems.
Protostomes vs Deuterostomes	Protostomes: spiral/determinate cleavage, mouth from blastopore. Deuterostomes: radial/indeterminate cleavage, anus from blastopore.
Porifera	~5,000 species, mostly marine; no true tissues; choanocytes, spicules, ostia and osculum.
Arthropoda	Largest animal phylum; jointed appendages, chitinous exoskeleton, moulting (ecdysis), open circulatory system.
Mollusca	2nd largest invertebrate phylum (~50,000 species); mantle, radula, haemocyanin pigment; giant squid = largest invertebrate.
Chordata (3 features)	Notochord + dorsal hollow nerve cord + paired pharyngeal gill slits (at some life stage).
Mammalia subclasses	Prototheria (egg-laying), Metatheria (pouched), Eutheria (placental) - named for nourishing young with milk.

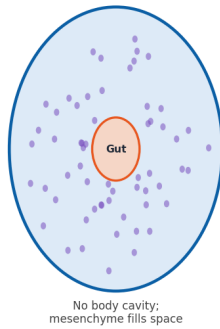
Diagrams & Illustrations

Body Organization: Acoelomate, Pseudocoelomate and Coelomate: a comparison of three body-cavity plans in animals - acoelomate (mesenchyme-filled, e.g. Platyhelminthes), pseudocoelomate (false coelom, e.g. Nematoda) and coelomate (true, mesoderm-lined coelom, e.g. Annelida).



Body Organization: Acoelomate, Pseudocoelomate and Coelomate

Acoelomate
(e.g. Platyhelminthes)



Pseudocoelomate
(e.g. Nematoda)



Coelomate
(e.g. Annelida)



Body Organization: Acoelomate, Pseudocoelomate and Coelomate

Major Phyla of Kingdom Animalia: a summary chart of the major animal phyla covered in this chapter - Porifera, Cnidaria, Platyhelminthes, Nematoda, Annelida, Arthropoda, Mollusca, Echinodermata and Chordata - with a key feature and example of each.

Major Phyla of Kingdom Animalia

Phylum	Key Feature	Example
Porifera	Pore-bearing, no tissues	<i>Sycon (sponge)</i>
Cnidaria	Diploblastic, nematocysts	<i>Hydra, Obelia</i>
Platyhelminthes	Acoelomate flatworm	<i>Taenia (tapeworm)</i>
Nematoda	Pseudocoelomate roundworm	<i>Ascaris</i>
Annelida	Segmented, coelomate	<i>Earthworm</i>
Arthropoda	Jointed legs, exoskeleton	<i>Insects, crabs</i>
Mollusca	Mantle, shell, radula	<i>Snail, octopus</i>
Echinodermata	Water vascular system	<i>Starfish</i>
Chordata	Notochord, dorsal nerve cord	<i>Fish, birds, mammals</i>

Major Phyla of Kingdom Animalia

Classes of Vertebrates (Phylum Chordata): a comparison chart of the five main vertebrate classes - Pisces, Amphibia, Reptilia, Aves and Mammalia - showing habitat, skin covering, heart chambers and reproduction type.



Classes of Vertebrates (Phylum Chordata)

Class	Habitat	Skin	Heart	Fertilization
<i>Pisces</i>	Aquatic	Scales	2-chambered	External
<i>Amphibia</i>	Water & land	Moist, glandular	3-chambered	External
<i>Reptilia</i>	Land	Dry, scaly	Partly 4-chambered	Internal
<i>Aves</i>	Land/air	Feathers	4-chambered	Internal
<i>Mammalia</i>	Land/water/air	Hair	4-chambered	Internal

Classes of Vertebrates (Phylum Chordata)

Short Questions & Answers

Q1. Differentiate radial and bilateral symmetry.

Ans. In radial symmetry, any plane passing through the central axis divides the animal into near-mirror-image halves (e.g. Cnidaria), whereas in bilateral symmetry only one specific plane divides the animal into two equal halves, with distinct anterior/posterior ends and dorsal/ventral surfaces (most Bilateria).

Q2. Differentiate acoelomate, pseudocoelomate and coelomate.

Ans. Acoelomates (e.g. Platyhelminthes) have no body cavity, with mesenchyme filling the space between gut and body wall; pseudocoelomates (e.g. Nematoda) have a false coelom derived from the blastocoel, not lined by mesoderm; coelomates (e.g. Annelida onward) have a true coelom fully lined by mesoderm.

Q3. Differentiate protostomes and deuterostomes (any two points).

Ans. In protostomes, cleavage is spiral and determinate and the mouth develops from the blastopore, whereas in deuterostomes, cleavage is radial and indeterminate and the blastopore develops into the anus, with the mouth forming separately.

Q4. What is polymorphism in coelenterates? Give an example.

Ans. Polymorphism is the occurrence of more than two structurally and functionally distinct types of individuals (zooids) within the same colonial organism; Obelia shows polymorphism with gastrozooids (feeding), blastostyles (asexual reproduction) and medusae (sexual reproduction), while Physalia has up to five zooid types.

Q5. What is metamorphosis? Name its three stages in insects.

Ans. Metamorphosis is an abrupt change of form or structure during an animal's life cycle; in insects with complete metamorphosis, the three main stages are larva, pupa, and adult (following the egg stage).

Q6. Differentiate amniotes and anamniotes, giving examples.

Ans. Amniotes (Reptilia, Aves, Mammalia) develop protective foetal membranes (amnion, chorion, allantois) around the embryo, while anamniotes (Cyclostomata, Chondrichthyes, Osteichthyes, Amphibia) lack these membranes and generally depend more on water for reproduction.



Long Questions & Answers

Q1: What is Cnidaria? Explain the diploblastic organization and alternation of generations in Cnidaria.

Cnidaria (Coelenterata) are diploblastic, radially symmetrical, aquatic animals named for their cnidocyte cells, which produce stinging nematocysts used in defence and prey capture. Their body develops from just two germ layers, an outer ectoderm (forming the body covering and, in most species, nematocyst-producing cells) and an inner endoderm (specialized for digestion), separated by a jelly-like, largely non-cellular mesogloea. Cnidarians have only a single body cavity, the gastrovascular cavity (enteron), which opens to the outside through one mouth and serves both digestive and circulatory functions (a sac-type digestive system); a diffuse nerve net coordinates the body, since there is no central nervous system. Cnidarians occur in two basic forms: the sessile, cylindrical polyp (mainly nutritive, e.g. Hydra) and the free-swimming, umbrella-shaped medusa (mainly reproductive, bearing gonads). Many cnidarians, such as Obelia, show alternation of generations: an asexually reproducing polyp generation (via budding, producing medusa buds from a specialized blastostyle zooid) alternates with a sexually reproducing medusa generation, whose gametes fuse to form a zygote that develops into a new polyp colony; both generations are diploid, unlike the haploid/diploid alternation seen in plants. Hydra, by contrast, exists only in polyp form and shows no alternation of generations.

Q2: Describe the parasitic adaptations in phylum Platyhelminthes. How does the tapeworm affect a person?

Parasitic Platyhelminthes have evolved a distinctive set of adaptations for their endoparasitic lifestyle: the epidermis is replaced by a resistant protective cuticle; adhesive organs such as suckers and hooks develop for firm attachment to host tissue; the muscular and nervous systems undergo degeneration since active, independent movement is less necessary; the digestive system becomes simplified (or is absent altogether, as in tapeworms) due to increasing dependence on nutrients absorbed directly from the host; the reproductive system becomes highly complex, and enormous numbers of eggs are produced to maximize the chance of reaching a new host; and the life cycle typically becomes complex, often requiring more than one host species. *Taenia solium* (pork tapeworm) illustrates these effects well: its ribbon-like body is divided into segments called proglottids, largely filled with reproductive organs, and it lives in the small intestine of humans, its definitive host, attaching using hooks and suckers on its scolex (head). Its mature, egg-filled proglottids break off and pass out with faeces; if these eggs are ingested by an intermediate host such as a pig or cow, the resulting larva becomes embedded in the animal's voluntary muscles. If a person then eats improperly cooked, infected meat, the surviving larva develops into an adult tapeworm within the human intestine, where it can grow very long, absorb digested nutrients directly through its body surface (having no gut of its own), and cause malnutrition and digestive disturbance in the host; because the parasite can regenerate a new worm from just its head, complete removal (often requiring medication) is essential to cure the infection.



Q3: Give an account of the major classes of Arthropoda. What is the economic importance of insects?

Phylum Arthropoda, the largest animal phylum, contains segmented, bilaterally symmetrical, triploblastic, coelomate (haemocoelic) animals bearing jointed appendages and covered by a chitinous exoskeleton periodically shed by moulting (ecdysis). Its major classes include Crustacea (mostly aquatic, gill-breathing, e.g. crabs, prawns, Daphnia, Cyclops, with a carapace over the cephalothorax and two pairs of antennae), Insecta (the largest class in the entire animal kingdom, with a body divided into head, thorax and abdomen, three pairs of legs and often one or two pairs of wings on the thorax, a pair of antennae and compound eyes, separate sexes, and metamorphosis during development, e.g. beetles, butterflies, mosquitoes), Arachnida (a fused cephalothorax and typically unsegmented or segmented abdomen, chelicerae, pedipalps, and four pairs of legs but no antennae, respiration by book lungs or gills, e.g. spiders, scorpions, mites and ticks), and Myriapoda (many segments, each bearing a pair of legs, a single pair of antennae, e.g. centipedes and millipedes). Insects are of enormous economic importance to humans, both harmful and beneficial. Harmful insects transmit serious diseases (Anopheles mosquitoes transmit the malaria parasite Plasmodium; tsetse flies transmit Trypanosoma, causing sleeping sickness; house flies spread cholera and hepatitis-causing organisms) and destroy crops and stored food (locusts, and various pests of sugarcane, cotton and vegetables), causing major economic losses to farmers. Beneficial insects include honeybees (honey and wax), silkworms (silk), predatory insects that control other pest populations, and scavenger insects that help decompose dead organic matter.

Q4: Explain the two major classes of Pisces, and describe the adaptations of fishes for aquatic life.

Superclass Pisces includes three classes, though the two major, more familiar groups are Chondrichthyes and Osteichthyes. Class Chondrichthyes (sharks and rays) have an entirely cartilaginous endoskeleton (considered a secondarily degenerated rather than primitive feature), placoid scales, a J-shaped stomach, 5 to 7 pairs of gills without a covering operculum, no swim bladder, and separate sexes that may be oviparous or viviparous; some sharks reach 30-50 feet, among the largest living vertebrates. Class Osteichthyes (bony fishes) have a predominantly bony skeleton (the notochord may persist only in parts), dermal scales (ganoid, cycloid or ctenoid, never placoid), gills covered by a protective operculum, a swim bladder usually present for buoyancy, a two-chambered heart with nucleated red blood cells, and mostly external fertilization. Fishes show several key adaptations for aquatic life: a streamlined, boat-shaped body that minimizes water resistance during swimming; a swim bladder, a hydrostatic organ that allows the fish to control its buoyancy by adjusting internal gas volume; paired fins (pectoral and pelvic) and unpaired fins (dorsal, caudal, anal) that provide balance and propulsion; a two-chambered heart with an afferent-efferent branchial circulatory arrangement suited to gill respiration; and gills richly supplied with blood capillaries, allowing efficient extraction of dissolved oxygen from water and removal of carbon dioxide.



Q5: Describe the general characteristics of mammals and differentiate the three subclasses Prototheria, Metatheria and Eutheria.

Mammals, named by Linnaeus for young that are nourished by milk from the mother's mammary glands, are considered the most advanced animal group, largely due to their highly developed brain and nervous system; they are believed to have evolved from reptile-like ancestors called cotylosaurs (mammal-like reptiles), becoming dominant during the Cenozoic period. General characteristics of mammals include a body covering of hair rather than scales, a muscular diaphragm separating the thoracic and abdominal cavities, a lower jaw formed of a single bone articulating directly with the skull, an external ear (pinna) and a chain of three middle-ear bones (malleus, incus, stapes), deciduous (milk) and permanent tooth sets in many species, a 4-chambered heart with only a left aortic arch, non-nucleated red blood cells, a well-developed voice apparatus (larynx and epiglottis), and being warm-blooded (homeothermic) and, in most cases, viviparous. Mammals are divided into three subclasses. Subclass Prototheria are egg-laying mammals that form a reptile-mammal connecting link, combining mammalian traits (fur, mammary glands) with reptilian traits (a single cloacal opening for digestive and urinogenital systems); examples are the duck-billed platypus and echidna, found in Australia. Subclass Metatheria are pouched mammals (marsupials) whose young are born immature and complete their development while attached to a nipple within the mother's abdominal pouch (marsupium), as in the kangaroo and opossum. Subclass Eutheria are placental mammals, in which the developing young is nourished through a placenta (which also has endocrine/hormonal functions) and is born fully developed; this subclass, showing the fullest expression of mammalian characteristics, includes humans, whales, elephants, horses, rodents and bats.

MCQs with Answers

1. Kingdom Animalia consists of organisms that are:

(a) autotrophic and unicellular (b) ingestive heterotrophs, multicellular, diploid (c) absorptive heterotrophs only (d) photosynthetic and motile

Correct Answer: (b) ingestive heterotrophs, multicellular, diploid. Animalia includes multicellular, diploid, eukaryotic, ingestive heterotrophs developing from two dissimilar gametes.

2. The simplest animals, lacking tissues organized into organs, belong to subkingdom:

(a) Eumetazoa (b) Parazoa (c) Radiata (d) Bilateria

Correct Answer: (b) Parazoa. Subkingdom Parazoa (phylum Porifera) lacks true tissue organization into organs.

3. The stinging cells characteristic of Cnidaria are called:

(a) choanocytes (b) cnidocytes (c) flame cells (d) nephridia

Correct Answer: (b) cnidocytes. Cnidocytes are specialized cells in Cnidaria that produce the stinging nematocysts.

4. Platyhelminthes are classified as:



(a) coelomates (b) pseudocoelomates (c) acoelomates (d) hemocoelomates

Correct Answer: (c) acoelomates. Platyhelminthes (flatworms) are acoelomates, lacking a true body cavity; mesenchyme fills the space instead.

5. The pseudocoelom of nematodes develops from the:

(a) mesoderm splitting (b) blastocoel (c) archenteron (d) ectoderm folding

Correct Answer: (b) blastocoel. The pseudocoelom is derived from the blastocoel of the embryo, not from a splitting of mesoderm.

6. Which is the largest phylum in the animal kingdom?

(a) Mollusca (b) Annelida (c) Arthropoda (d) Chordata

Correct Answer: (c) Arthropoda. Arthropoda is the largest animal phylum, containing more species than any other.

7. The rasping, tooth-bearing structure found in many molluscs is called the:

(a) radula (b) mantle (c) spicule (d) nephridium

Correct Answer: (a) radula. The radula is a rasping, tongue-like structure with horny teeth used for feeding in many molluscs.

8. The three defining features of phylum Chordata include the notochord, a dorsal hollow nerve cord, and:

(a) a closed circulatory system (b) paired pharyngeal gill slits (c) a segmented exoskeleton (d) jointed appendages

Correct Answer: (b) paired pharyngeal gill slits. The three chordate hallmark features are the notochord, dorsal hollow nerve cord, and paired pharyngeal gill slits.

9. Vertebrates with protective foetal membranes around the embryo (Reptilia, Aves, Mammalia) are called:

(a) anamniotes (b) amniotes (c) tetrapods (d) craniates

Correct Answer: (b) amniotes. Amniotes develop foetal membranes (amnion, chorion, allantois) protecting the embryo.

10. Egg-laying mammals such as the duck-billed platypus belong to subclass:

(a) Eutheria (b) Metatheria (c) Prototheria (d) Chondrichthyes

Correct Answer: (c) Prototheria. Subclass Prototheria comprises egg-laying mammals like the platypus and echidna.

Quick Revision Summary

- Kingdom Animalia: multicellular, diploid, eukaryotic, ingestive heterotrophs. Parazoa (Porifera, no tissues) vs Eumetazoa (tissues/organs); Radiata (Cnidaria) vs Bilateria; Acoelomate/Pseudocoelomate/Coelomate; Protostomes vs Deuterostomes.
- Diploblastic (2 germ layers, Cnidaria, sac-type gut, no CNS) vs Triploblastic (3 germ layers, most Bilateria, tube-type gut, organ systems).
- Porifera: pore-bearing, no tissues, choanocytes/spicules. Cnidaria: cnidocytes/nematocysts, polyp+medusa, alternation of generations, polymorphism, corals/coral reefs.
- Platyhelminthes: acoelomate flatworms, mostly parasitic (Taenia, Fasciola). Nematoda: pseudocoelomate roundworms (Ascaris, hookworm, pinworm).



- Annelida: segmented, coelomate, closed circulation, nephridia (earthworm, Nereis, leech). Arthropoda: largest phylum, jointed legs, exoskeleton, moulting, Crustacea/Insecta/Arachnida/Myriapoda.
- Mollusca: 2nd largest invertebrate phylum, mantle+shell, radula, haemocyanin (Gastropoda/Bivalvia/Cephalopoda). Echinodermata: spiny-skinned, water vascular system, radial as adults (bilateral larvae).
- Hemichordata: prechordates (Balanoglossus). Chordata: notochord + dorsal hollow nerve cord + gill slits; Protochordata (Urochordata, Cephalochordata) vs Vertebrata (Pisces + Tetrapoda).
- Vertebrate classes: Cyclostomata (jawless), Chondrichthyes (cartilage, sharks/rays), Osteichthyes (bony fish), Amphibia (anamniote, metamorphosis), Reptilia (amniote, scaly), Aves (feathers, 4-chambered heart), Mammalia (hair, milk; Prototheria/Metatheria/Eutheria). Notes by freebooks.pk.

Exam Tips

- Master the classification hierarchy: Parazoa/Eumetazoa -> Radiata/Bilateria -> Acoelomate/Pseudocoelomate/Coelomate -> Protostome/Deuterostome — a recurring theme across many questions.
 - Be ready to differentiate diploblastic vs triploblastic and radial vs bilateral symmetry with examples.
 - Memorise one key defining feature + one example organism for each phylum covered (Porifera through Chordata) — a very common short-question/table format.
 - Learn the 3 defining chordate characters (notochord, dorsal hollow nerve cord, pharyngeal gill slits) and the anamniote/amniote split among vertebrate classes.
 - Practise the aquatic-to-land adaptation list (skin, shelled eggs, lungs, jointed limbs, sense organs) — a classic extensive question.
 - Know the 3 mammalian subclasses (Prototheria, Metatheria, Eutheria) with one example and one key distinguishing feature each.
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FSc Part-I Biology — Punjab Board

CHAPTER 11

Bioenergetics

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Bioenergetics from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Bioenergetics is the quantitative study of energy relationships and energy conversions in biological systems, and all biological energy transformations obey the laws of thermodynamics; nearly all life on Earth is ultimately powered by solar energy, which chloroplasts capture and convert into chemical energy stored in sugars. These notes are prepared by freebooks.pk.

The chapter works through photosynthesis, the energy-capturing process (its reactants and products, the role of chloroplasts, photosynthetic pigments, light absorption and action spectra, the role of carbon dioxide, and the light-dependent and light-independent/Calvin cycle reactions), and then respiration, the energy-releasing process (aerobic vs anaerobic respiration, the role of mitochondria and ATP, and the four stages of cellular respiration: glycolysis, pyruvate oxidation, the Krebs cycle, and the respiratory electron transport chain with oxidative phosphorylation).

Learning Objectives

- Define bioenergetics and describe the overall relationship between photosynthesis and respiration.
- Describe the structure of the chloroplast and the roles of chlorophylls and accessory pigments.
- Differentiate absorption spectrum and action spectrum, and explain the role of CO₂ in photosynthesis.
- Describe the light-dependent reactions of photosynthesis, including photosystems, the Z-scheme, and chemiosmosis.
- Describe the light-independent reactions (Calvin cycle) and its three phases.
- Differentiate aerobic and anaerobic respiration and describe the fate of pyruvate under each.
- Describe the four stages of cellular respiration (glycolysis, pyruvate oxidation, Krebs cycle, respiratory chain) and calculate ATP yield.

Key Concepts

Bioenergetics and the Photosynthesis-Respiration Relationship

Bioenergetics is the quantitative study of energy relationships and energy conversions in biological systems, governed by the laws of thermodynamics. All organisms need free energy to stay alive, and nearly all life is powered directly or indirectly by solar energy, though no organism can use sunlight directly for metabolism — instead, chloroplasts capture light energy and convert it into chemical energy stored in sugars and other organic molecules. With the emergence of photosynthesis, molecular oxygen accumulated in the atmosphere, making possible the evolution of respiration, which releases energy and couples some of it to forming ATP, the key chemical link between catabolism and anabolism.



Photosynthesis is an energy-capturing process (using solar energy to build energy-rich organic molecules that cannot form without an energy input), while glycolysis and respiration are energy-releasing processes (breaking down that stored chemical energy in a controlled, stepwise manner). The overall photosynthesis equation ($6\text{CO}_2 + 6\text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$) is almost exactly the reverse of the aerobic respiration equation ($\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy}$): photosynthesis uses respiration's products and vice versa. Photosynthesis occurs only during daylight while respiration continues day and night; at low light (dawn/dusk), the two rates may briefly equal each other so there is no net gas exchange with the atmosphere, a condition called the compensation point.

Chloroplasts and Photosynthetic Pigments

Water is one of photosynthesis's two raw materials (with CO_2); Van Niel's 1930s hypothesis (based on photosynthetic bacteria) proposed that water, not CO_2 , is split to release oxygen, and this was confirmed in the 1940s using an O^{18} isotopic tracer, showing that plants supplied with heavy-oxygen water (H_2O^{18}) released O^{18} gas, while those supplied with heavy-oxygen CO_2 did not. Hydrogen from split water reduces NADP to NADPH, the "reducing power" that, along with ATP from light reactions, is used to reduce CO_2 into sugar during dark reactions. Chloroplasts, present in about half a million per square millimetre of leaf surface (mostly in mesophyll cells, with 20-100 per cell), have a double membrane enclosing the fluid-filled stroma (containing sugar-synthesizing enzymes) and an internal membrane system of flattened sacs called thylakoids (sometimes stacked into columns called grana), which house chlorophyll, other pigments, and the electron transport chain, and carry out ATP synthesis by chemiosmosis.

Thylakoid membranes contain several pigment types, chiefly chlorophylls, plus accessory carotenoids (red-to-orange carotenes and yellow-to-orange xanthophylls) that broaden the range of usable light. Chlorophyll a and b (found in eukaryotic plants/algae) differ only in one functional group (a methyl group in chlorophyll a vs. a carbonyl group in chlorophyll b), giving them slightly different absorption spectra and colours (blue-green vs. yellow-green); chlorophyll a is the most abundant and directly participates in light reactions, while chlorophyll b and carotenoids are accessory pigments, absorbing light and passing the energy to chlorophyll a (order of transfer: carotenoids $\rightarrow$ chlorophyll b $\rightarrow$ chlorophyll a). A chlorophyll molecule has a light-absorbing porphyrin "head" (with a central magnesium atom — its deficiency causes chlorosis/yellowing) and a hydrophobic phytol "tail" anchoring it in the thylakoid membrane.

Light Absorption and the Role of Carbon Dioxide

Visible light (about 380-750 nm) is the radiation most important to photosynthesis; only about 1% of light striking a leaf is actually absorbed. A graph of a pigment's relative light absorption at each wavelength is its absorption spectrum, showing chlorophyll's two absorption peaks near 430 nm (blue) and 670 nm (red); a graph of photosynthetic effectiveness at each wavelength is the action spectrum (first obtained by T.W. Engelmann in 1883, using *Spirogyra* and aerobic bacteria to detect oxygen release). The action spectrum closely parallels chlorophyll's absorption spectrum (confirming chlorophyll as the key photosynthetic pigment) but shows broader peaks and a shallower valley, because accessory



pigments like carotenoids absorb additional wavelengths (e.g. green light) and pass that energy on to chlorophyll.

Sugar is formed during the light-independent reactions by reducing CO₂ using the ATP and NADPH generated in light-dependent reactions, so photosynthesis cannot occur without CO₂. About 90% of global photosynthesis occurs in aquatic environments (using dissolved CO₂, bicarbonates and carbonates), with the remaining 10% on land, using atmospheric CO₂ (about 0.03-0.04%) that diffuses into leaves through adjustable pores called stomata; stomata cover only 1-2% of leaf surface yet allow proportionally much more gas exchange, and their opening/closing (regulated by guard cells, and following an internal circadian rhythm) is coordinated with the plant's photosynthetic needs, being open mostly during daylight.

Light-Dependent Reactions: Photosystems and Photophosphorylation

Photosynthesis is a redox process occurring in two parts: light-dependent reactions (using light directly, generating ATP and NADPH) and light-independent/dark reactions (using that stored ATP and NADPH to reduce CO₂ into sugar, whether or not light is present). In the thylakoid membrane, pigments are organized into photosystems, each with a light-gathering antenna complex (chlorophyll a, b and carotenoids channeling energy inward) and a reaction center (special chlorophyll a plus a primary electron acceptor). Photosystem II (reaction-center chlorophyll P680, absorbing best at 680 nm) and Photosystem I (reaction-center chlorophyll P700, absorbing best at 700 nm) are named by order of discovery, not sequence of action.

In the predominant non-cyclic electron flow, light excites an electron in PS II's P680, captured by its primary acceptor; the resulting electron "hole" is filled by electrons extracted from water via an enzyme, splitting water into hydrogen ions and oxygen (photolysis) — the main source of atmospheric oxygen replenishment. The photoexcited electron passes via an electron transport chain (plastoquinone, cytochromes, plastocyanin) to PS I, its energy loss driving ATP synthesis (non-cyclic photophosphorylation, so-called because light drives it). At PS I, light re-excites the electron (filling the earlier P700 hole), and the newly excited electron passes through a second transport chain to ferredoxin, then via NADP reductase reduces NADP⁺ to NADPH — this whole non-cyclic pathway, from water to NADPH, is called the Z-scheme. In the less common cyclic electron flow, only PS I is involved, and the electron eventually returns to PS I's reaction center, generating ATP (cyclic photophosphorylation) but no NADPH or oxygen. In both pathways, ATP synthesis occurs by chemiosmosis: the electron transport chain pumps H⁺ into the thylakoid space, and the resulting proton gradient drives H⁺ back through ATP synthase, powering ATP formation.

Light-Independent Reactions: The Calvin Cycle

The Calvin cycle, occurring in the chloroplast stroma, is the cyclic series of enzyme-catalyzed reactions by which carbon is fixed and reduced to synthesize sugar, using the ATP and NADPH generated by light reactions; its path was worked out by Melvin Calvin (Nobel Prize, 1961) and has three phases. In Phase 1 (carbon fixation), CO₂ reacts with the five-carbon sugar RuBP (ribulose biphosphate), catalyzed by the enzyme Rubisco (the most abundant



protein on Earth), forming an unstable six-carbon intermediate that immediately splits into two molecules of the three-carbon compound 3-phosphoglycerate (PGA) — since the first stable product is three carbons, the Calvin cycle is also called the C₃ pathway. In Phase 2 (reduction), each PGA molecule is phosphorylated by ATP (forming 1,3-bisphosphoglycerate) and then reduced by NADPH to form glyceraldehyde 3-phosphate (G3P), the same three-carbon sugar produced in glycolysis; of every six G3P molecules formed (from 3 CO₂ + 3 RuBP), only one leaves the cycle as net carbohydrate gain, used to build glucose, sucrose, starch and other organic compounds.

In Phase 3 (regeneration of the CO₂ acceptor), the remaining five G3P molecules are rearranged, using three more ATP molecules, back into three molecules of the five-carbon RuBP, regenerating the CO₂ acceptor so the cycle can continue. Overall, three turns of the cycle (fixing 3 CO₂) consume 9 ATP and 6 NADPH to net one G3P molecule.

Respiration: Aerobic and Anaerobic Pathways

Respiration is the universal process by which organisms break down carbon-containing compounds to harvest usable energy for cellular activities. "External respiration" refers to gas exchange (O₂/CO₂) between an organism and its environment, while cellular respiration is the stepwise intracellular breakdown of fuel molecules (typically glucose) to release energy. Before entering a mitochondrion, glucose is first split into two molecules of pyruvic acid in a process called glycolysis (occurring in the cytosol, without requiring oxygen); this same basic reaction is believed to have occurred in the earliest cells on Earth. From this point, pyruvate can follow different pathways depending on oxygen availability: alcoholic fermentation and lactic acid fermentation occur without oxygen (anaerobic), while complete glucose breakdown to CO₂ and water, releasing far more energy, requires oxygen (aerobic respiration).

In alcoholic fermentation (in primitive cells and some eukaryotes like yeast), pyruvic acid is converted into ethanol and CO₂. In lactic acid fermentation (e.g. in human muscle cells during intense exercise, when oxygen cannot be supplied fast enough), each pyruvic acid molecule is converted directly into lactic acid. Both fermentation pathways yield only a small fraction of glucose's stored energy as ATP (about 2%). Mitochondria, the cell's "powerhouses," have an outer membrane and a folded inner membrane (cristae) housing the enzymes and coenzymes that gradually release energy from organic molecules and transfer it to ATP's chemical bonds; ATP's terminal ("high-energy") phosphate bond releases about 7.3 kcal of free energy upon hydrolysis, powering processes such as biosynthesis, active transport, muscle contraction and nerve conduction. Biological oxidation, which ultimately supplies the free energy for nearly all cellular processes (apart from photosynthesis and some chemosynthesis), often proceeds via dehydrogenase-catalyzed removal of hydrogen atoms, since cellular respiration is essentially an oxidation process.

Cellular Respiration Stage 1: Glycolysis and Pyruvate Oxidation

Cellular respiration is divided into four stages: glycolysis, pyruvate (pyruvic acid) oxidation, the Krebs (citric acid) cycle, and the respiratory chain; only glycolysis occurs in the cytosol without requiring oxygen, while the remaining three occur inside the mitochondria and



require oxygen. Glycolysis breaks glucose down to pyruvic acid via enzyme-catalyzed steps requiring ATP and the coenzyme NAD, and has two phases. In the preparatory phase, glucose is phosphorylated (using 2 ATP) and rearranged, ultimately splitting into two three-carbon molecules (G3P and DHAP, readily interconverted). In the oxidative (payoff) phase, each G3P is oxidized (its hydrogens transferred to NAD, forming NADH) while gaining a phosphate to form 1,3-bisphosphoglycerate (BPG); this high-energy phosphate is then transferred to ADP (forming ATP) as BPG converts to 3-phosphoglycerate, which is further converted through several intermediate steps (via 2-phosphoglycerate and phosphoenolpyruvate) to pyruvate, transferring a second high-energy phosphate to ADP to form a second ATP. Overall, glycolysis nets 2 ATP and 2 NADH per glucose molecule (from an initial investment of 2 ATP and a total production of 4 ATP).

Pyruvate does not enter the Krebs cycle directly: it is first decarboxylated (releasing one carbon as CO₂), converting the 3-carbon pyruvate into a 2-carbon acetic acid unit, which combines with coenzyme A to form acetyl-CoA (active acetate) upon entering the mitochondrion, with additional hydrogen atoms transferred to NAD in the process.

Cellular Respiration Stages 2-4: Krebs Cycle and the Respiratory Chain

Acetyl CoA enters the Krebs (citric acid) cycle, discovered by biochemist Hans Krebs, by combining with the 4-carbon oxaloacetate to form 6-carbon citrate (regenerating free CoA). Citrate is rearranged to isocitrate, then oxidized (releasing CO₂, forming NADH) to alpha-ketoglutarate, which is further oxidized and decarboxylated (another NADH and CO₂ released) to succinate, with enough free energy released in this step to directly form one ATP molecule. Succinate is oxidized to fumarate (using FAD as the oxidizing agent, forming FADH₂), then hydrated to malate, and finally oxidized (another NADH formed) back to oxaloacetate, completing the cycle so it can combine with a new acetyl-CoA and repeat. Each turn of the Krebs cycle (per acetyl-CoA/pyruvate) yields 3 NADH, 1 FADH₂, 1 ATP, and releases 2 CO₂.

In the respiratory chain (electron transport chain), NADH transfers its hydrogen/electrons through a series of redox carriers — coenzyme Q, then a series of cytochromes (b, c, a, a₃, containing iron-bearing haem groups like those in haemoglobin) — ultimately to molecular oxygen, the final, most electronegative electron acceptor, forming water. Three points along this chain release enough energy to synthesize ATP, so each NADH entering the chain yields about 3 ATP via oxidative phosphorylation (ATP synthesis coupled to oxygen-dependent electron transport). As in photosynthesis, this ATP synthesis occurs by chemiosmosis, but here the electron transport chain pumps protons across the inner mitochondrial membrane (from the matrix into the intermembrane space), and their subsequent diffusion back through ATP synthase drives ATP formation — though the specific carrier and coupling molecules differ from those used in photosynthesis.

Important Definitions

Term	Definition
Bioenergetics	



Term	Definition
	The quantitative study of energy relationships and energy conversions (governed by thermodynamics) in biological systems.
Photosynthesis	The process by which chlorophyll-containing organisms use light energy to convert CO ₂ and water into energy-rich glucose and oxygen.
Photolysis	The light-driven splitting of water molecules into hydrogen ions, electrons and oxygen during the light reactions of photosynthesis.
Photophosphorylation	The light-driven synthesis of ATP occurring during the light-dependent reactions of photosynthesis (cyclic or non-cyclic).
Chemiosmosis	The process in which a proton (H ⁺) gradient across a membrane, created by an electron transport chain, drives ATP synthesis via ATP synthase.
Glycolysis	The cytosolic, oxygen-independent breakdown of one glucose molecule into two molecules of pyruvic acid, with a net gain of 2 ATP and 2 NADH.
Krebs cycle (citric acid cycle)	The mitochondrial cyclic series of reactions that completes the oxidation of acetyl-CoA, producing NADH, FADH ₂ , ATP and CO ₂ .
Oxidative phosphorylation	The synthesis of ATP that occurs in the respiratory (electron transport) chain, coupled to the reduction of oxygen to water.

Key Facts

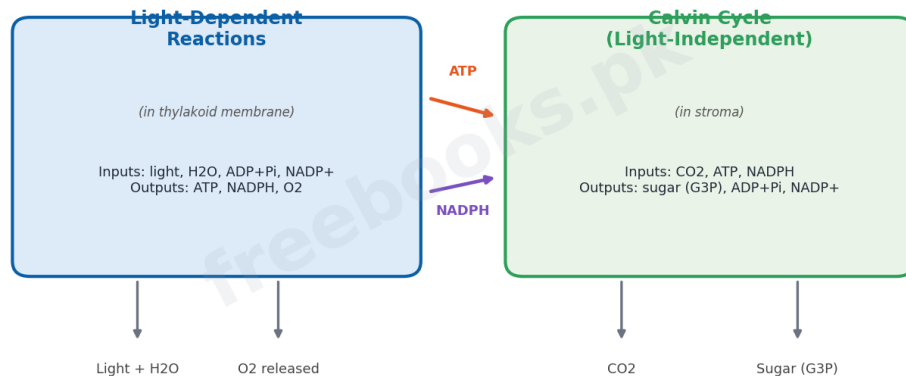
Item	Fact
Photosynthesis (overall equation)	$6\text{CO}_2 + 6\text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ (occurs in chloroplasts).
Aerobic respiration (overall equation)	$\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy}$ (the reverse of photosynthesis).
Source of photosynthetic O ₂	Water (confirmed by Van Niel's hypothesis and O ¹⁸ isotope-tracer experiments).
Chlorophyll absorption peaks	Photosystem II: P680 (680 nm); Photosystem I: P700 (700 nm).
Calvin cycle discoverer	Melvin Calvin - Nobel Prize, 1961; enzyme Rubisco = most abundant protein on Earth.
Glycolysis net yield	1 glucose $\rightarrow$ 2 pyruvate + net 2 ATP + 2 NADH (occurs in the cytosol, no O ₂ required).
ATP high-energy bond	Hydrolysis of ATP's terminal phosphate bond releases about 7.3 kcal of free energy.
Anaerobic fermentation efficiency	Only about 2% of glucose's stored energy is converted into ATP without oxygen.



Diagrams & Illustrations

Overview of Photosynthesis: a diagram showing the two-phase overview of photosynthesis - light-dependent reactions (using light, H₂O and producing ATP, NADPH and O₂) feeding into light-independent Calvin cycle reactions (using CO₂, ATP and NADPH to produce sugar).

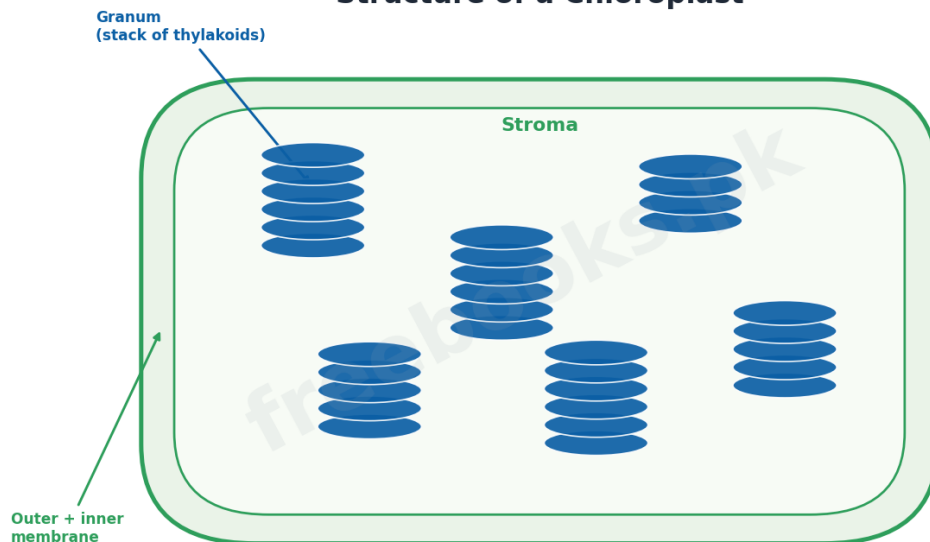
Overview of Photosynthesis



Overview of Photosynthesis

Structure of a Chloroplast: a labelled diagram of a chloroplast showing the outer double membrane, the stroma, and the internal thylakoid membrane system stacked into grana.

Structure of a Chloroplast



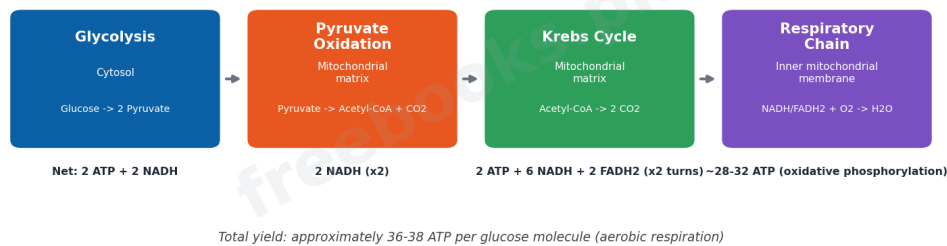
Light reactions occur on thylakoid/granum membranes; Calvin cycle occurs in the stroma

Structure of a Chloroplast

Stages of Aerobic Respiration: a flow diagram of the four stages of aerobic cellular respiration - glycolysis, pyruvate oxidation, the Krebs cycle and the respiratory (electron transport) chain - with their approximate ATP yield.



Stages of Aerobic Respiration



Stages of Aerobic Respiration

Short Questions & Answers

Q1. What is the net production of ATP during glycolysis?

Ans. Glycolysis produces 4 ATP molecules but consumes 2 ATP in its preparatory phase, giving a net gain of 2 ATP per glucose molecule, along with 2 NADH.

Q2. What is the main difference between photophosphorylation and oxidative phosphorylation?

Ans. Photophosphorylation is the light-driven synthesis of ATP during the light reactions of photosynthesis in chloroplasts, whereas oxidative phosphorylation is the synthesis of ATP during the respiratory electron transport chain in mitochondria, driven by the reduction of oxygen to water.

Q3. What is the role of accessory pigments in light absorption?

Ans. Accessory pigments such as chlorophyll b and carotenoids absorb light at wavelengths not well absorbed by chlorophyll a and transfer that energy to chlorophyll a, broadening the range of light wavelengths usable for photosynthesis.

Q4. When and why is there no net exchange of CO₂ and O₂ between leaves and the atmosphere?

Ans. At low light intensities, such as dawn or dusk, the rate of photosynthesis may briefly equal the rate of respiration, so the oxygen released by photosynthesis is exactly used up by respiration and the CO₂ released by respiration is exactly used up by photosynthesis; this is called the compensation point.

Q5. Differentiate cyclic and non-cyclic photophosphorylation.

Ans. Non-cyclic photophosphorylation involves both photosystem I and II, produces ATP, NADPH and oxygen, and electrons flow from water to NADPH (Z-scheme); cyclic photophosphorylation involves only photosystem I, produces only ATP (no NADPH or oxygen), with electrons returning to the same reaction center.

Q6. What are T.W. Engelmann and Melvin Calvin famous for?

Ans. T.W. Engelmann obtained the first action spectrum of photosynthesis in 1883 using *Spirogyra* and aerobic bacteria; Melvin Calvin discovered the path of carbon fixation and reduction in the light-independent reactions (the Calvin cycle), for which he won the Nobel Prize in 1961.



Long Questions & Answers

Q1: Give an account of the light-dependent reactions of photosynthesis, explaining the Z-scheme.

The light-dependent reactions occur in the thylakoid membranes of the chloroplast, where photosynthetic pigments are organized into photosystems, each with a light-gathering antenna complex and a reaction center. In the predominant pathway, non-cyclic electron flow, light striking Photosystem II excites an electron in its reaction-center chlorophyll (P680), which is captured by a primary electron acceptor; the resulting electron "hole" in P680 is refilled by electrons extracted from water molecules through an enzyme-catalyzed reaction (photolysis), which splits water into hydrogen ions and oxygen gas, the source of atmospheric oxygen replenishment. The photoexcited electron then passes down an electron transport chain (plastoquinone, cytochromes, plastocyanin) to Photosystem I, and the energy released as it moves down this chain is used to synthesize ATP by chemiosmosis, a process called non-cyclic photophosphorylation. Meanwhile, light also excites an electron in PS I's reaction-center chlorophyll (P700); this hole is filled by the electron arriving from PS II, while the newly excited P700 electron passes through a second electron transport chain to the iron-containing protein ferredoxin, and finally, via the enzyme NADP reductase, reduces NADP^+ to NADPH. This entire electron pathway, tracing electrons from water through both photosystems to NADPH, is called the Z-scheme because of its characteristic zigzag shape when the redox potentials are plotted. In both non-cyclic and the less common cyclic electron flow (which uses only Photosystem I and generates ATP but no NADPH or oxygen), ATP synthesis occurs by chemiosmosis: the electron transport chain pumps protons into the thylakoid interior space, creating a proton gradient whose energy is released as protons diffuse back out through ATP synthase complexes, driving ATP formation from ADP and inorganic phosphate.

Q2: Give an account of the light-independent reactions (Calvin cycle) of photosynthesis.

The light-independent (dark) reactions take place in the stroma of the chloroplast and do not require light directly, proceeding equally well in light or darkness provided the ATP and NADPH generated by the light reactions are available; these reactions constitute the Calvin cycle, whose path was elucidated by Melvin Calvin (Nobel Prize, 1961), and comprise three phases. In Phase 1, carbon fixation, a molecule of CO_2 combines with the five-carbon sugar ribulose biphosphate (RuBP), a reaction catalyzed by the abundant enzyme Rubisco, forming an unstable six-carbon intermediate that immediately splits into two molecules of the three-carbon compound 3-phosphoglycerate (PGA) — since three-carbon PGA is the first stable product, the Calvin cycle is also called the C_3 pathway. In Phase 2, reduction, each PGA molecule receives a phosphate group from ATP (forming 1,3-bisphosphoglycerate) and is then reduced, using electrons donated by NADPH, to glyceraldehyde 3-phosphate (G3P), the same three-carbon sugar produced during glycolysis; for every three CO_2 molecules fixed (reacting with 3 RuBP), six G3P molecules are formed, but only one of these six leaves the cycle as the net carbohydrate product, to be used in synthesizing glucose, sucrose, starch and other organic compounds. In Phase 3, regeneration of the CO_2 acceptor, the



remaining five G3P molecules undergo a complex series of rearrangements, using three further ATP molecules, to regenerate three molecules of the five-carbon RuBP, allowing the cycle to accept new CO₂ and continue. Overall, fixing three CO₂ molecules to net one G3P molecule consumes nine ATP and six NADPH generated by the light reactions.

Q3: Describe the various steps involved in the oxidative breakdown of glucose to pyruvate (glycolysis).

Glycolysis, the breakdown of one glucose molecule into two molecules of pyruvic acid, occurs in the cytosol and does not require oxygen, though it proceeds in both aerobic and anaerobic conditions; it comprises a preparatory phase and an oxidative (payoff) phase. In the preparatory phase, glucose first receives a phosphate group from ATP, forming glucose-6-phosphate, which is isomerized to fructose-6-phosphate; a second ATP then donates another phosphate, forming fructose 1,6-bisphosphate, which is enzymatically split into two three-carbon molecules, glyceraldehyde 3-phosphate (G3P/PGAL) and dihydroxyacetone phosphate (readily interconverted into more G3P) — this phase consumes 2 ATP per glucose molecule. In the oxidative phase, each G3P molecule is oxidized (transferring two hydrogen atoms/electrons to NAD⁺, forming NADH) while simultaneously gaining an inorganic phosphate group, forming 1,3-bisphosphoglycerate (BPG), a high-energy intermediate; this high-energy phosphate is then transferred to ADP, forming one ATP molecule and leaving 3-phosphoglycerate (3-PG), which is converted to 2-phosphoglycerate and then, by loss of a water molecule, to phosphoenolpyruvate (PEP); PEP's remaining high-energy phosphate is finally transferred to a second ADP, forming a second ATP molecule and leaving pyruvate (pyruvic acid) as the end product. Since each glucose molecule yields two three-carbon fragments, these oxidative-phase reactions occur twice per glucose, so the total yield is 4 ATP and 2 NADH, but since 2 ATP were consumed in the preparatory phase, the net yield of glycolysis is 2 ATP and 2 NADH, plus 2 molecules of pyruvate.

Q4: Sketch and discuss the Krebs cycle and its energy-yielding steps.

Before entering the Krebs cycle, pyruvate (a 3-carbon molecule) is oxidatively decarboxylated, releasing one carbon as CO₂ and forming a 2-carbon acetate unit, which combines with coenzyme A to form acetyl-CoA, with an additional pair of hydrogen atoms transferred to NAD⁺ to form NADH. The Krebs (citric acid) cycle then begins as acetyl-CoA combines with the 4-carbon oxaloacetate to form 6-carbon citrate, regenerating free coenzyme A in the process. Citrate is rearranged into its isomer isocitrate, which then undergoes an NAD-linked oxidation with loss of a CO₂ molecule, forming the 5-carbon alpha-ketoglutarate; this in turn is further oxidized (producing another NADH) and decarboxylated (releasing a second CO₂), forming succinate, a step in which enough free energy is released to directly synthesize one ATP molecule. Succinate is then oxidized to fumarate by the coenzyme FAD (rather than NAD), producing FADH₂; a molecule of water is added to fumarate to form malate, which undergoes a final NAD-linked oxidation to regenerate oxaloacetate, completing the cycle so that oxaloacetate can combine with a new acetyl-CoA molecule and begin again. Each single turn of the Krebs cycle (corresponding to one acetyl-CoA/one original pyruvate) yields three molecules of NADH, one molecule of FADH₂, one molecule of ATP (formed directly, by substrate-level phosphorylation), and releases two



molecules of CO₂; because each glucose molecule yields two pyruvate (and hence two acetyl-CoA), the Krebs cycle turns twice per glucose molecule, doubling this yield.

Q5: Discuss the respiratory electron transport chain and oxidative phosphorylation, and sum up the total ATP yield from one glucose molecule.

In the respiratory (electron transport) chain, located in the inner mitochondrial membrane, the NADH and FADH₂ produced during glycolysis, pyruvate oxidation and the Krebs cycle donate their electrons (and associated energy) to a sequence of redox carriers: NADH is oxidized by coenzyme Q, which is oxidized by cytochrome b, then cytochrome c, then the cytochrome a/a₃ complex, with molecular oxygen serving as the final, most electronegative electron acceptor, combining with electrons and protons to form water. Three of these transfer steps release enough free energy to synthesize an ATP molecule each, so complete oxidation of one NADH via this chain yields approximately 3 ATP (while FADH₂, entering the chain at a later point, yields approximately 2 ATP); this coupling of electron transport to ATP synthesis, called oxidative phosphorylation, occurs by chemiosmosis, in which the electron transport chain pumps protons from the mitochondrial matrix into the intermembrane space, and the resulting proton gradient drives ATP synthesis as protons diffuse back through ATP synthase. Summing the ATP yield from all stages: glycolysis nets 2 ATP directly plus 2 NADH (worth about 6 ATP via the respiratory chain); pyruvate oxidation (occurring twice per glucose) yields 2 NADH (about 6 ATP); and the Krebs cycle (also turning twice per glucose) yields 2 ATP directly, 6 NADH (about 18 ATP) and 2 FADH₂ (about 4 ATP) — giving a total yield in the range of about 36-38 ATP molecules from the complete aerobic oxidation of one glucose molecule, vastly more than the roughly 2 ATP obtainable from fermentation alone.

MCQs with Answers

1. The overall equation of photosynthesis shows that the raw materials are carbon dioxide, water and:

(a) oxygen (b) light energy (c) glucose (d) ATP

Correct Answer: (b) light energy. Photosynthesis uses CO₂, water and light energy as raw materials/energy input to produce glucose and oxygen.

2. Van Niel's hypothesis, later confirmed by O¹⁸ isotope experiments, showed that the oxygen released in photosynthesis comes from:

(a) carbon dioxide (b) glucose (c) water (d) ATP

Correct Answer: (c) water. The oxygen released during photosynthesis originates from water, not carbon dioxide, as confirmed by O¹⁸-tracer experiments.

3. The reaction-center chlorophyll of Photosystem II is best known as:

(a) P680 (b) P700 (c) P600 (d) P870

Correct Answer: (a) P680. Photosystem II's reaction-center chlorophyll, P680, absorbs light best at 680 nm.

4. Rubisco, the enzyme that catalyzes carbon fixation in the Calvin cycle, is notable for being:



(a) the smallest known enzyme (b) the most abundant protein on Earth (c) found only in animal cells (d) a coenzyme, not an enzyme

Correct Answer: (b) the most abundant protein on Earth. Rubisco (ribulose biphosphate carboxylase) is considered the most abundant protein on Earth.

5. The Calvin cycle is also known as the C₃ pathway because its first stable product is a:

(a) 2-carbon compound (b) 3-carbon compound (c) 4-carbon compound (d) 6-carbon compound

Correct Answer: (b) 3-carbon compound. The first stable product of carbon fixation is 3-phosphoglycerate (PGA), a 3-carbon compound, giving the name C₃ pathway.

6. Glycolysis occurs in the:

(a) mitochondrial matrix (b) thylakoid membrane (c) cytosol (d) nucleus

Correct Answer: (c) cytosol. Glycolysis takes place in the cytosol and does not require the presence of oxygen.

7. The net ATP yield from glycolysis per glucose molecule is:

(a) 0 ATP (b) 2 ATP (c) 4 ATP (d) 36 ATP

Correct Answer: (b) 2 ATP. Glycolysis produces 4 ATP but consumes 2 ATP, giving a net yield of 2 ATP per glucose molecule.

8. The Krebs cycle takes place in the:

(a) cytosol (b) mitochondrial matrix (c) thylakoid lumen (d) nuclear envelope

Correct Answer: (b) mitochondrial matrix. The Krebs (citric acid) cycle occurs within the mitochondrial matrix.

9. In the respiratory electron transport chain, the final acceptor of electrons is:

(a) NAD⁺ (b) coenzyme Q (c) molecular oxygen (d) FAD

Correct Answer: (c) molecular oxygen. Molecular oxygen is the final, most electronegative electron acceptor, forming water.

10. ATP synthesis coupled to a proton gradient across a membrane is known as:

(a) substrate-level phosphorylation (b) chemiosmosis (c) glycolysis (d) fermentation

Correct Answer: (b) chemiosmosis. Chemiosmosis is the process where a proton gradient generated by electron transport drives ATP synthesis via ATP synthase.

Quick Revision Summary

- Bioenergetics = study of energy transformations in living systems. Photosynthesis (energy-capturing) vs Respiration (energy-releasing); overall equations are near-exact reverses of each other. Compensation point = photosynthesis rate equals respiration rate.
- Chloroplast: double membrane, stroma (Calvin cycle enzymes), thylakoids/grana (light reactions, pigments). Chlorophyll a = main pigment (P680 in PSII, P700 in PSI); chlorophyll b + carotenoids = accessory pigments.
- Absorption spectrum (pigment's light absorption by wavelength) vs Action spectrum (photosynthetic effectiveness by wavelength) - closely match, confirming



chlorophyll's role. Van Niel + O^{18} tracer proved photosynthetic O_2 comes from water.

- Light reactions (thylakoid): PS II $\rightarrow$ photolysis of water (releases O_2) $\rightarrow$ electron transport $\rightarrow$ PS I $\rightarrow$ NADPH; ATP made by chemiosmosis (non-cyclic = Z-scheme, makes ATP+NADPH+ O_2 ; cyclic = PS I only, makes ATP only).
- Calvin cycle (stroma, C3 pathway): Carbon fixation ($CO_2 + RuBP \rightarrow 2$ PGA via Rubisco) $\rightarrow$ Reduction (PGA $\rightarrow$ G3P using ATP+NADPH) $\rightarrow$ Regeneration of RuBP (using ATP). Net: $3CO_2 + 9ATP + 6NADPH \rightarrow 1$ G3P.
- Respiration: Glycolysis (cytosol, glucose $\rightarrow$ 2 pyruvate, net 2 ATP + 2 NADH) $\rightarrow$ Pyruvate oxidation (pyruvate $\rightarrow$ acetyl-CoA + CO_2 + NADH) $\rightarrow$ Krebs cycle (mitochondrial matrix, acetyl-CoA $\rightarrow$ $2CO_2 + 3NADH + 1FADH_2 + 1ATP$ per turn) $\rightarrow$ Respiratory chain (NADH/FADH $_2 \rightarrow$ ETC $\rightarrow$ $O_2 \rightarrow H_2O + ATP$ via oxidative phosphorylation/chemiosmosis).
- Anaerobic respiration (fermentation): alcoholic (yeast: pyruvate $\rightarrow$ ethanol + CO_2) or lactic acid (muscle: pyruvate $\rightarrow$ lactic acid); only ~2% of glucose's energy converted to ATP, vs ~36-38 ATP from full aerobic respiration. Notes by freebooks.pk.

Exam Tips

- Learn the overall equations of photosynthesis and respiration side by side — note how one is the reverse of the other.
- Be clear on absorption spectrum vs action spectrum, and why the action spectrum has broader peaks (accessory pigments).
- Master the Z-scheme (non-cyclic electron flow) step by step: PS II $\rightarrow$ photolysis $\rightarrow$ ETC $\rightarrow$ PS I $\rightarrow$ NADPH; also know cyclic electron flow (PS I only, ATP only).
- Memorise the 3 phases of the Calvin cycle (fixation, reduction, regeneration) with the key molecules (RuBP, Rubisco, PGA, G3P) at each step.
- Practise adding up ATP yield: glycolysis (net 2 ATP), Krebs cycle (1 ATP/turn $\times$ 2), respiratory chain (~3 ATP/NADH, ~2 ATP/FADH $_2$) to reach the ~36-38 ATP total per glucose.
- Compare cyclic vs non-cyclic photophosphorylation, and photophosphorylation vs oxidative phosphorylation — both are classic exam "differentiate" questions.

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FSc Part-I Biology — Punjab Board

CHAPTER 12

Nutrition

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Nutrition from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Nutrition is the sum total of all processes involved in taking in and using nutrients (food or substances supplying elements necessary for metabolism) for growth, repair and the maintenance of life activities; organisms are broadly autotrophic (manufacturing their own organic compounds) or heterotrophic (obtaining organic molecules from the environment). These notes are prepared by freebooks.pk.

The chapter covers mineral nutrition and its deficiencies in plants, special modes of plant nutrition (saprophytic, parasitic, symbiotic and insectivorous), the diverse feeding methods of animals (detritivores, herbivores, carnivores, omnivores, filter/fluid/macrophagous feeders) and parasitic nutrition in animals, the general processes of holozoic nutrition (ingestion, digestion, absorption, assimilation, egestion) illustrated in Amoeba, Hydra, Planaria and cockroach, and a detailed account of human digestion, absorption and common nutrition-related diseases.

Learning Objectives

- Define nutrition and differentiate autotrophic and heterotrophic nutrition.
- Describe mineral nutrition in plants and the effects of common mineral deficiencies.
- Describe saprophytic, parasitic, symbiotic and insectivorous modes of plant nutrition.
- Classify animals by feeding method and describe parasitic nutrition in animals.
- Describe the five processes of holozoic nutrition and digestion in Amoeba, Hydra, Planaria and cockroach.
- Describe digestion in the human oral cavity, stomach and small intestine, and the process of absorption.
- Describe common diseases related to nutrition and digestion.

Key Concepts

Nutrition: Autotrophic, Heterotrophic and Mineral Nutrition in Plants

A nutrient is any food or substance that supplies the body with elements necessary for metabolism; some nutrients (carbohydrates, fats, proteins) provide energy while others (water, electrolytes, minerals, vitamins) are essential to metabolic processes. Nutrition is the sum total of all processes by which organisms take in and use these elements for growth, repair and maintenance. Organisms are divided into autotrophs, which manufacture their own organic compounds from inorganic raw materials (CO₂, water, nitrates) and can exist in a purely inorganic environment, and heterotrophs, which cannot manufacture organic compounds from simple inorganic nutrients and must obtain organic molecules as food from the environment.

Photosynthetic (autotrophic) organisms obtain carbon, oxygen and hydrogen from CO₂ and water, but need other elements too: nitrogen (for proteins), phosphorus (for ATP and nucleic



acids), magnesium (for chlorophyll) and iron (for cytochromes), obtained mainly from the soil; farmers replenish these through manure, sewage sludge or fertilizers (e.g. urea, super phosphates, ammonium nitrate). Deficiencies of specific minerals cause characteristic disorders: nitrogen deficiency causes stunted growth and chlorosis (loss of chlorophyll, especially in older leaves), phosphorus deficiency causes stunted root growth, potassium deficiency causes yellow-brown leaf margins and premature death, and magnesium deficiency also causes chlorosis.

Special Modes of Plant Nutrition

Saprophytic nutrition is feeding on dead and decaying matter (e.g. dead leaves, rotting wood); saprophytes secrete extracellular enzymes to digest this matter and absorb the soluble products, and some bacteria break down dead proteins to release nitrates for plant roots, contributing to the nitrogen cycle. Parasitic nutrition is feeding by living in or on another living organism (the host) of a different species; for example, *Puccinia* is a parasitic fungus destroying wheat, and *Cuscuta* (dodder) is a leafless twining parasitic plant that penetrates the host's conducting tissue with suckers.

Symbiotic nutrition is mutual nutrition between two different species living in association, such as lichens (fungus + alga, where the alga photosynthesizes food and the fungus supplies water, minerals and protection), mycorrhizae (fungus + plant roots, improving nutrient/water uptake) and root nodules of leguminous plants (containing nitrogen-fixing bacteria that convert atmospheric nitrogen into nitrates the plant can use). Some plants (insectivorous plants) supplement inorganic nutrition by trapping and digesting insects for nitrogenous compounds while remaining true autotrophs: the pitcher plant (*Sarracenia*) traps insects in a fluid-filled leaf modified into a pitcher; the Venus flytrap (*Dionaea muscipula*) has a bilobed leaf that snaps shut on sensitive-hair contact; and the sundew (*Drosera*) traps insects on sticky, glandular tentacle-like hairs, digesting them with secreted enzymes in all three cases.

Methods of Animal Nutrition and Parasitic Nutrition

Animals show far greater dietary variety than plants and can be classified by feeding method: detritivores feed on organic debris (e.g. earthworms ingesting decaying vegetation); herbivores feed on plants (e.g. rodents and ungulates, with grinding premolars/ molars and no canines); carnivores feed on other animals (large canine teeth for catching/ tearing prey, e.g. cats, dogs, lions — the predator-prey relationship helps stabilize ecosystems, as shown when rabbits introduced to Australia without natural predators multiplied disastrously); and omnivores eat both plant and animal food (e.g. crows, bears, humans), with intermediate tooth structure. Filter feeders extract food particles from water using structures like cilia-covered gills (e.g. mussels, some whales); fluid feeders ingest liquid food (e.g. aphids sucking phloem sap, mosquitoes sucking blood); and macrophagous feeders take in large food pieces via tentacular feeding (*Hydra*), scraping with a radula (garden snail *Helix*), or seizing/swallowing prey (dogfish).

A parasite lives upon (ectoparasite, e.g. fleas, lice, ticks, leeches) or within (endoparasite, e.g. *Entamoeba histolytica*, tapeworm, roundworms) a host organism to obtain food; obligate



parasites can only live parasitically, while facultative parasites can also live independently. Endoparasites are commonly found in the vertebrate intestine, absorbing the host's digested food, and may weaken the host directly or via toxic excretory products.

Holozoic Nutrition: General Processes and Digestion in Amoeba and Hydra

Since most required nutrients (except water and oxygen) occur naturally as complex proteins, starches, fats and other molecules unusable until broken down, holozoic nutrition (typical of most animals) involves five characteristic processes: ingestion (taking in complex food), digestion (enzymatic breakdown of complex compounds into simpler, diffusible molecules — intracellular, within cells, or extracellular, in a gut cavity/lumen), absorption (uptake of digested molecules across membranes into cells or blood), assimilation (using absorbed products for energy or building cellular material), and egestion (elimination of undigested waste).

In *Amoeba proteus*, digestion is entirely intracellular: pseudopodia surround a food particle to form a food vacuole, into which lysosomal hydrolytic enzymes are secreted, first killing/softening the food in an acidic environment (~pH 5.6) and then completing digestion in an alkaline environment (~pH 7.3); digested products pass into the cytoplasm via fine canals, and undigested matter is egested at any point on the body surface. In *Hydra*, a diploblastic cnidarian, food is captured using stinging nematocyst-bearing tentacles (which paralyze prey like *Daphnia*) and pushed through the single mouth opening into the gastrovascular cavity (coelenteron); glandular gastrodermal cells secrete enzymes for extracellular digestion, after which gastrodermal cells phagocytose food particles to complete digestion intracellularly in digestive vacuoles, with indigestible matter expelled back out through the same mouth (a sac-like digestive system with one opening for both ingestion and egestion).

Digestion in Planaria and Cockroach

In *Planaria* (a free-living flatworm), a single mouth on the ventral surface leads through a muscular, eversible pharynx into a much-branched intestine (anterior and two lateral branches with many blind-ending caecae); the pharynx is protruded to engulf prey, extracellular digestion begins via gland-cell secretions in the intestine, and small particles are then phagocytosed and digested intracellularly, with the branched intestine also aiding diffusion of nutrients to body cells; undigested food is egested back out through the mouth.

The cockroach has a tubular digestive system divided into foregut (mouth cavity, pharynx, crop, gizzard — receiving saliva from salivary glands that begins starch digestion), midgut (mesenteron, with finger-like hepatic caecae secreting digestive enzymes that complete food breakdown), and hindgut (a long coiled tube ending in the rectum, which opens via the anus). Food is cut by mandibles, mixed with saliva, temporarily stored in the crop, ground in the gizzard, then enzymatically digested in the midgut, with indigestible matter stored briefly in the rectum before egestion — a more efficient tubular system than a sac-like one, since separate mouth and anus openings and specialized regions allow more efficient, one-directional digestion and absorption.



Digestion in Man: Oral Cavity, Swallowing and the Stomach

The human digestive system is a long coiled tube from mouth to anus (oral cavity, esophagus, stomach, small intestine [duodenum, jejunum, ileum], large intestine [caecum, colon, rectum]), with associated glands (salivary glands, liver, pancreas); there are three sites of digestion: the oral cavity, the stomach, and the small intestine. In the oral cavity, food is selected (by taste, smell and sight), masticated by molar teeth (increasing surface area for enzymes and enabling swallowing), and lubricated and partly digested by saliva, secreted by three pairs of glands (sublingual, submaxillary, parotid); saliva contains water and mucus (lubrication), sodium bicarbonate and salts (pH stabilization) and the enzyme ptyalin (salivary amylase), which digests starch and glycogen into maltose. Swallowing forms the masticated food into a bolus, which the tongue and pharyngeal muscles push backward while the soft palate closes the nasal passage and the epiglottis covers the windpipe (glottis), directing the bolus safely into the esophagus, down which it travels by peristalsis (coordinated waves of circular and longitudinal muscle contraction and relaxation); reversed peristalsis (antiperistalsis) causes vomiting.

At the stomach entrance, the cardiac sphincter controls food entry; the elastic, muscular stomach stores food (allowing discontinuous feeding) and partly digests it, its wall having an outer connective tissue layer, a middle muscular layer (longitudinal and circular muscles for churning), and an inner mucosa with tubular gastric glands containing mucous cells (secreting protective mucus), parietal/oxynitic cells (secreting hydrochloric acid, adjusting pH to 2-3 for pepsin activity and killing microorganisms) and zymogen cells (secreting inactive pepsinogen, activated to pepsin by acid, which hydrolyzes proteins to peptones and polypeptides); gastric juice secretion is stimulated by the hormone gastrin (released in response to protein-rich food). Churning converts food into a semi-solid mass called chyme, which is gradually released into the duodenum through the relaxing pyloric sphincter.

Digestion in the Small Intestine and Absorption

In the small intestine (duodenum, jejunum, ileum), the acidity of arriving chyme stimulates the hormone secretin (produced by duodenal mucosa), which travels via blood to the pancreas, stimulating pancreatic juice secretion and inhibiting further gastric secretion. Pancreatic juice contains pancreatic amylase/amylopsin (digesting starch to maltose), lipase (hydrolyzing some fats into fatty acids and glycerol), and trypsinogen (activated to trypsin by the duodenal enzyme enterokinase, then splitting proteins into peptones/polypeptides), plus sodium bicarbonate, which neutralizes stomach acid since pancreatic enzymes require a less acidic environment. Bile, produced by the liver and stored in the gall bladder, contains no enzymes but its bile salts emulsify fats (breaking them into small globules for lipase to act on more efficiently); its green colour comes from pigments formed by haemoglobin breakdown (blocked bile flow causes jaundice, and precipitated cholesterol can form gallstones). In the jejunum and ileum, intestinal enzymes (amino peptidase, dipeptidase, lipase, maltase, lactase) complete digestion of any remaining food.

Nearly all absorption occurs in the ileum, whose internal surface bears finger-like villi (each supplied with blood capillaries and a lymphatic lacteal, covered by epithelial cells bearing microvilli), which vastly increase the absorptive surface area; simple sugars and amino acids



are absorbed (by diffusion or active transport) into blood capillaries, while most fatty acids and glycerol are absorbed into epithelial cells, recombined into fats, and enter the lacteals as lipoprotein droplets, eventually reaching the bloodstream via the thoracic lymphatic duct. Undigested residue passes through the ileocolic sphincter into the large intestine (caecum with the appendix, colon, rectum), which absorbs water and salts, houses beneficial bacteria that synthesize vitamin K, and stores/expels the remaining feces via the rectum and anus.

Common Diseases Related to Nutrition and Digestion

Dyspepsia is incomplete/imperfect digestion, symptomatic of other disorders, causing abdominal discomfort, flatulence, heartburn, nausea and vomiting. Food poisoning results from eating food contaminated with bacterial toxins (e.g. Salmonella, Campylobacter, from undercooked or contaminated meat/milk/eggs), causing diarrhoea, vomiting and abdominal pain; a severe form, botulism (caused by Clostridium botulinum toxin from improperly preserved food), can cause cardiac and respiratory paralysis. Obesity results from storing excess food intake as fat in adipose tissue, increasing risk of high blood pressure, heart disease and diabetes; anorexia nervosa (loss of appetite from fear of obesity, mainly in adolescent females) and bulimia nervosa (binge eating followed by self-induced vomiting or purging, in slightly older girls) are serious eating disorders requiring psychiatric treatment.

Piles (haemorrhoids) are dilated, tortuous anorectal veins that may bleed, aggravated by constipation, treated with dietary fibre/laxatives or surgery in severe cases. An ulcer forms when the protective mucus lining of the stomach or duodenum breaks down, allowing digestive enzymes to erode the underlying wall (a severe ulcer can perforate the digestive tract, causing dangerous infection); excessive gastric acid secretion is a key factor, and smoking, spicy food, alcohol, caffeine and stress should be avoided by ulcer patients.

Important Definitions

Term	Definition
Nutrition	The sum total of processes by which organisms take in and use nutrients for growth, repair and maintenance of life activities.
Autotroph / Heterotroph	An autotroph manufactures its own organic compounds from inorganic raw materials; a heterotroph must obtain organic molecules as food from the environment.
Saprophyte	An organism that feeds on dead and decaying organic matter by secreting extracellular enzymes and absorbing the digested products.
Symbiosis	A mutually beneficial nutritional association between two organisms of different species (e.g. lichens, mycorrhizae, root nodules).
Ingestion	The taking in of complex food into the body, the first step of holozoic nutrition.
Digestion	The enzymatic breakdown of complex food molecules into simpler, diffusible molecules that can cross cell membranes.
Peristalsis	Coordinated waves of muscular contraction and relaxation in the digestive tract that move food along the canal.



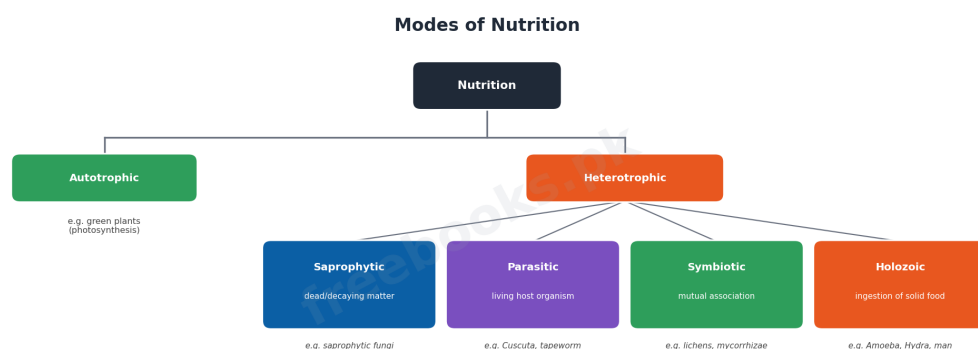
Term	Definition
Villi	Finger-like projections of the ileum's internal lining that greatly increase surface area for absorption of digested food.

Key Facts

Item	Fact
Two nutrition types	Autotrophic (self-manufactured organic compounds) and heterotrophic (obtained as food).
3 sites of human digestion	Oral cavity, stomach, and small intestine.
Saliva enzyme	Ptyalin (salivary amylase) - digests starch/glycogen into maltose.
Gastric juice components	Mucus (protection), HCl (pH 2-3, kills microbes), pepsinogen -> pepsin (protein digestion).
Pancreatic juice enzymes	Amylopsin (starch->maltose), lipase (fats->fatty acids+glycerol), trypsinogen->trypsin (proteins->peptides).
Bile (liver)	No enzymes; bile salts emulsify fats; pigments from haemoglobin breakdown; stored in gall bladder.
Main site of absorption	Ileum - via villi and microvilli, into blood capillaries and lacteals.
Botulism cause	Toxin of Clostridium botulinum bacteria - causes cardiac and respiratory paralysis.

Diagrams & Illustrations

Modes of Nutrition: a classification chart of nutrition types - autotrophic and heterotrophic - with heterotrophic subtypes: saprophytic, parasitic, symbiotic and holozoic nutrition, each with an example.

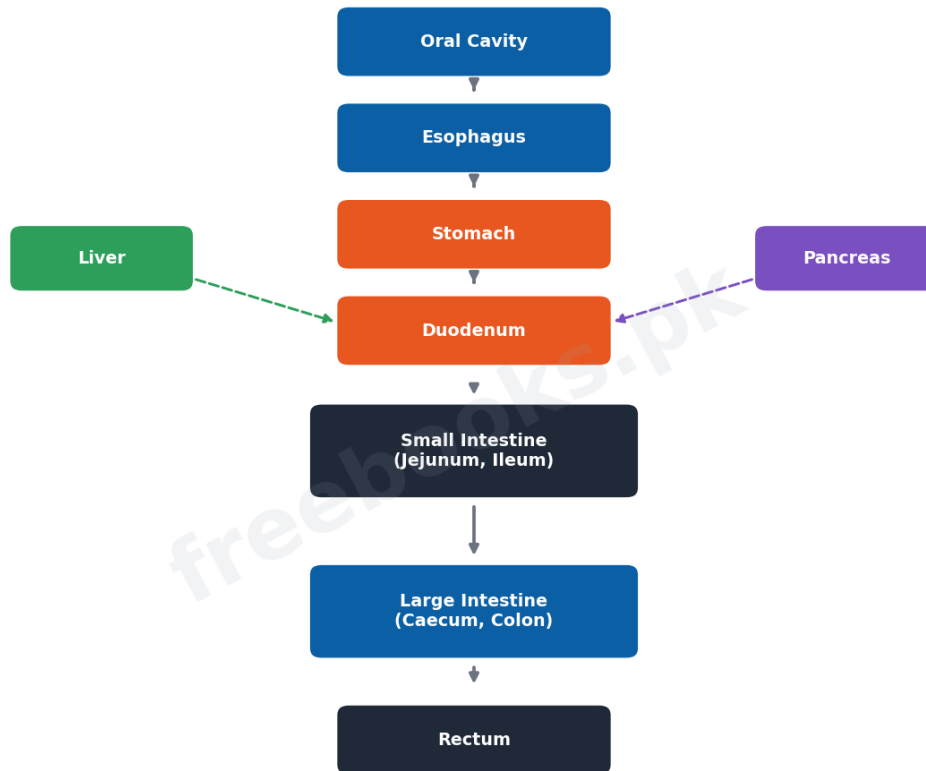


Modes of Nutrition



The Human Digestive System: a labelled diagram of the human digestive system showing the oral cavity, esophagus, stomach, small intestine (duodenum, jejunum, ileum), large intestine (caecum, colon, rectum), liver and pancreas.

The Human Digestive System



Accessory glands (liver, pancreas) secrete digestive juices into the duodenum

The Human Digestive System

Digestive Enzymes and Their Sites of Action: a summary chart of the major human digestive enzymes (ptyalin, pepsin, trypsin, amylase, lipase, maltase, lactase) with their site of secretion and the substrate/product of each.



Digestive Enzymes and Their Sites of Action

Enzyme	Site	Substrate	Product
Ptyalin (amylase)	Salivary glands (mouth)	Starch/glycogen	Maltose
Pepsin	Stomach	Proteins	Peptones, polypeptides
Trypsin	Pancreas	Proteins	Peptones, polypeptides
Amylopsin (amylase)	Pancreas	Starch	Maltose
Lipase	Pancreas / intestine	Fats	Fatty acids + glycerol
Maltase	Small intestine	Maltose	Glucose
Lactase	Small intestine	Lactose	Glucose + galactose

Digestive Enzymes and Their Sites of Action

Short Questions & Answers

Q1. What is the advantage of a digestive tract (tube-within-a-tube) compared with a digestive cavity?

Ans. A tubular digestive system with separate mouth and anus allows one-way, continuous movement of food, permitting different regions to specialize for specific digestive functions, making digestion and absorption more efficient than a sac-like cavity with only one opening for both ingestion and egestion.

Q2. What are the functions of the human liver?

Ans. The liver secretes bile (containing bile salts that emulsify fats and pigments from haemoglobin breakdown), stores bile in the gall bladder, helps regulate blood glucose, and is involved in detoxification and metabolism of nutrients absorbed from the intestine.

Q3. Differentiate saprophytic and parasitic nutrition.

Ans. Saprophytic nutrition involves feeding on dead and decaying organic matter by secreting extracellular enzymes and absorbing the products, whereas parasitic nutrition involves feeding on or within a living host organism of a different species, often causing harm to the host.

Q4. What is holozoic nutrition? Name its five processes.

Ans. Holozoic nutrition is the mode of nutrition typical of most animals, in which complex food is taken in and processed through five characteristic stages: ingestion, digestion, absorption, assimilation and egestion.

Q5. Differentiate ectoparasite and endoparasite.

Ans. An ectoparasite lives on the outer surface of its host (e.g. fleas, lice, ticks), while an endoparasite lives within the body of its host (e.g. Entamoeba histolytica, tapeworm, roundworms).

Q6. What prevents the stomach wall from being digested by its own enzymes?

Ans. A thick layer of mucus, secreted by mucous cells of the gastric glands, coats the inner stomach wall and protects it from being digested by hydrochloric acid and pepsin.



Long Questions & Answers

Q1: Define nutrition. Describe the role of different mineral elements in plant nutrition.

Nutrition is the sum total of all processes by which organisms take in and utilize nutrients - substances that supply elements necessary for metabolism - for growth, repair and maintenance of their vital activities. While autotrophic (photosynthetic) plants derive their basic carbon, hydrogen and oxygen from carbon dioxide and water, they require several other mineral elements from the soil for healthy growth. Nitrogen is essential for building proteins, and its deficiency causes stunted growth and chlorosis (yellowing), particularly in older leaves. Phosphorus is a component of ATP and nucleic acids, and its deficiency causes stunted root growth. Potassium deficiency causes yellow-brown leaf margins and premature plant death. Magnesium is a central component of the chlorophyll molecule, so its deficiency also causes chlorosis, while iron is required for cytochromes involved in cellular respiration. Since soil nutrients are depleted by repeated cropping, farmers must replenish them using animal manure, sewage sludge or chemical fertilizers such as urea, super phosphates and ammonium nitrate, ensuring plants receive an adequate mineral supply for normal metabolism and growth.

Q2: What is holozoic nutrition? Describe the characteristic processes involved in holozoic nutrition, giving the example of Amoeba.

Holozoic nutrition is the mode of nutrition characteristic of most animals, in which solid, complex food is taken into the body and processed through five defined stages. Ingestion is the taking in of complex food into the organism's body. Digestion is the enzymatic breakdown of complex organic molecules (such as proteins, starches and fats) into simpler, diffusible molecules (such as amino acids, simple sugars and fatty acids); this may occur intracellularly (within cells) or extracellularly (in a gut cavity or lumen, with enzymes secreted into it). Absorption is the uptake of these diffusible digested molecules across a membrane into the cell or bloodstream. Assimilation is the use of these absorbed products to release energy or build new cellular material. Egestion is the elimination of any undigested matter from the body. In *Amoeba proteus*, digestion is entirely intracellular: when the organism contacts a food particle, its pseudopodia flow around and fuse over it, enclosing it within a food vacuole; lysosomes then fuse with this vacuole and release hydrolytic enzymes, first killing and softening the food in an acidic environment (about pH 5.6), after which the medium becomes alkaline (about pH 7.3) and digestion is completed; the digested products then pass through fine cytoplasmic canals into the surrounding cytoplasm for use in metabolism, while any undigested residue is egested at any point on the cell surface into the surrounding water.

Q3: Describe digestion in the oral cavity and stomach of man.

In the oral cavity, food undergoes selection (via taste, smell and sight, rejecting unpleasant or harmful items), mastication (grinding by the molar teeth into smaller pieces, easing swallowing and increasing surface area for enzyme action), and lubrication and initial



digestion by saliva, secreted by three pairs of glands (parotid, submaxillary and sublingual). Saliva contains water and mucus (lubricating and moistening food), sodium bicarbonate and salts (stabilizing pH), and the enzyme ptyalin (salivary amylase), which begins digesting starch and glycogen into maltose. During swallowing, the tongue forces the food bolus to the back of the mouth, the soft palate rises to close the nasal passage, and the epiglottis folds down to cover the windpipe (glottis), safely directing the bolus into the esophagus, down which it is propelled by peristaltic waves of muscular contraction. At the junction with the stomach, the cardiac sphincter relaxes to admit food and then closes to prevent regurgitation. In the stomach, an elastic, muscular organ that stores and partly digests food, the mucosal lining's gastric glands contain mucous cells (secreting protective mucus), parietal cells (secreting hydrochloric acid, lowering pH to 2-3, activating pepsin and killing ingested microorganisms) and zymogen cells (secreting inactive pepsinogen, converted to active pepsin by the acidic environment, which hydrolyzes proteins into peptones and polypeptides); muscular contractions of the stomach wall churn this mixture into a semi-solid mass called chyme, which is gradually released through the relaxing pyloric sphincter into the duodenum.

Q4: Describe digestion in the small intestine, and describe how absorption of digested food occurs.

When acidic chyme enters the duodenum from the stomach, it stimulates the intestinal mucosa to release the hormone secretin, which travels via the blood to the pancreas and stimulates the release of pancreatic juice while also inhibiting further gastric secretion. Pancreatic juice contains pancreatic amylase (amylase), which digests starch into maltose; lipase, which hydrolyzes fats into fatty acids and glycerol; and trypsinogen, which is converted into active trypsin by the enzyme enterokinase (secreted by the duodenal lining) and then splits proteins into peptones and polypeptides; pancreatic juice also contains sodium bicarbonate, neutralizing stomach acid so that pancreatic enzymes, which require a less acidic environment, can function effectively. The liver secretes bile, stored in the gall bladder and released into the duodenum; although bile contains no digestive enzymes, its bile salts emulsify fats into smaller globules, greatly increasing the surface area available for lipase action. In the jejunum and ileum, intestinal enzymes such as aminopeptidase, dipeptidase, maltase and lactase complete the breakdown of any remaining polypeptides and disaccharides into amino acids and simple sugars. Nearly all absorption of digested nutrients occurs in the ileum, whose inner lining is thrown into folds bearing numerous finger-like villi, each covered with epithelial cells bearing even smaller microvilli, and richly supplied with blood capillaries and a lymphatic lacteal; this arrangement dramatically increases the surface area for absorption. Simple sugars and amino acids are absorbed by diffusion or active transport directly into the blood capillaries, while most fatty acids and glycerol are absorbed into the villus epithelial cells, recombined into fats, and transported via the lacteals and thoracic lymphatic duct into the bloodstream.

Q5: Describe common diseases related to nutrition and digestion.

Several disorders affect the digestive system and overall nutrition. Dyspepsia is incomplete or imperfect digestion, a symptom rather than a distinct disease, producing abdominal



discomfort, flatulence, heartburn, nausea and vomiting, often due to excessive stomach acidity or faulty stomach/intestinal function. Food poisoning results from eating food contaminated with bacterial toxins, most commonly from Salmonella or Campylobacter present in undercooked meat, eggs or unpasteurized milk, causing diarrhoea, vomiting and abdominal pain within 12-24 hours; a much more severe form, botulism, is caused by toxins from Clostridium botulinum in improperly preserved food, which can cause potentially fatal cardiac and respiratory paralysis. Obesity results when excess food intake is stored as fat in adipose tissue, raising the risk of high blood pressure, heart disease, diabetes mellitus and stomach disorders. Anorexia nervosa is a serious loss of appetite driven by fear of obesity, mainly affecting adolescent girls, requiring psychiatric treatment and sometimes non-oral feeding in severe cases, while bulimia nervosa involves cycles of overeating followed by self-induced vomiting or purging, risking electrolyte imbalance and requiring prolonged, supervised treatment. Piles (haemorrhoids) are dilated, tortuous anorectal veins that may bleed and are aggravated by constipation, generally managed with dietary fibre, stool softeners or, in severe cases, surgery. Finally, an ulcer develops when the protective mucus lining of the stomach or duodenum breaks down, allowing digestive enzymes to erode the underlying tissue; excessive gastric acid secretion is a key contributing factor, and patients are advised to avoid smoking, spicy food, alcohol, caffeine and stress.

MCQs with Answers

1. Organisms that manufacture their own organic compounds from inorganic raw materials are called:

(a) heterotrophs (b) autotrophs (c) saprophytes (d) parasites

Correct Answer: (b) autotrophs. Autotrophs manufacture their own organic compounds from inorganic materials like CO₂, water and nitrates.

2. Chlorosis (yellowing of leaves) is most commonly caused by a deficiency of:

(a) potassium (b) nitrogen or magnesium (c) phosphorus (d) sulphur

Correct Answer: (b) nitrogen or magnesium. Chlorosis is typically caused by nitrogen or magnesium deficiency, both linked to chlorophyll formation.

3. Cuscuta (dodder) is an example of a plant showing:

(a) saprophytic nutrition (b) symbiotic nutrition (c) parasitic nutrition (d) insectivorous nutrition

Correct Answer: (c) parasitic nutrition. Cuscuta (dodder) is a leafless twining plant that lives as a parasite on its host.

4. The Venus flytrap and pitcher plant are examples of plants with:

(a) parasitic nutrition (b) saprophytic nutrition (c) insectivorous nutrition (d) symbiotic nutrition

Correct Answer: (c) insectivorous nutrition. Both are insectivorous plants that trap and digest insects to supplement their nutrient supply while remaining true autotrophs.

5. Earthworms, which feed on organic debris, are classified as:

(a) herbivores (b) carnivores (c) detritivores (d) filter feeders

Correct Answer: (c) detritivores. Earthworms feed on decaying organic matter (detritus) and are classified as detritivores.



6. The enzyme in human saliva that digests starch is:

- (a) pepsin (b) trypsin (c) ptyalin (salivary amylase) (d) lipase

Correct Answer: (c) ptyalin (salivary amylase). Ptyalin (salivary amylase) digests starch and glycogen into maltose in the mouth.

7. Hydrochloric acid in the stomach performs all of the following EXCEPT:

- (a) activating pepsinogen to pepsin (b) killing ingested microorganisms (c) emulsifying fats (d) adjusting stomach pH to 2-3

Correct Answer: (c) emulsifying fats. Emulsifying fats is the function of bile salts, not hydrochloric acid.

8. Bile, secreted by the liver, functions mainly to:

- (a) digest proteins directly (b) emulsify fats for lipase action (c) neutralize stomach acid (d) absorb amino acids

Correct Answer: (b) emulsify fats for lipase action. Bile contains no digestive enzymes; its bile salts emulsify fats, aiding lipase action.

9. Almost all absorption of digested food in humans occurs in the:

- (a) stomach (b) duodenum (c) ileum (d) large intestine

Correct Answer: (c) ileum. The ileum, with its villi and microvilli, is the main site of absorption of digested nutrients.

10. Botulism, a severe form of food poisoning, is caused by toxins from:

- (a) Salmonella (b) Clostridium botulinum (c) Campylobacter (d) Escherichia coli

Correct Answer: (b) Clostridium botulinum. Botulism is caused by the powerful toxin of Clostridium botulinum, affecting the central nervous system.

Quick Revision Summary

- Nutrition = taking in + using nutrients. Autotrophic (self-made food) vs Heterotrophic (food from environment). Mineral deficiencies: N/Mg -> chlorosis, P -> stunted roots, K -> leaf margin yellowing.
- Special plant nutrition: Saprophytic (dead matter), Parasitic (living host, e.g. Cuscuta), Symbiotic (lichens, mycorrhizae, root nodules), Insectivorous (pitcher plant, Venus flytrap, sundew - true autotrophs supplementing N supply).
- Animal feeding types: Detritivores, Herbivores, Carnivores, Omnivores, Filter feeders, Fluid feeders, Macrophagous feeders. Parasites: ectoparasite (on host) vs endoparasite (within host); obligate vs facultative.
- Holozoic nutrition = Ingestion -> Digestion (intracellular/extracellular) -> Absorption -> Assimilation -> Egestion. Amoeba: intracellular digestion in food vacuole. Hydra: sac-like gastrovascular cavity, one opening. Planaria: branched intestine, extra+intracellular digestion. Cockroach: tubular gut (fore/mid/hind).
- Human digestion sites: Oral cavity (ptyalin - starch->maltose), Stomach (HCl + pepsin - proteins->peptones, pH 2-3), Small intestine (pancreatic amylase/lipase/trypsin + bile emulsifying fats + intestinal enzymes).
- Absorption mainly in ileum via villi + microvilli: sugars/amino acids -> blood capillaries; fatty acids/glycerol -> lacteals (as lipoproteins) -> thoracic duct -> blood. Large intestine: absorbs water/salts, vitamin K synthesis by bacteria.



- Diseases: Dyspepsia, Food poisoning (Salmonella/Campylobacter, Botulism-Clostridium botulinum), Obesity, Anorexia nervosa, Bulimia nervosa, Piles (haemorrhoids), Ulcer (mucus breakdown, gastric acid). Notes by freebooks.pk.

Exam Tips

- Learn the 5 processes of holozoic nutrition in order (ingestion, digestion, absorption, assimilation, egestion) with the Amoeba example.
- Compare digestive systems across organisms: sac-like (Hydra) vs branched sac (Planaria) vs tubular (cockroach, man) — a common "differentiate" theme.
- Memorise the enzyme table: ptyalin (mouth), pepsin (stomach), trypsin/amylase/lipase (pancreas), maltase/lactase/peptidases (intestine) — with substrate and product for each.
- Be ready to explain why the stomach doesn't digest itself (mucus layer) and why pancreatic enzymes need bicarbonate neutralization.
- Know the structure of a villus (capillaries + lacteal + microvilli) and which nutrients are absorbed into which vessel.
- Revise the nutrition-related disease list (dyspepsia, food poisoning, botulism, obesity, anorexia/bulimia, piles, ulcer) with one key cause/feature each.

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FSc Part-I Biology — Punjab Board

CHAPTER 13

Gaseous Exchange

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Gaseous Exchange from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Respiration occurs at two levels: organismic respiration (breathing/ventilation, the physical exchange of gases with the environment) and cellular respiration (the metabolic process by which cells use oxygen, produce carbon dioxide, and extract energy from food as ATP). Gaseous exchange is the physical process, always by diffusion, that supplies oxygen for cellular respiration and removes carbon dioxide. These notes are prepared by freebooks.pk.

The chapter compares air and water as respiratory media, describes gaseous exchange in plants (stomata, lenticels, photorespiration), surveys respiratory organs and mechanisms across representative animals (Hydra, earthworm, cockroach, fish, frog, birds and man), explains the mechanics of breathing (inspiration and expiration) and the transport of oxygen and carbon dioxide in blood, and covers common respiratory disorders.

Learning Objectives

- Differentiate organismic (breathing) and cellular respiration, and explain why gaseous exchange always occurs by diffusion.
- Compare the advantages and disadvantages of air and water as respiratory media.
- Describe gaseous exchange in plants through stomata and lenticels, and explain photorespiration.
- Describe the properties of respiratory surfaces and respiration in Hydra, earthworm and cockroach.
- Describe respiration in fish, frog and birds, and explain the human air passageways and lungs.
- Explain the mechanics of inspiration and expiration in man.
- Describe the transport of oxygen and carbon dioxide in blood and common respiratory disorders.

Key Concepts

Need of Respiratory Gas Exchange

At all levels of activity, living organisms require an uninterrupted supply of energy, and respiration is one of the most important metabolic activities supplying it. Respiration occurs at two levels: organismic respiration, also called breathing or ventilation, is the physical exchange of gases between an organism and its environment; cellular respiration is the metabolic process directly involved in producing energy, in which cells utilize oxygen, produce carbon dioxide, and extract and conserve energy from food molecules in a biologically useful form such as ATP.

Gaseous exchange during organismic respiration is carried out only by diffusion — respiratory gases move between the body fluid and the outside medium (water or air) simply because there is no active transport mechanism to move respiratory gases across biological membranes.



Advantages and Disadvantages of Gas Exchange in Air and in Water

Air is a better respiratory medium than water for two main reasons. Firstly, the oxygen content of air is much higher than that of an equal volume of water: a litre of water cannot contain even 10 ml of oxygen, whereas fresh air contains about 200 ml of oxygen per litre. Secondly, oxygen diffuses about 8000 times more quickly in air than in water.

Breathing (ventilation) is directly involved in gas exchange, and ventilating water is far more difficult than ventilating air because water is about 8000 times denser than air and, in terms of viscosity, about 50 times more viscous — making gas exchange more difficult in water than in air.

Gaseous Exchange in Plants

Unlike animals, plants have no special organ or system for gaseous exchange — every cell carries out gas exchange according to its own needs, and the vascular tissues (xylem and phloem) play no role in transporting gases. In mesophyll cells specialized for photosynthesis there are large air spaces (comprising up to 40% of leaf volume) which are directly involved in gas exchange. Stomata, present mainly in leaves and young stems, are the main sites of gas exchange in plants (an estimated 12,000 stomata per square centimetre of leaf surface in tobacco); in older stems, dead cork tissue has special pores called lenticels for gas exchange. Land plant roots obtain oxygen from air in soil spaces, while aquatic plants obtain oxygen by diffusion from oxygen dissolved in water.

Photorespiration is a light-dependent respiratory process occurring in plants during daytime, in which oxygen is absorbed and carbon dioxide is released, but the oxygen absorbed is not used to produce ATP. It occurs because rubisco (ribulose biphosphate carboxylase/oxygenase, the most abundant protein in chloroplasts) can act as an oxygenase as well as a carboxylase: when it adds oxygen instead of carbon dioxide to RuBP, a two-carbon compound (glycolate) is produced, which is converted through the peroxisomes and mitochondria (via glycine and serine) with the release of carbon dioxide — the reverse of the Calvin cycle. Photorespiration reduces carbon fixation into carbohydrates by about 25% in most plants; it becomes more pronounced on hot, dry days when closed stomata (preventing water loss) cause oxygen to build up and carbon dioxide to fall inside the leaf.

Respiratory Organs in Hydra, Earthworm and Cockroach

Respiratory surfaces in animals share common features: a large, moist surface area; a thin epithelium (often just two cells thick) minimizing diffusion distance; ventilation to maintain a steep diffusion gradient; and an extensive capillary network to keep blood flowing and maintain the gradient. Hydra has no specialized respiratory organs — gas exchange occurs over its entire general body surface and the lining of its digestive cavity (enteron), both in contact with water. The earthworm, though more complex, also lacks specialized respiratory organs; gas exchange occurs through its moist, capillary-rich skin (kept moist by mucous gland secretions and coelomic fluid), with oxygen combining with haemoglobin in the blood to form oxyhaemoglobin.



The cockroach has a specialized tracheal respiratory system: branching, chitin-lined air tubules called tracheae communicate with the exterior through 10 pairs of spiracles (2 pairs in the thorax, 8 in the abdomen); tracheae divide into fine, fluid-filled tracheoles that directly supply oxygen to tissues by diffusion, bypassing the blood entirely. Abdominal muscle contraction and expansion pump air through the spiracles (anterior spiracles open on expansion, posterior ones on contraction), producing inhalation and exhalation.

Respiration in Fish, Frog and Birds

Fish respire through gills, paired and highly modified structures near the junction of head and trunk, present in four to five pairs and constantly ventilated by a one-way flow of water entering through the mouth and passing out through the gill openings; the heart pumps deoxygenated blood to the gills in a single circuit. In frogs, gas exchange occurs through the lungs (pulmonary respiration), the skin (cutaneous respiration), and the buccal chamber, all richly supplied with blood vessels; air is drawn in through the nostrils and pushed into the simple, sac-like lungs by raising the floor of the buccal cavity (buccal/positive-pressure breathing).

Birds have the most efficient respiratory system among animals, needed for their high metabolic rate. Instead of alveoli, bird lungs contain tiny, thin-walled parabronchi, open at both ends, through which air flows in one direction and is constantly renewed; blood flow in the lung runs opposite to airflow (counter-current exchange), maximizing oxygen uptake. Nine air sacs extend throughout the body, acting as bellows that push air through the parabronchi, so no stale air remains.

Respiration in Man: Air Passageways and Lungs

In man, air passes through nostrils, nasal cavities (lined with ciliated mucous epithelium that warms, moistens and filters air), pharynx, larynx, trachea, bronchi, bronchioles and alveolar ducts into the alveolar sacs. The larynx (voice box) contains the epiglottis, a hinged cartilage flap that covers the glottis (opening of the larynx) during swallowing to prevent food or liquid from entering the airway; the glottis is lined by two vocal cords used in voice production.

The trachea (windpipe) is held open by C-shaped cartilage rings and divides into right and left bronchi, which subdivide progressively into smaller bronchi and then bronchioles (diameter 1 mm or less, lacking cartilage, composed mainly of smooth muscle). Bronchioles finally open into air-sacs, the functional unit of the lung, each made of microscopic alveoli surrounded by a rich capillary network — the actual site of gas exchange. The lungs are spongy, enclosed in the chest cavity (bounded by ribs and the muscular diaphragm floor) and covered by a double-layered membrane called the pleura.

Mechanics of Breathing: Inspiration and Expiration

Breathing is a purely mechanical process with two phases. The lungs themselves are passive — they neither pull air in nor push it out; the diaphragm becomes less dome-like when its muscles contract and more dome-like when relaxed; and when the intercostal muscles between the ribs contract, the ribs are elevated, while relaxation lets them settle down. During inspiration, contraction of the rib muscles elevates the ribs upward and outward while



the diaphragm contracts and flattens, together increasing the chest cavity's volume and reducing pressure on the lungs; the lungs expand, creating a partial vacuum into which air rushes from the higher-pressure atmosphere.

During expiration, the rib muscles relax (ribs move down and inward) and the diaphragm relaxes (becomes more dome-like), reducing chest cavity volume and exerting pressure on the lungs, forcing air out. Premature infants (less than about 7 months gestation) often lack enough surfactant — a lipoprotein mixture that reduces surface tension in the alveoli — leading to respiratory distress syndrome as the lungs tend to collapse.

Transport of Respiratory Gases

In humans, oxygen is carried mainly by the pigment haemoglobin in red blood cells, which combines reversibly with oxygen to form bright red oxyhaemoglobin ($\text{Hb} + \text{O}_2 \rightleftharpoons \text{HbO}_2$); a small amount of oxygen also dissolves directly in plasma. At sea level, fully oxygenated blood carries about 20 ml of oxygen per 100 ml of blood; at an oxygen pressure around 100 mm Hg (as in the lungs) haemoglobin is nearly fully saturated, but below about 60 mm Hg (as in tissues) oxygen saturation drops sharply, releasing oxygen where it is needed. Rising carbon dioxide, rising temperature, and falling pH (rising acidity) all decrease haemoglobin's affinity for oxygen, favouring oxygen release into actively respiring tissues.

Carbon dioxide, far more soluble than oxygen, is transported in blood in several forms: about 70% as bicarbonate ions (via carbonic acid formed with the help of carbonic anhydrase, $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$), about 20% bound to haemoglobin as carbaminohaemoglobin, about 5% carried by other plasma proteins, and a small amount carried combined with potassium in corpuscles; in the lungs these reactions reverse and carbon dioxide diffuses out into the alveoli. Common respiratory disorders include lung cancer (strongly linked to smoking, which causes about 90% of cases), tuberculosis (caused by *Mycobacterium tuberculosis*, associated with malnutrition and poor living conditions), asthma (an allergic, inflammatory narrowing of the bronchioles), and emphysema (breakdown of alveolar walls, mainly in smokers, reducing the surface area available for gas exchange).

Important Definitions

Term	Definition
Respiration	The sum of processes (organismic/breathing and cellular) by which organisms obtain oxygen, release carbon dioxide, and extract usable energy (ATP) from food.
Gaseous exchange	The diffusion-driven exchange of oxygen and carbon dioxide between an organism's body fluids and the surrounding air or water.
Photorespiration	A light-dependent process in which rubisco fixes oxygen instead of carbon dioxide, releasing CO_2 and reducing the rate of carbon fixation and plant growth.
Stomata	



Term	Definition
	Small pores, mainly on leaves and young stems, that are the main sites of gaseous exchange in plants.
Tracheole	A fine, fluid-filled branch of the insect tracheal system that delivers oxygen directly to tissue cells by diffusion.
Alveolus	A microscopic, thin-walled air sac in the lung, surrounded by capillaries, where gaseous exchange with the blood occurs.
Haemoglobin	The iron-containing respiratory pigment in red blood cells that reversibly binds oxygen to form oxyhaemoglobin.
Emphysema	A respiratory disorder, common among smokers, in which alveolar walls break down and combine, reducing the surface area for gas exchange.

Key Facts

Item	Fact
Oxygen content: air vs water	Fresh air has about 200 ml O ₂ per litre; water holds less than 10 ml O ₂ per litre.
O ₂ diffusion rate	Oxygen diffuses about 8000 times faster in air than in water.
Stomatal density	About 12,000 stomata per square centimetre of leaf surface in tobacco.
Air space in leaf	Mesophyll air spaces may comprise up to 40% of total leaf volume.
Cockroach spiracles	10 pairs total - 2 pairs thoracic, 8 pairs abdominal, opening into the tracheal system.
Max O ₂ carried by blood	About 20 ml of oxygen per 100 ml of fully oxygenated blood at sea level.
CO ₂ transport in blood	About 70% as bicarbonate ions, about 20% as carbaminohaemoglobin, about 5% by plasma proteins.
Normal breathing rate	15-20 breaths per minute at rest in humans; total lung capacity about 5 litres.

Diagrams & Illustrations

Respiratory Organs Across Animal Groups: a comparison chart of respiratory structures in different animals - the general body/enteron surface of Hydra, the moist skin of earthworm, the tracheal system of cockroach, the gills of fish, and the lungs/parabronchi and air sacs of frog and birds.

Comparison of respiratory organs across animal groups - Biology 1st Year (Freebooks.pk)

Respiratory Organs Across Animal Groups



The Human Respiratory System: a labelled diagram of the human respiratory system showing the nasal cavity, pharynx, larynx, trachea, bronchi, bronchioles, alveoli/lungs and diaphragm.

The human respiratory system - Biology 1st Year (Freebooks.pk)

The Human Respiratory System

Mechanics of Breathing: Inspiration and Expiration: a diagram comparing the position of the ribs and diaphragm during inspiration (ribs up and out, diaphragm flattened, chest volume increased) and expiration (ribs down and in, diaphragm domed, chest volume decreased).

Mechanics of inspiration and expiration - Biology 1st Year (Freebooks.pk)

Mechanics of Breathing: Inspiration and Expiration

Short Questions & Answers

Q1. Why is air a better respiratory medium than water?

Ans. Air contains far more oxygen per unit volume than water (about 200 ml/L versus less than 10 ml/L) and oxygen diffuses about 8000 times faster in air than in water, so gas exchange is much easier and faster in air.

Q2. What are stomata and lenticels?

Ans. Stomata are small pores, mainly on leaves and young stems, through which plants exchange gases; lenticels are pores in the dead cork tissue of older stems that serve the same purpose once stomata are no longer present.

Q3. What is photorespiration?

Ans. Photorespiration is a light-dependent process in which the enzyme rubisco fixes oxygen instead of carbon dioxide onto RuBP, releasing carbon dioxide instead of fixing it, which lowers the overall rate of carbon dioxide fixation and plant growth.

Q4. How does the cockroach's tracheal system deliver oxygen without using blood?

Ans. Air enters through spiracles into tracheae, which branch into fine fluid-filled tracheoles that directly surround tissues and cells, so oxygen diffuses straight from the tracheoles into the cells without needing to be carried by blood.

Q5. What is counter-current exchange in bird lungs, and why is it efficient?

Ans. In bird lungs, blood flows through the parabronchi in the opposite direction to airflow, which maintains a diffusion gradient along the full length of the parabronchus and allows more oxygen to be extracted from the air than in a system with unidirectional flow.

Q6. What is the function of the epiglottis?

Ans. The epiglottis is a cartilage flap in the larynx that folds down to cover the glottis (opening of the windpipe) during swallowing, preventing food or liquid from entering the respiratory passage.



Long Questions & Answers

Q1: Compare air and water as respiratory media, explaining the advantages and disadvantages of each.

Gaseous exchange in living organisms always occurs by diffusion across a moist respiratory surface, and the medium involved - air or water - strongly affects how easily this happens. Air is the better respiratory medium for two key reasons. First, the oxygen content of air is far higher than that of an equal volume of water: a litre of fresh air contains about 200 ml of oxygen, whereas a litre of water cannot hold even 10 ml of dissolved oxygen. Second, oxygen molecules diffuse roughly 8000 times faster through air than through water, because water molecules are far more tightly packed. Ventilation - the physical movement of the respiratory medium over the respiratory surface - is also much harder in water than in air, since water is about 8000 times denser than air and, in terms of viscosity, about 50 times more viscous; this means aquatic animals must expend considerably more energy moving water over their gills than terrestrial animals expend moving air over their lungs. As a result, aquatic animals such as fish have evolved highly efficient, richly vascularized gills with continuous one-way water flow to compensate for water's poorer properties as a respiratory medium, while air-breathing animals can rely on simpler ventilation mechanisms.

Q2: Describe gaseous exchange in plants, and explain the process and significance of photorespiration.

Unlike animals, plants possess no specialized respiratory organs or system; every living cell exchanges gases according to its own metabolic needs, and the vascular tissues (xylem and phloem) play no part in gas transport. In leaves, mesophyll cells specialized for photosynthesis are surrounded by extensive air spaces, which may make up as much as 40% of total leaf volume, and these air spaces connect to the atmosphere mainly through stomata - tiny pores concentrated on leaf surfaces (for example, about 12,000 stomata per square centimetre in tobacco) and, to a lesser extent, through lenticels in the cork tissue of older, woody stems. Roots obtain oxygen from air trapped between soil particles, while submerged aquatic plants absorb dissolved oxygen directly from the surrounding water. Photorespiration is a light-dependent process that occurs alongside photosynthesis: the enzyme rubisco, which normally fixes carbon dioxide onto ribulose biphosphate (RuBP) during the Calvin cycle, can also act as an oxygenase and add oxygen to RuBP instead, producing a two-carbon compound called glycolate. This glycolate is processed through the peroxisomes and mitochondria (via glycine and serine), ultimately releasing carbon dioxide - effectively reversing the carbon-fixing work of the Calvin cycle and reducing net carbon fixation by up to 25% in many plants. Photorespiration becomes especially pronounced on hot, dry days, when stomata close to conserve water, causing oxygen to accumulate and carbon dioxide to become depleted inside the leaf, favouring rubisco's oxygenase activity over its carboxylase activity.



Q3: Describe respiratory organs and mechanisms in Hydra, earthworm, cockroach and fish.

Different animal groups show a progression in the specialization of respiratory structures. Hydra, a simple diploblastic organism, has no respiratory organs at all; gaseous exchange occurs by diffusion across its entire general body surface and across the lining of its digestive cavity (the gastrovascular cavity or enteron), both of which are in direct contact with surrounding water. The earthworm, though structurally more complex, likewise lacks specialized respiratory organs; instead, gas exchange takes place across its thin, richly capillarized skin, which is kept moist by secretions from epidermal mucous glands and by coelomic fluid exuded through dorsal pores, allowing oxygen to dissolve and diffuse into the underlying blood, where it combines with haemoglobin. The cockroach possesses a fully specialized tracheal respiratory system independent of the blood: air enters through 10 pairs of spiracles (openings on the body wall) into branching, chitin-lined tracheae, which divide further into extremely fine, fluid-filled tracheoles that penetrate directly among and within tissues, delivering oxygen straight to cells by diffusion; rhythmic contraction and expansion of the abdominal muscles pumps air in and out through the spiracles. Fish, being fully aquatic, respire through gills - highly vascularized, feathery structures arranged in four to five pairs near the head, over which water flows continuously and unidirectionally, entering through the mouth and exiting through gill openings or slits; the fish heart pumps deoxygenated blood in a single circuit directly to the gills, where it becomes oxygenated before being distributed to the rest of the body.

Q4: Explain the human air passageways from the nostrils to the alveoli, and describe the structure of the lungs.

Air entering the human respiratory system first passes through the nostrils into the nasal cavities, which are lined with ciliated mucous epithelium; here, larger dust particles are trapped by nasal hairs and mucus while the air itself is warmed, moistened and filtered of smaller particles. From the nasal cavities, air passes into the pharynx, a muscular, mucous-membrane-lined passage shared with the digestive tract, and then into the larynx (voice box), a cartilaginous structure whose epiglottis folds down during swallowing to cover the glottis (the opening of the larynx) and prevent food or liquid from entering the airway; the glottis itself is lined by two fibrous vocal cords involved in sound production. Below the larynx, the trachea (windpipe) - held permanently open by a series of C-shaped cartilage rings that prevent it from collapsing - descends into the thorax, where it divides into a right and a left bronchus, each entering a lung. Within the lungs, the bronchi divide and subdivide repeatedly into progressively smaller bronchi and then into bronchioles (tubes of 1 mm diameter or less), which lack cartilage and are composed mainly of smooth muscle. The bronchioles finally open into large numbers of air-sacs, the functional unit of the lung, each composed of many microscopic, single-layered alveoli; a dense network of blood capillaries overlies each alveolus, creating the actual site of gaseous exchange. The lungs themselves are spongy, elastic sacs housed within the chest cavity - bounded at the sides by the ribs and intercostal muscles and at the base by the diaphragm, a sheet of skeletal muscle - and each lung is enclosed by a double-layered membranous sac called the pleura.



Q5: Describe the mechanics of breathing in man, and explain how oxygen and carbon dioxide are transported in the blood.

Breathing in man is a purely mechanical process consisting of two alternating phases, inspiration and expiration, occurring rhythmically about 15 to 20 times per minute at rest. The lungs themselves are passive, elastic structures that cannot actively pull air in or push it out; movement of air depends instead on changes in the volume of the chest cavity, brought about by the diaphragm (a domed sheet of muscle at the floor of the chest, which flattens on contraction and domes upward on relaxation) and by the intercostal muscles between the ribs (which elevate the ribs on contraction and allow them to settle on relaxation). During inspiration, the rib muscles contract, lifting the ribs upward and outward, while the diaphragm simultaneously contracts and flattens; together these actions enlarge the chest cavity and lower the pressure around the lungs, causing the elastic lungs to expand and drawing air in from the higher-pressure atmosphere. During expiration, both sets of muscles relax - the ribs move downward and inward and the diaphragm resumes its domed shape - reducing the volume of the chest cavity, compressing the lungs, and forcing air back out. Once inhaled, oxygen diffuses across the thin alveolar and capillary walls into the blood, where it is carried mainly bound to haemoglobin in red blood cells as oxyhaemoglobin ($\text{Hb} + \text{O}_2$ reversibly forming HbO_2); at the high oxygen pressure found in the lungs haemoglobin becomes almost fully saturated, while at the lower oxygen pressures found in respiring tissues oxyhaemoglobin readily releases its oxygen, a process further favoured by rising carbon dioxide levels, higher temperature and lower pH in active tissues. Carbon dioxide produced by tissues is transported back to the lungs mostly (about 70%) as bicarbonate ions formed via carbonic acid with the help of the enzyme carbonic anhydrase, with smaller amounts carried bound to haemoglobin as carbaminohaemoglobin (about 20%) and dissolved in plasma proteins (about 5%); in the lungs, these reactions run in reverse, releasing carbon dioxide to diffuse out into the alveoli and be exhaled.

MCQs with Answers

1. The physical exchange of gases between an organism and its environment is called:

(a) cellular respiration (b) organismic respiration (c) photorespiration (d) fermentation

Correct Answer: (b) organismic respiration. Organismic respiration (breathing/ventilation) is the physical exchange of gases with the environment, distinct from cellular respiration.

2. Oxygen diffuses fastest through:

(a) water (b) air (c) soil (d) blood plasma alone

Correct Answer: (b) air. Oxygen diffuses about 8000 times faster in air than in water.

3. The main sites of gaseous exchange in leaves are the:

(a) lenticels (b) stomata (c) root hairs (d) vascular bundles

Correct Answer: (b) stomata. Stomata, mainly on leaves and young stems, are the main sites of gaseous exchange in plants.

4. Photorespiration occurs when rubisco acts as a(n):



(a) carboxylase only (b) oxygenase, adding O₂ to RuBP (c) protease (d) kinase

Correct Answer: (b) oxygenase, adding O₂ to RuBP. Photorespiration occurs when rubisco's oxygenase activity adds oxygen instead of carbon dioxide to RuBP.

5. In the cockroach, oxygen is delivered directly to tissues by:

(a) haemoglobin in blood (b) tracheoles (c) gills (d) skin diffusion only

Correct Answer: (b) tracheoles. Fine, fluid-filled tracheoles deliver oxygen directly to tissue cells by diffusion, without blood involvement.

6. Counter-current exchange in bird lungs refers to:

(a) blood and air flowing in the same direction (b) blood flowing opposite to airflow in the parabronchi (c) two-way air movement in alveoli (d) blood bypassing the lungs

Correct Answer: (b) blood flowing opposite to airflow in the parabronchi. Blood flow in bird lungs is opposite to the direction of airflow through the parabronchi, maximizing oxygen extraction.

7. The cartilage flap that covers the glottis during swallowing is the:

(a) larynx (b) epiglottis (c) trachea (d) pharynx

Correct Answer: (b) epiglottis. The epiglottis folds down to cover the glottis during swallowing, preventing food or liquid from entering the airway.

8. During inspiration, the diaphragm:

(a) relaxes and becomes more dome-like (b) contracts and becomes flatter (c) stays completely still (d) moves upward only

Correct Answer: (b) contracts and becomes flatter. During inspiration the diaphragm contracts and flattens, helping to increase chest cavity volume.

9. Most carbon dioxide is transported in blood as:

(a) dissolved gas in plasma (b) carbaminohaemoglobin (c) bicarbonate ions (d) carbonic anhydrase

Correct Answer: (c) bicarbonate ions. About 70% of blood carbon dioxide is transported as bicarbonate ions.

10. Emphysema is a respiratory disorder involving:

(a) excess mucus production only (b) breakdown of alveolar walls, reducing surface area (c) narrowing of the trachea (d) paralysis of the diaphragm

Correct Answer: (b) breakdown of alveolar walls, reducing surface area.

Emphysema involves breakdown of alveolar walls, which combine into fewer, larger alveoli with reduced total surface area for gas exchange.

Quick Revision Summary

- Respiration = organismic (breathing/ventilation) + cellular (ATP production). Gas exchange always by diffusion, no active transport across respiratory membranes.
- Air > water as respiratory medium: ~200 ml O₂/L in air vs <10 ml/L in water; O₂ diffuses ~8000x faster in air; water is ~8000x denser and ~50x more viscous, harder to ventilate.
- Plants: no special respiratory organs; gas exchange via stomata (leaves/young stems, ~12,000/cm² in tobacco) and lenticels (older stems). Photorespiration:



rubisco adds O₂ to RuBP -> glycolate -> CO₂ released, reduces carbon fixation ~25%.

- Animal respiratory organs: Hydra - general/enteron surface; Earthworm - moist skin; Cockroach - tracheae/tracheoles via spiracles (10 pairs), no blood involvement; Fish - gills, one-way water flow; Frog - lungs+skin+buccal chamber; Birds - parabronchi + air sacs, counter-current exchange, most efficient system.
- Man: nostrils -> nasal cavity -> pharynx -> larynx (epiglottis, glottis, vocal cords) -> trachea (cartilage rings) -> bronchi -> bronchioles -> alveoli (gas exchange site). Lungs in pleura, sit above diaphragm.
- Breathing mechanics: Inspiration = rib muscles + diaphragm contract -> chest volume up -> lungs expand -> air in. Expiration = both relax -> chest volume down -> air out.
- Gas transport: O₂ via haemoglobin ($\text{Hb} + \text{O}_2 \rightleftharpoons \text{HbO}_2$, ~20ml O₂/100ml blood at sea level); CO₂ mainly (~70%) as bicarbonate, ~20% carbaminohaemoglobin, ~5% plasma proteins. Disorders: lung cancer (smoking), TB (Mycobacterium tuberculosis), asthma, emphysema. Notes by freebooks.pk.

Exam Tips

- Be clear on the difference between organismic respiration (breathing) and cellular respiration (ATP production) - a classic definition/differentiate question.
- Learn the two reasons air beats water as a respiratory medium: oxygen content and diffusion rate, plus density/viscosity for ventilation.
- Trace the animal respiratory organ progression: no organs (Hydra) -> skin (earthworm) -> tracheae (cockroach) -> gills (fish) -> lungs+skin (frog) -> parabronchi+air sacs (birds, most efficient).
- Memorise the human air passageway sequence in order: nostrils -> nasal cavity -> pharynx -> larynx -> trachea -> bronchi -> bronchioles -> alveoli.
- Understand inspiration vs expiration mechanics in terms of rib muscles, diaphragm shape, chest volume and pressure change - a very common long question.
- Know the CO₂ transport percentages (bicarbonate ~70%, carbaminohaemoglobin ~20%, plasma proteins ~5%) and the factors (CO₂, temperature, pH) that affect haemoglobin-oxygen binding.

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FSc Part-I Biology — Punjab Board

CHAPTER 14

Transport

Key Concepts • Definitions • Short & Long Questions • MCQs • Diagrams • Exam Tips

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This chapter covers Transport from the 1st Year (FSc Part-I) Biology syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Living cells and organisms must obtain materials and remove wastes through diffusion, facilitated diffusion, osmosis, active transport, endocytosis and exocytosis; in complex, multicellular organisms these processes alone are too slow, so elaborate transport systems have evolved for the mass movement of materials within the body. These notes are prepared by freebooks.pk.

The chapter covers transport in plants (uptake of water and minerals by roots, water potential, ascent of sap by the cohesion-tension theory, transpiration and stomatal movement, and translocation of organic solutes by the pressure-flow theory) and transport in animals (open and closed circulatory systems, the evolution of the vertebrate heart, human blood composition, the structure and working of the human heart and blood vessels, the lymphatic system, and immunity).

Learning Objectives

- Describe the uptake of water and minerals by roots through the apoplast, symplast and vacuolar pathways.
- Explain water potential and its components, and define osmosis and plasmolysis.
- Describe the cohesion-tension theory, root pressure and imbibition in the ascent of sap.
- Describe the types of transpiration, the factors affecting its rate, and the mechanism of stomatal opening and closing.
- Explain translocation of organic solutes through phloem via the pressure-flow theory.
- Differentiate open and closed circulatory systems and outline the evolution of the vertebrate heart.
- Describe the composition of human blood, the structure of the heart, and the cardiac cycle.
- Describe the lymphatic system and the types of immunity.

Key Concepts

Uptake and Transport of Water and Minerals by Roots

Roots anchor the plant and absorb water and minerals from the soil, mainly through root hairs — extensions of epidermal cells that provide about 67% of a root's total absorptive surface area. Most minerals enter along with water in bulk flow, though some move by diffusion, facilitated diffusion (via carrier proteins in the cell membrane), or active transport (against the concentration gradient, using ATP; this is selective and dependent on respiration). Symbiotic relationships such as mycorrhizae (fungal associations that improve phosphorus and trace-metal uptake in exchange for sugars) and nitrogen-fixing bacteria in legume root nodules help plants acquire scarce nutrients such as nitrogen.



Water and minerals reach the xylem by three pathways. In the apoplast pathway, they move through the continuous system of adjacent cell walls, but this pathway becomes discontinuous at the endodermis because of the waxy Casparian strips, forcing materials to cross into the symplast there. In the symplast pathway, materials move through the interconnected cytoplasm of cells, linked by plasmodesmata. In the vacuolar pathway, materials move from vacuole to vacuole across cell membranes by osmosis. Osmosis is the movement of water molecules from a region of higher concentration to a region of lower concentration through a partially permeable membrane; water entering a cell is endosmosis, and water leaving a cell is exosmosis.

Water Potential, Osmosis and Plasmolysis

Water potential (symbol Ψ_w) is a measure of the tendency of water molecules to move from one region to another, and water always moves from higher to lower water potential. Pure water has the maximum water potential, defined as zero; all solutions therefore have a negative water potential. Water potential has two components: solute (osmotic) potential (Ψ_s), which is always negative and becomes more negative as more solute is present, and pressure potential (Ψ_p), the pressure that builds up inside a cell as water enters and inflates it. The total water potential is the sum of the two: $\Psi_w = \Psi_s + \Psi_p$.

When a living cell is placed in a solution of lower water potential than its own contents, water leaves the cell by exosmosis and the protoplast shrinks away from the cell wall — a process called plasmolysis (the point where this is about to begin is incipient plasmolysis). If the plasmolysed cell is then placed in distilled water (the highest possible water potential), water re-enters by endosmosis and the cell becomes deplasmolysed; continued entry of water increases the pressure potential until the cell becomes fully turgid. Because animal cells lack a rigid cell wall, they cannot withstand high pressure potential and would burst in a very dilute solution, so animals instead rely on osmoregulation to keep internal water and salt levels constant.

Ascent of Sap: Cohesion-Tension Theory, Root Pressure and Imbibition

The upward movement of water and dissolved minerals from roots to leaves through the xylem is called the ascent of sap, explained mainly by the cohesion-tension theory proposed by Dixon. Cohesion is the mutual attraction between water molecules (via hydrogen bonds), which holds them together as a continuous, chain-like column inside the narrow xylem tubes; tension is the pulling force applied to this water column, generated by transpiration at the leaf surface; adhesion is the attraction of water molecules to the cellulose-rich walls of the xylem, which keeps the water column from breaking; and the xylem walls themselves must be mechanically strong (reinforced by lignin and cellulose) to resist collapsing inward under this tension. Together these forces can pull water upward through tall trees to heights of up to 200 metres, at speeds of up to 8 metres per hour.

Root pressure is a secondary force: active secretion of salts into the xylem sap lowers its water potential, so water enters the xylem by osmosis and builds up hydrostatic pressure that pushes sap upward — though this pressure (typically 100 to 200 kPa) is usually too weak to raise water to the full height of most plants, and is most noticeable at night when



transpiration is low, sometimes appearing as guttation (droplets of water exuded from hydathodes at leaf tips). Imbibition is the uptake of water by dry cell-wall components (cellulose, pectin, lignin) without dissolving, causing them to swell; it is especially important in the germination of seeds, whose dry cell walls can increase up to 200 times in volume as they imbibe water, rupturing the seed coat.

Transpiration and the Opening and Closing of Stomata

Transpiration, the loss of water vapour from aerial plant parts, occurs by three routes: cuticular transpiration through the leaf cuticle (about 5-7% of total loss), lenticular transpiration through lenticels in the bark of stems (about 1-2%), and stomatal transpiration through stomatal pores, which accounts for roughly 90% of total water loss. Although transpiration can be a 'necessary evil' — risking wilting and even death under drought — it drives the ascent of sap, distributes dissolved minerals, cools the plant through evaporation, and keeps cell surfaces wet for gaseous exchange. Its rate is affected by light, temperature (roughly doubling for every 10 degrees Celsius rise, until extreme heat forces stomatal closure), carbon dioxide concentration, humidity, wind, and the availability of soil water.

Two hypotheses explain the opening and closing of stomata. The older starch-sugar hypothesis proposed that sugars produced by photosynthesis in guard cells during the day lower their water potential, causing them to take up water and become turgid, opening the pore; at night, sugars are converted to starch or used in respiration, so guard cells become flaccid and close. The now widely accepted potassium ion hypothesis holds that stomata open when potassium ions (K^+) are actively pumped into guard cells (lowering their osmotic potential so water follows by osmosis, making them turgid), controlled by light and low internal carbon dioxide levels, and close when potassium diffuses back out; under water stress, the hormone abscisic acid overrides these signals and forces stomatal closure to prevent excessive water loss.

Translocation of Organic Solutes: Phloem and the Pressure-Flow Theory

Organic solutes, chiefly sucrose, are transported through the phloem by sieve elements, which are joined end to end into sieve tubes and are closely associated with companion cells that supply them with ATP and proteins via plasmodesmata. Transport occurs from source regions (a mature photosynthesizing leaf, or a storage organ during its exporting phase) to sink regions (roots, tubers, developing fruits, immature leaves, or growing shoot and root tips); studies using phloem-feeding aphids, whose stylets tap directly into sieve tubes, showed that phloem sap is mostly sucrose in solution.

The pressure-flow theory (proposed by Ernst Munch) explains phloem transport as movement driven by an osmotically generated pressure gradient between source and sink, and has replaced earlier 'active' theories for lack of supporting evidence. At the source, sucrose is actively loaded into the sieve tube, and water then follows by osmosis from the nearby xylem, raising the hydrostatic pressure at that end. At the sink, sucrose is unloaded and used or stored, and water correspondingly leaves the sieve tube by osmosis, lowering the pressure there. This pressure difference physically pushes the sieve-tube contents in bulk flow from source to sink, much like water flowing through a hose — far faster than



diffusion alone could account for (sugar movement in phloem is about 1 metre per hour, versus roughly 1 metre per eight years by simple diffusion).

Transport in Animals: Open and Closed Circulatory Systems and Evolution of the Vertebrate Heart

Unicellular and simple aquatic multicellular animals (such as Hydra and Planaria) rely entirely on diffusion, osmosis and active transport for material exchange and have no circulatory system, aided by a large surface-area-to-volume ratio. Larger, more complex animals, with far less exposed surface area relative to volume, need a circulatory system with three essential components: a circulating fluid (blood), a contractile pump (a modified vessel or heart), and vessels to carry the fluid. In an open circulatory system (found in arthropods such as the cockroach, and molluscs), blood — called haemolymph — leaves the vessels and directly bathes the tissues in body cavities called sinuses; in a closed circulatory system (found in annelids such as the earthworm, cephalopod molluscs, and vertebrates), blood always remains within an interconnected network of arteries, capillaries and veins, allowing more efficient maintenance of blood pressure and more economical use of blood volume.

The vertebrate heart shows a clear evolutionary progression. In fish, the heart is effectively two-chambered (with an additional sinus venosus and conus/bulbus arteriosus) and works as a single-circuit pump, receiving and pumping only deoxygenated blood to the gills. In amphibians, the heart has two atria and one ventricle, so oxygenated and deoxygenated blood mix in the single ventricle before being pumped out. In reptiles, the ventricle is only partially divided (except in crocodiles, where it is complete), reducing but not eliminating mixing. In birds and mammals, the heart is completely four-chambered, so oxygenated and deoxygenated blood never mix, and the heart functions as a true double-circuit pump with separate pulmonary circulation (heart to lungs and back) and systemic circulation (heart to body and back).

Human Blood and the Heart: Composition, Cardiac Cycle and Blood Vessels

Human blood, about one-twelfth of body weight, consists of plasma (about 55% by volume — mostly water, with dissolved proteins, salts, nutrients, hormones, wastes and gases) and cells or cell-like bodies (about 45% by volume): red blood cells (erythrocytes, biconcave and without a nucleus, carrying oxygen bound to haemoglobin), white blood cells (leucocytes — granulocytes such as neutrophils, eosinophils and basophils, and agranulocytes such as monocytes and lymphocytes — involved in body defence), and platelets (cell fragments from megakaryocytes that trigger blood clotting by converting fibrinogen to fibrin). Blood transports nutrients, gases, hormones and wastes, helps regulate pH, temperature and water/salt balance, and defends the body through phagocytosis and immunity.

The human heart, enclosed in the protective pericardium, has four chambers — two thin-walled atria and two thick-walled ventricles — with the tricuspid valve between the right atrium and ventricle and the bicuspid (mitral) valve between the left atrium and ventricle, plus semilunar valves at the bases of the pulmonary trunk and aorta, all ensuring one-way blood flow. The cardiac cycle has three phases: diastole (chambers relaxed and filling), atrial



systole (atria contract, pushing blood into the ventricles), and ventricular systole (ventricles contract, pushing blood into the pulmonary trunk and aorta, producing the 'lubb-dubb' heart sounds); the whole cycle takes about 0.8 seconds and is initiated by the sino-atrial node (the pacemaker). Blood leaves the heart through elastic, thick-walled arteries (carrying blood at high pressure, e.g. 120 mm Hg systolic), passes through microscopic, single-cell-thick capillaries where exchange with tissues occurs, and returns through valved veins at low pressure; disorders include atherosclerosis, hypertension, thrombus formation, heart attack and stroke.

Lymphatic System and Immunity

The lymphatic system returns fluid from body tissues to the blood: lymph capillaries end blindly in tissues, collecting excess interstitial fluid (then called lymph), which passes through progressively larger lymph vessels, lymph nodes (masses of lymphoid tissue containing lymphocytes that filter and defend), and ultimately drains via the thoracic duct into a subclavian vein; in the intestine, lymph capillaries called lacteals absorb digested fats. The lymphatic system returns about 3 litres of fluid and dissolved proteins to the blood each day, and, together with the spleen (which filters blood) and other lymphoid masses (tonsils, adenoids, thymus), helps defend the body against foreign invaders.

Immunity is the body's capacity to recognize foreign material and mobilize cells and antibodies to remove it. T-lymphocytes (matured under the influence of the thymus) mount a cell-mediated response, directly combating microorganisms or foreign tissue, while B-lymphocytes mount a humoral response, forming plasma cells that secrete antibodies (immunoglobulins) that bind and neutralize specific antigens. Active immunity develops when the body itself produces antibodies, either naturally (after infection) or artificially (through vaccination), and tends to be long-lasting; passive immunity results from injecting ready-made antibodies (antisera, as used against tetanus, rabies or snake venom), giving immediate but short-lived protection. AIDS is a viral disease that destroys the immune system, leaving the body unable to fight infections or certain cancers.

Important Definitions

Term	Definition
Water potential	The tendency of water molecules in a system to move to another system, measured relative to pure water ($\Psi_w = 0$); water moves from higher to lower water potential.
Osmosis	The movement of water molecules from a region of higher water potential to a region of lower water potential through a partially permeable membrane.
Plasmolysis	The shrinkage of a plant cell's protoplast away from its cell wall due to exosmosis of water in a solution of lower water potential than the cell.
Transpiration	The loss of water vapour from the aerial parts of a plant, mainly through stomata, and also through the cuticle and lenticels.
Translocation	The transport of organic solutes, chiefly sucrose, through the phloem from source regions to sink regions.



Term	Definition
Open circulatory system	A circulatory system (e.g. in cockroach) in which blood leaves the vessels and directly bathes body tissues in sinuses.
Closed circulatory system	A circulatory system (e.g. in earthworm and vertebrates) in which blood remains confined within a network of arteries, capillaries and veins.
Immunity	The capacity of the body to recognize foreign material and mobilize cells and antibodies to remove it effectively.

Key Facts

Item	Fact
Root hair surface contribution	Root hairs provide about 67% of a root's total absorptive surface area.
Water potential equation	Total water potential = solute potential + pressure potential ($\Psi_w = \Psi_s + \Psi_p$).
Xylem tension pulling height	Cohesion-tension can pull water up to about 200 metres; flow speeds up to 8 m/hour in tall trees.
Transpiration route split	Stomatal ~90%, cuticular ~5-7%, lenticular ~1-2% of total transpiration.
Phloem vs diffusion speed	Sugar movement in phloem ~1 metre/hour, versus ~1 metre/8 years by simple diffusion.
Blood composition	Plasma ~55% and cells/platelets ~45% by volume; plasma is about 90% water.
Blood cell counts	RBCs ~5-5.5 million/mm ³ (male), ~4.5 million/mm ³ (female); WBCs 7,000-8,000/mm ³ ; platelets ~250,000/mm ³ .
Cardiac cycle and pressure	One heartbeat (systole + diastole) takes about 0.8 seconds; normal blood pressure is about 120/80 mm Hg.

Diagrams & Illustrations

Root Pathways for Water and Mineral Uptake: a cross-sectional diagram of a root showing the apoplast, symplast and vacuolar pathways carrying water and minerals from the soil, across the epidermis, cortex and endodermis (with Casparian strips), into the xylem.

Root pathways for water and mineral uptake: apoplast, symplast and vacuolar - Biology 1st Year (Freebooks.pk)

Root Pathways for Water and Mineral Uptake

Pressure-Flow Theory of Phloem Transport: a diagram showing sucrose being loaded into the sieve tube at a source leaf (raising pressure as water enters by osmosis) and unloaded at a sink such as a root or fruit (lowering pressure as water leaves), driving bulk flow from source to sink.



The Human Heart: Structure and Blood Flow: a labelled diagram of the human heart showing the four chambers (right/left atria and ventricles), the tricuspid, bicuspid and semilunar valves, and the pulmonary and systemic circulation pathways.

The human heart: structure and blood flow - Biology 1st Year
(Freebooks.pk)

The Human Heart: Structure and Blood Flow

Short Questions & Answers

Q1. What is the Casparian strip, and why is it important?

Ans. The Casparian strip is a waxy, water-impermeable band in the radial and transverse walls of endodermal cells; it blocks the apoplast pathway at the endodermis, forcing water and minerals to cross into the symplast through the cell membrane, allowing the plant to control which substances reach the xylem.

Q2. Differentiate active and passive immunity.

Ans. Active immunity develops when the body itself produces antibodies in response to an antigen (naturally through infection or artificially through vaccination) and is long-lasting, whereas passive immunity results from injecting ready-made antibodies (antisera), giving immediate but short-lived protection since the body does not produce its own antibodies.

Q3. Why is diffusion too slow to explain sugar movement in phloem?

Ans. Sugar movement in phloem averages about 1 metre per hour, while simple diffusion would move sugar only about 1 metre in eight years, so diffusion alone cannot account for the observed speed; the pressure-flow (bulk flow) mechanism is needed instead.

Q4. What is guttation, and what causes it?

Ans. Guttation is the loss of liquid water as droplets from hydathodes at leaf tips or margins; it is caused by root pressure, the positive hydrostatic pressure built up in the xylem by active secretion of solutes into root xylem sap, and is most noticeable at night when transpiration is low and humidity is high.

Q5. Differentiate open and closed circulatory systems with one example each.

Ans. In an open circulatory system (e.g. cockroach), blood leaves the vessels and directly bathes body tissues in sinuses; in a closed circulatory system (e.g. earthworm), blood remains confined within a network of arteries, capillaries and veins and never directly contacts tissues.

Q6. What is the function of the sino-atrial node?

Ans. The sino-atrial node, located in the wall of the right atrium, acts as the heart's natural pacemaker, generating the electrical impulses that initiate each heartbeat and cause the atria to contract.



Long Questions & Answers

Q1: Describe how water and minerals are taken up by plant roots, including the apoplast, symplast and vacuolar pathways.

Roots absorb water and dissolved minerals mainly through root hairs, thin tubular extensions of epidermal cells that dramatically increase the root's absorptive surface area (contributing roughly two-thirds of it). Minerals dissolved in soil water enter root hair or epidermal cells partly passively, by diffusion or facilitated diffusion through membrane carrier proteins, and partly by active transport, which requires ATP and allows the plant to accumulate minerals against their concentration gradient; symbiotic partners such as mycorrhizal fungi and nitrogen-fixing bacteria further assist mineral uptake. Once inside the root, water and minerals travel toward the xylem by three interconnected pathways. In the apoplast pathway, movement occurs through the continuous, non-living network of adjacent cell walls, requiring no membrane crossings; however, this pathway is blocked at the endodermis by the Casparian strip, a band of waterproof material embedded in the radial and transverse walls of endodermal cells, forcing water and solutes to cross into the symplast by passing through a cell membrane at this point - allowing the plant selective control over what reaches the xylem. In the symplast pathway, water and minerals move through the living cytoplasm of a chain of interconnected cells, passing from one cell to the next through plasmodesmata, cytoplasmic channels that cross adjacent cell walls. In the vacuolar pathway, materials move from vacuole to vacuole across successive cell membranes by osmosis, crossing both symplast and apoplast in the process. All three pathways ultimately deliver water and minerals to the dead, hollow xylem cells, from which they are pulled upward toward the shoot.

Q2: Explain the concept of water potential and describe the cohesion-tension theory of the ascent of sap.

Water potential (Ψ_w) is a measure of the tendency of water molecules in a system to move to another system, and water always moves from a region of higher water potential to one of lower water potential. Pure water has the maximum possible water potential, arbitrarily defined as zero; because dissolving any solute lowers water potential, all solutions have a negative water potential. Water potential has two components: the solute (osmotic) potential (Ψ_s), which becomes more negative as solute concentration increases, and the pressure potential (Ψ_p), the physical pressure that builds up as water enters and inflates a walled plant cell, making it turgid; the total water potential is their sum, $\Psi_w = \Psi_s + \Psi_p$. This concept explains osmosis (the movement of water through a partially permeable membrane from higher to lower water potential) and underlies the ascent of sap, the upward movement of water and dissolved minerals from roots to leaves through the xylem, chiefly explained by the cohesion-tension theory proposed by Dixon. According to this theory, water molecules within the narrow xylem tubes are held together in a continuous, unbroken column by cohesion - mutual attraction through hydrogen bonding. As water evaporates from mesophyll cells during transpiration, it lowers their water potential, causing water to move out of the adjacent xylem by osmosis; because the remaining water molecules in the xylem are cohesively bonded to one another, this creates tension, a pulling force transmitted all the



way down the water column to the roots, drawing more water in from the soil. Adhesion, the attraction between water molecules and the cellulose walls of the xylem vessels, prevents the water column from pulling away from the vessel walls and breaking, while the mechanical strength of lignified xylem walls prevents them from collapsing inward under this tension. Together, these forces are strong enough to pull water upward through the tallest trees, to heights approaching 200 metres.

Q3: Describe the process of transpiration and explain the mechanism of opening and closing of stomata.

Transpiration is the evaporative loss of water vapour from the aerial parts of a plant and occurs through three routes: cuticular transpiration, through the waxy cuticle covering leaf surfaces (accounting for roughly 5 to 7 percent of total water loss); lenticular transpiration, through lenticels, small pores in the bark of woody stems (roughly 1 to 2 percent); and stomatal transpiration, through the microscopic pores called stomata on leaf surfaces, which accounts for about 90 percent of total transpiration and is therefore the most significant and most tightly regulated route. The rate of transpiration is influenced by several environmental factors: light (which triggers stomatal opening), temperature (higher temperatures increase evaporation but extreme heat forces stomatal closure to prevent excessive water loss), carbon dioxide concentration (low internal CO₂ favours stomatal opening), humidity (drier air increases the rate of water loss), wind (which removes humid air from around the leaf surface, increasing the diffusion gradient), and the availability of soil water. The opening and closing of stomata is controlled by a pair of guard cells surrounding each pore. According to the widely accepted potassium ion hypothesis, stomata open when potassium ions are actively pumped into the guard cells from surrounding epidermal cells; this lowers the osmotic potential inside the guard cells, so water follows by osmosis, making the guard cells turgid and causing them to bow apart, opening the pore between them. This active transport of potassium is promoted by light and by low internal carbon dioxide concentrations. At night, or when carbon dioxide levels rise, potassium ions diffuse back out of the guard cells, water follows by osmosis, the guard cells become flaccid, and the stoma closes. Under conditions of water stress, the plant hormone abscisic acid is released and overrides these normal signals, forcing potassium efflux and stomatal closure to conserve water even during daylight.

Q4: Explain how the pressure-flow theory accounts for the movement of sugars through the phloem.

Organic solutes manufactured during photosynthesis, chiefly the sugar sucrose, are transported throughout the plant body via the phloem, specifically through living but enucleate sieve tube cells joined end to end at sieve plates, each closely associated with one or more companion cells that supply it with ATP and proteins through plasmodesmata. Transport occurs from source regions - typically mature, actively photosynthesizing leaves, or storage organs during their exporting phase - to sink regions, which include roots, developing fruits, immature leaves, and growing shoot or root tips, wherever sugars are being actively used or stored. The most widely accepted explanation for how this movement occurs is the pressure-flow theory, first proposed by Ernst Munch, which describes



translocation as bulk flow driven by an osmotically generated pressure gradient between source and sink. At the source, sucrose produced by photosynthesis is actively transported (using energy) through the bundle sheath and companion cells into the sieve tube elements, sharply raising the sucrose concentration there; this lowers the water potential inside the sieve tube, so water moves in from the adjacent xylem by osmosis, substantially raising the hydrostatic pressure at the source end of the sieve tube. At the sink end, sucrose is unloaded from the sieve tube - actively or passively, depending on the tissue - and used in respiration or converted to storage compounds, lowering the sucrose concentration and raising the water potential inside the sieve tube at that end; water therefore leaves the sieve tube by osmosis into surrounding cells, lowering the hydrostatic pressure at the sink. Because of this stark difference in hydrostatic pressure between the high-pressure source end and the low-pressure sink end, the entire fluid content of the sieve tube - water together with its dissolved sucrose and other solutes - is physically pushed along the tube from source to sink by bulk flow, much as water is pushed through a garden hose under pressure; sieve plates along the way increase resistance and help maintain this pressure gradient. This passive, pressure-driven mechanism, requiring energy only at the loading and unloading steps rather than along the transport pathway itself, comfortably accounts for the observed speed of sugar movement in phloem (about one metre per hour), which is far too fast to be explained by diffusion alone.

Q5: Describe the composition of human blood and the structure and working of the human heart, including the cardiac cycle.

Human blood, making up about one-twelfth of body weight, consists of two main components: plasma, which forms about 55 percent of blood volume and is roughly 90 percent water carrying dissolved plasma proteins, inorganic ions, organic nutrients, nitrogenous wastes, hormones and dissolved gases; and formed elements, about 45 percent of blood volume, comprising red blood cells (erythrocytes), white blood cells (leucocytes) and platelets. Red blood cells, the most numerous blood cells, are biconcave discs that lose their nucleus before entering circulation and are about 95 percent haemoglobin by cytoplasmic content, the pigment responsible for carrying oxygen; they are produced in red bone marrow and survive for about four months before being broken down in the liver and spleen. White blood cells, far less numerous but larger, are divided into granulocytes (neutrophils, eosinophils and basophils, produced in bone marrow) and agranulocytes (monocytes and lymphocytes, produced in lymphoid tissue), and are chiefly responsible for defending the body against infection through phagocytosis and immune responses. Platelets are cell fragments, not complete cells, released from megakaryocytes in bone marrow, and are essential for blood clotting, converting the soluble plasma protein fibrinogen into insoluble fibrin threads that trap blood cells and seal wounds. The human heart, a muscular double pump enclosed within the protective, fluid-filled pericardium, has four chambers: two thin-walled atria that receive blood, and two thick-walled ventricles that pump it out. The right atrium receives deoxygenated blood from the body via the venae cavae and passes it through the tricuspid valve into the right ventricle, which pumps it via the pulmonary trunk to the lungs; oxygenated blood returns via the pulmonary veins to the left atrium, passes through the bicuspid (mitral) valve into the left ventricle, and is pumped via the aorta to the rest of the body - with semilunar valves at the bases of both the pulmonary trunk and the



aorta preventing backflow. This entire sequence, one cardiac cycle, consists of three phases: diastole, when all heart chambers are relaxed and filling with blood; atrial systole, when both atria contract together, forcing blood through the tricuspid and bicuspid valves into the relaxed ventricles; and ventricular systole, when both ventricles contract together, forcing blood out through the pulmonary trunk and aorta while the atrioventricular valves snap shut (producing the 'lubb' sound) followed shortly by closure of the semilunar valves (the 'dubb' sound). One complete cardiac cycle takes about 0.8 seconds and is triggered by electrical impulses originating in the sino-atrial node, the heart's natural pacemaker, located in the wall of the right atrium.

MCQs with Answers

1. The waxy band in endodermal cell walls that blocks the apoplast pathway is the:

(a) cuticle (b) Casparian strip (c) sieve plate (d) tonoplast

Correct Answer: (b) Casparian strip. The Casparian strip, embedded in endodermal cell walls, blocks the apoplast pathway and forces water/minerals into the symplast.

2. Pure water has a water potential of:

(a) +100 kPa (b) zero (c) always negative (d) equal to solute potential only

Correct Answer: (b) zero. Pure water has the maximum water potential, defined as zero; all solutions have negative water potential.

3. The cohesion-tension theory of ascent of sap was proposed by:

(a) Munch (b) Sacks (c) Dixon (d) Van Mohl

Correct Answer: (c) Dixon. The cohesion-tension theory, explaining the ascent of sap, was proposed by Dixon.

4. Which route accounts for the largest share of total plant transpiration?

(a) Cuticular (b) Lenticular (c) Stomatal (d) Root surface

Correct Answer: (c) Stomatal. Stomatal transpiration accounts for about 90% of total water loss from a plant.

5. According to the potassium ion hypothesis, stomata open when:

(a) potassium diffuses out of guard cells (b) potassium is actively pumped into guard cells, and water follows by osmosis (c) starch is converted to sugar only (d) abscisic acid is released

Correct Answer: (b) potassium is actively pumped into guard cells, and water follows by osmosis. Active pumping of potassium into guard cells lowers their osmotic potential, water follows by osmosis, and the turgid guard cells open the stoma.

6. The pressure-flow theory of phloem transport was proposed by:

(a) Dixon (b) Ernst Munch (c) Sacks (d) Van Mohl

Correct Answer: (b) Ernst Munch. Ernst Munch proposed the pressure-flow theory to explain translocation in phloem.

7. An open circulatory system, in which blood directly bathes tissues, is found in:



(a) earthworm (b) cockroach (c) human (d) octopus

Correct Answer: (b) cockroach. The cockroach (phylum Arthropoda) has an open circulatory system where haemolymph directly bathes tissues in sinuses.

8. In birds and mammals, the heart functions as a:

(a) single-circuit pump with mixing of blood (b) double-circuit pump with no mixing of oxygenated and deoxygenated blood (c) two-chambered pump (d) pump without valves

Correct Answer: (b) double-circuit pump with no mixing of oxygenated and deoxygenated blood. The four-chambered heart of birds and mammals is a double-circuit pump with complete separation of oxygenated and deoxygenated blood.

9. Blood clotting mainly depends on the conversion of fibrinogen to fibrin, a process triggered by:

(a) red blood cells (b) platelets (c) eosinophils (d) plasma water

Correct Answer: (b) platelets. Platelets help convert the soluble plasma protein fibrinogen into insoluble fibrin threads, forming a blood clot.

10. Passive immunity, such as that given by antivenom serum, provides protection that is:

(a) long-lasting because antibodies are produced by the body (b) immediate but short-lived, since ready-made antibodies are injected (c) the same as active immunity (d) only effective against viruses

Correct Answer: (b) immediate but short-lived, since ready-made antibodies are injected. Passive immunity involves injecting ready-made antibodies, giving immediate but short-lived protection since the body does not produce its own.

Quick Revision Summary

- Water/mineral uptake: root hairs (~67% of absorptive surface) -> apoplast (cell walls, blocked at endodermis by Casparian strips), symplast (via plasmodesmata), vacuolar (vacuole to vacuole) pathways -> xylem. Minerals via diffusion, facilitated diffusion, and active transport (ATP).
- Water potential: $\Psi_w = \Psi_s$ (solute potential, always negative) + Ψ_p (pressure potential). Osmosis = water movement, high to low Ψ_w . Plasmolysis = protoplast shrinkage in low- Ψ_w solution; deplasmolysis in distilled water.
- Ascent of sap = Cohesion-Tension Theory (Dixon): cohesion (H-bonds in water column) + tension (from transpiration pull) + adhesion (to xylem walls) + strong xylem walls -> pulls water up to 200m. Also: root pressure (minor, causes guttation) and imbibition (important in seed germination).
- Transpiration: cuticular (~5-7%), lenticular (~1-2%), stomatal (~90%). Factors: light, temperature, CO₂, humidity, wind, soil water. Stomata open/close via K⁺ ion pumping into/out of guard cells (water follows by osmosis); abscisic acid closes stomata under water stress.
- Translocation: phloem sieve tubes + companion cells carry sucrose. Pressure-Flow Theory (Munch): sucrose loaded at source -> water enters by osmosis -> high pressure; sucrose unloaded at sink -> water leaves -> low pressure; pressure gradient drives bulk flow source to sink.



- Animal transport: no system in Hydra/Planaria (diffusion only). Open circulatory system (cockroach, haemolymph bathes tissues) vs Closed (earthworm, vertebrates, blood stays in vessels). Vertebrate heart evolution: fish (2-chamber, single circuit) -> amphibians (3-chamber, some mixing) -> reptiles (partial ventricle division) -> birds/mammals (4-chamber, double circuit, no mixing).
 - Human blood: plasma (55%, mostly water) + RBCs (O₂ via haemoglobin), WBCs (defense), platelets (clotting - fibrinogen to fibrin). Heart: 4 chambers, tricuspid/bicuspid/semilunar valves, SA node = pacemaker. Cardiac cycle (diastole, atrial systole, ventricular systole) ~0.8 sec. Lymphatic system returns fluid to blood via lymph nodes/thoracic duct. Immunity: T-cells (cell-mediated), B-cells (humoral/antibodies); active (long-lasting) vs passive (immediate, short-lived) immunity.
- Notes by freebooks.pk.

Exam Tips

- Learn the three root uptake pathways (apoplast, symplast, vacuolar) and exactly where/why the Casparian strip forces a pathway switch - a very common diagram-based question.
- Master the water potential equation ($\Psi_w = \Psi_s + \Psi_p$) and be ready to apply it to simple 'which way will water move' problems between two cells or solutions.
- Learn cohesion-tension theory as four linked ideas: cohesion, tension, adhesion, and strong xylem walls - examiners often ask you to name and explain each separately.
- Be clear on the difference between the starch-sugar hypothesis and the (now preferred) potassium ion hypothesis for stomatal movement, and the added role of abscisic acid.
- Walk through the pressure-flow theory as a numbered sequence (loading at source -> water entry -> high pressure -> bulk flow -> unloading at sink -> water exit -> low pressure) - this step-by-step structure matches how it's usually marked.
- Compare open vs closed circulatory systems and the 2/3/4-chambered hearts of fish/amphibians/reptiles vs birds-mammals side by side; know exactly why mixing does or doesn't occur in each.
- Memorise the cardiac cycle sequence (diastole -> atrial systole -> ventricular systole) with valve names and heart sounds, and know that the SA node is the pacemaker.

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