

CHSE Odisha · +2 Science

BOTANY

+2 1st Year (Class XI) · As per CHSE Syllabus 2023-24

Theory in simple language · Formula boxes
Solved problems · Exam Q&A · Practice & revision

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BOTANY

+2 1st Year (Class XI) · Theory + Practical

Exam Pattern & How to Study

GOLDEN RULES FOR WRITING ANSWERS

- Always write the **formula first**, then substitute values, then the answer **with units**.
- Underline or box the final answer. Examiners mark step-by-step, so even a wrong final answer earns step marks.
- For theory answers, use short points and draw a diagram wherever possible.
- Attempt questions you know best first, but keep their numbering exactly as in the paper.

How to Use These Botany Notes

Botany is the study of plants. In the CHSE +2 1st Year examination, Botany is one half of the Biology paper (the other half is Zoology). These notes follow the CHSE split-up syllabus 2023-24 and are written in simple language for students who find science words difficult. Every chapter gives you the main ideas, easy comparison tables, "Remember" boxes with memory tricks, and solved exam questions.

Unit	Chapters covered in these notes
I. Diversity of Living Organisms	Ch 1 The Living World; Ch 2 Biological Classification; Ch 3 Plant Kingdom
II. Structural Organisation in Plants	Ch 5 Morphology of Flowering Plants; Ch 6 Anatomy of Flowering Plants
III. Cell: Structure and Function	Ch 8 Cell: The Unit of Life; Ch 9 Biomolecules
IV. Plant Physiology	Ch 11 Photosynthesis in Higher Plants; Ch 12 Respiration in Plants; Ch 13 Plant Growth and Development
Practical	Microscope, plant families, sections, mitosis, food tests, enzyme activity, modifications

STUDY PLAN

(1) Read the theory of one chapter. (2) Learn the tables and "Remember" boxes. (3) Practise the question bank of that chapter. (4) In the last month, attempt the model papers within time and read the quick-revision sheet daily. In Botany, neat labelled diagrams earn marks: whenever a "diagram description" is given, practise drawing it from the labelled-part table.

SYLLABUS NOTE

Angiosperms (as a separate group in Plant Kingdom) and the topic "plant life cycles and alternation of generations" are excluded for this session. Chapters 4, 7 and 10 of NCERT belong to Zoology or are taught in other units, so they are not part of these Botany notes.

Chapter 1. The Living World

1.1 What is "living"?

Living things show some special features that non-living things do not show. The most important ones are:

- **Growth** – increase in mass and number of cells. In plants growth continues throughout life; in animals it stops after a certain age. Note: non-living things like crystals and mountains also "grow" by adding material from outside, so growth alone is not a defining feature.
- **Reproduction** – producing young ones of the same kind. It is not a defining feature because mules, worker bees and infertile couples do not reproduce but are still living.
- **Metabolism** – the sum of all chemical reactions in the body (building up = anabolism, breaking down = catabolism). Metabolism is a **defining feature** of life; no non-living thing shows it.
- **Cellular organisation** – all living things are made of cells. This is also a defining feature.
- **Consciousness** – the ability to sense the surroundings and respond (response to light, water, touch, temperature). It is the most defining feature; human beings alone are self-conscious.

REMEMBER

Defining features of life = **Metabolism, Cellular organisation and Consciousness** (M-C-C). Growth and reproduction are NOT defining features.

1.2 Diversity and biodiversity

DEFINITION

Biodiversity is the number and types of living organisms present on Earth. About 1.7 to 1.8 million species have been described so far, and many more remain to be discovered.

Each kind of organism has a common name which differs from place to place. To avoid confusion, scientists give one **scientific name** to each organism. This process of standardised naming is called **nomenclature**. Nomenclature is possible only when the organism is correctly described and identified. **Identification** means finding the correct name of an organism by comparing it with known organisms.

1.3 Need for classification

It is impossible to study millions of organisms one by one. Therefore we group them on the basis of easily observable characters. **Classification** is the process by which anything is grouped into convenient categories based on some easily observable characters. For example "plants", "animals", "mammals", "dogs" are categories.

- It makes the study of a huge variety of organisms easy.

- It shows how different organisms are related to each other (evolutionary relationships).
- It helps in correct identification and naming.
- It gives a basis for other branches of biology such as ecology, medicine and agriculture.

1.4 Three domains of life

Carl Woese (1990) divided all living organisms into three large groups called **domains**, based mainly on the structure of ribosomal RNA (rRNA):

Domain	Cell type	Examples	Key feature
Archaea	Prokaryotic	Methanogens, halophiles, thermoacidophiles	Live in extreme places; cell wall without peptidoglycan; membrane lipids with ether bonds
Bacteria	Prokaryotic	E. coli, cyanobacteria	"True" bacteria; cell wall with peptidoglycan
Eukarya	Eukaryotic	Protists, fungi, plants, animals	Membrane-bound nucleus and organelles

1.5 Taxonomy and systematics

DEFINITION

Taxonomy is the branch of biology that deals with characterisation, identification, nomenclature and classification of organisms. **Systematics** (from Latin *systema* = systematic arrangement) deals with the diversity of organisms and their evolutionary relationships (phylogeny). The word was used by Linnaeus in his book *Systema Naturae*.

The four basic processes of taxonomy are **characterisation, identification, classification and nomenclature**. Modern taxonomy also uses external and internal structure, cell structure, development and ecological information.

1.6 Concept of species

Species is the basic unit of classification. It is a group of individuals with fundamental similarities that can interbreed freely in nature to produce fertile offspring. For example *Mangifera indica* (mango), *Solanum tuberosum* (potato) and *Panthera leo* (lion). Here *indica*, *tuberosum* and *leo* are the species names (specific epithets).

1.7 Taxonomic hierarchy

Each step in classification is a rank or **category**; all the categories together form the **taxonomic hierarchy**. A concrete group of organisms at any level (e.g. "Mammalia" or "Poaceae") is called a **taxon** (plural taxa).

The obligate categories, from lowest to highest, are:

Species → Genus → Family → Order → Class → Phylum (animals) / Division (plants) → Kingdom

Category	Meaning	Mango	Wheat
Species	Interbreeding group	indica	aestivum
Genus	Group of related species	Mangifera	Triticum
Family	Group of related genera	Anacardiaceae	Poaceae
Order	Group of related families	Sapindales	Poales
Class	Group of related orders	Dicotyledonae	Monocotyledonae
Division	Group of related classes	Angiospermae	Angiospermae
Kingdom	Highest category	Plantae	Plantae

REMEMBER

Order of categories (top to bottom): "**King Philip Came Over For Good Soup**" = Kingdom, Phylum/Division, Class, Order, Family, Genus, Species. As we go up, the number of common characters **decreases** and the number of organisms included **increases**.

1.8 Binomial nomenclature

The system of giving every organism a two-word scientific name was given by **Carolus Linnaeus**. Plant names follow the **International Code of Botanical Nomenclature (ICBN)**; animal names follow the **ICZN**.

Rules of binomial nomenclature:

- Names are in Latin or Latinised and are written in italics.
- The first word is the **genus** name and the second word is the **specific epithet**.
- When handwritten, both words are underlined separately (because italics cannot be handwritten).
- The genus name begins with a capital letter; the specific epithet begins with a small letter. Example: *Mangifera indica*.
- The name of the author who first described the species is written after the name in short form, e.g. *Mangifera indica* Linn. (Linn. = Linnaeus).

1.9 Taxonomical aids

Aid	What it is
Herbarium	A store-house of dried, pressed and preserved plant specimens on sheets, arranged by a classification system. Each sheet has a label with name, family, place and date of collection.
Botanical garden	Living collections of plants for reference, e.g. Royal Botanical Garden Kew (England), Indian Botanical Garden Howrah, National Botanical Research Institute Lucknow.
Museum	Preserved specimens in jars (formalin) and stuffed animals, skeletons.
Zoological park	Wild animals kept in protected surroundings close to their natural habitat.
Key	A tool for identification based on pairs of contrasting characters (couplets); each statement is a "lead".
Flora, manual, monograph, catalogue	Written records: flora = plant species of an area; monograph = all information about one taxon; manual = information for identification.

Chapter 2. Biological Classification

2.1 History of classification

Aristotle was the first to classify plants (trees, shrubs, herbs) and animals (with red blood and without). **Linnaeus** gave the **two-kingdom** classification: Plantae and Animalia. This system had problems: it did not separate prokaryotes from eukaryotes, unicellular from multicellular, or photosynthetic (green algae) from non-photosynthetic (fungi) organisms. Fungi, bacteria and Chlamydomonas were all put in "plants".

2.2 Five-kingdom classification

R.H. Whittaker (1969) proposed the five-kingdom classification: **Monera, Protista, Fungi, Plantae and Animalia**. The criteria used were: cell structure, body organisation (thallus), mode of nutrition, reproduction and phylogenetic relationships.

Character	Monera	Protista	Fungi	Plantae	Animalia
Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cell wall	Non-cellulosic (polysaccharide + amino acid)	Present in some	Present, of chitin	Present, of cellulose	Absent
Nuclear membrane	Absent	Present	Present	Present	Present
Body organisation	Cellular	Cellular	Multicellular / loose tissue	Tissue / organ	Tissue / organ / organ system
Nutrition	Autotrophic (chemo/photo) and heterotrophic	Autotrophic and heterotrophic	Heterotrophic (saprophytic / parasitic)	Autotrophic (photosynthetic)	Heterotrophic (holozoic)

REMEMBER

Five kingdoms: "**My Pet Frog Plays Alone**" = Monera, Protista, Fungi, Plantae, Animalia.

2.3 Kingdom Monera (bacteria)

Bacteria are the only members of Monera. They are the most abundant micro-organisms and live everywhere: hot springs, deserts, snow, deep oceans and even inside other organisms.

Shapes of bacteria: Coccus (spherical), Bacillus (rod-shaped), Vibrio (comma-shaped) and Spirillum (spiral).

(a) Archaeobacteria

They live in the harshest habitats: **halophiles** in extreme salty areas, **thermoacidophiles** in hot springs, and **methanogens** in marshy areas. Their cell wall

structure is different, which helps them survive. Methanogens live in the gut of cattle (ruminants) and produce methane (biogas) from cow dung.

(b) Eubacteria ("true bacteria")

They have a rigid cell wall, and if motile, a flagellum.

- **Photosynthetic autotrophs - Cyanobacteria (blue-green algae):** have chlorophyll *a* like plants; unicellular, colonial or filamentous; colonies often covered by a gelatinous sheath; form blooms in polluted water. Some, such as *Nostoc* and *Anabaena*, fix atmospheric nitrogen in special cells called **heterocysts**.
- **Chemosynthetic autotrophs:** oxidise inorganic substances such as nitrates, nitrites and ammonia and use the released energy to make ATP. They help recycle nitrogen, phosphorus, iron and sulphur.
- **Heterotrophic bacteria:** most abundant; important decomposers; used in making curd from milk, production of antibiotics, and fixing nitrogen in legume roots (*Rhizobium*). Some cause diseases: cholera, typhoid, tetanus, citrus canker.

Reproduction: mainly by **fission** (binary fission); spores under unfavourable conditions; a primitive form of sexual reproduction by transfer of DNA from one bacterium to another.

Mycoplasma are organisms that completely lack a cell wall. They are the smallest living cells known and can survive without oxygen. Many are pathogenic in animals and plants.

2.4 Kingdom Protista

All single-celled eukaryotes are placed in Protista. Boundaries of this kingdom are not well defined. Members are mainly aquatic. They form a link with plants, animals and fungi. They have a well-defined nucleus and membrane-bound organelles; some have flagella or cilia. Reproduction is asexual and sexual (by cell fusion and zygote formation).

Group	Main features	Examples
Chrysophytes	Diatoms and golden algae (desmids); found in fresh and marine water; photosynthetic; cell walls form two thin overlapping shells (like a soap box) embedded with silica, so walls are indestructible. Their deposits form diatomaceous earth , used in polishing and filtration of oils and syrups. Chief "producers" in oceans.	Diatoms, desmids
Dinoflagellates	Mostly marine, photosynthetic; yellow, green, brown, blue or red; stiff cellulose plates on cell wall; usually two flagella (one longitudinal, one transverse in a furrow). Red dinoflagellates (<i>Gonyaulax</i>) cause red tides and release toxins that kill fish.	<i>Gonyaulax</i>
Euglenoids	Mostly fresh water; no cell wall but a protein-rich layer called pellicle makes the body flexible; two flagella (short and long). Photosynthetic in sunlight but behave like heterotrophs (predators) in darkness – a connecting link between plants and animals.	<i>Euglena</i>
Slime moulds	Saprophytic; under suitable conditions form an aggregation called plasmodium which may grow to several feet; in unfavourable conditions form fruiting bodies with spores that have true walls and survive for many years; spores spread by air currents.	Physarum
Protozoans	All heterotrophs, predators or parasites; believed to be primitive relatives of animals. Four groups: Amoeboid (<i>Amoeba</i> , <i>Entamoeba</i>), Flagellated (<i>Trypanosoma</i> – sleeping sickness), Ciliated (<i>Paramoecium</i>), Sporozoans (<i>Plasmodium</i> – malaria).	Amoeba, Paramoecium

2.5 Kingdom Fungi

Fungi are heterotrophic organisms. You see them as moulds on bread and rotten oranges, as mushrooms and toadstools, and as white spots on mustard leaves (white rust caused by *Albugo*). Wheat rust is caused by *Puccinia*. Some are useful: yeast for bread and beer; *Penicillium* gives the antibiotic penicillin.

- Body (except unicellular yeast) is made of long, slender, thread-like structures called **hyphae**. The network of hyphae is the **mycelium**.
- Some hyphae are continuous tubes filled with many nuclei – **coenocytic** hyphae. Others have cross walls called **septa**.
- Cell wall made of **chitin** and polysaccharides.
- Most are **saprophytes** (absorb soluble organic matter from dead substrates); some are **parasites**; some live with algae as **lichens** or with roots of higher plants as **mycorrhiza**.
- Vegetative reproduction: fragmentation, fission, budding. Asexual: spores called conidia, sporangiospores or zoospores. Sexual: oospores, ascospores, basidiospores, produced in fruiting bodies.

Sexual cycle in fungi has three steps:

Plasmogamy (fusion of protoplasm) → Karyogamy (fusion of two nuclei) → Meiosis in zygote → haploid spores

In ascomycetes and basidiomycetes an intermediate **dikaryotic** stage ($n + n$, two nuclei per cell) is seen; this phase is called **dikaryophase**.

Class	Mycelium	Asexual spores	Sexual spores	Examples
Phycomycetes	Aseptate, coenocytic; in water, on decaying wood, or parasites	Zoospores (motile) or aplanospores (non-motile), inside sporangium	Zygospore (fusion of two gametes)	<i>Mucor</i> , <i>Rhizopus</i> (bread mould), <i>Albugo</i>
Ascomycetes (sac fungi)	Septate, branched; unicellular in yeast	Conidia, on conidiophores	Ascospores, inside asci; fruiting body ascocarp	<i>Aspergillus</i> , <i>Claviceps</i> , <i>Neurospora</i> , yeast; edible morels and truffles
Basidiomycetes (club fungi)	Septate, branched	Generally absent; fragmentation common	Basidiospores (four) on basidium, exogenous; fruiting body basidiocarp; sex organs absent	<i>Agaricus</i> (mushroom), <i>Ustilago</i> (smut), <i>Puccinia</i> (rust)
Deuteromycetes (fungi imperfecti)	Septate, branched	Conidia only	Sexual stage not known	<i>Alternaria</i> , <i>Colletotrichum</i> , <i>Trichoderma</i>

REMEMBER

Neurospora (an ascomycete) is widely used in genetic and biochemical work. Deuteromycetes are called "imperfect" only because their perfect (sexual) stage has not been found; when it is found they are moved to Ascomycetes or Basidiomycetes. Many are decomposers that help mineral cycling.

2.6 Kingdom Plantae and Animalia (brief)

Plantae includes all eukaryotic, chlorophyll-containing organisms (algae, bryophytes, pteridophytes, gymnosperms, angiosperms). A few are partially heterotrophic: insectivorous plants (bladderwort, Venus fly trap) and parasites (*Cuscuta*). Cell wall is of cellulose. **Animalia** includes heterotrophic eukaryotes that are multicellular and lack cell walls; nutrition is holozoic; food is stored as glycogen or fat.

2.7 Viruses, viroids and lichens

These are not placed in the five-kingdom system.

Viruses: The name means "venom" or poisonous fluid. **D.J. Ivanowsky (1892)** found that tobacco mosaic disease was caused by an agent smaller than bacteria (it passed through bacteria-proof filters). **M.W. Beijerinck (1898)** called the infectious fluid "Contagium

vivum fluidum". **W.M. Stanley (1935)** showed that viruses can be crystallised and the crystals are mostly protein.

- Viruses are non-cellular. They are inert crystals outside a living cell, but once they infect a cell they take over its machinery and multiply, killing the host. So they are **obligate parasites** and are on the border of living and non-living.
- A virus has a protein coat called **capsid** (made of small subunits called **capsomeres**, arranged in helical or polyhedral form) enclosing genetic material – either RNA or DNA, never both.
- Plant viruses usually have single-stranded RNA (e.g. TMV); animal viruses have single or double-stranded RNA or double-stranded DNA; bacterial viruses (**bacteriophages**) usually have double-stranded DNA.
- Diseases: mumps, smallpox, herpes, influenza, AIDS in humans; mosaic, leaf rolling and curling, yellowing and vein clearing, dwarfing in plants.

Viroids: Discovered by **T.O. Diener (1971)** as the cause of **potato spindle tuber disease**. A viroid is a free RNA without a protein coat. Its RNA is of low molecular weight.

Prions: infectious agents made of abnormally folded protein; cause bovine spongiform encephalopathy (mad cow disease) in cattle and Creutzfeldt-Jakob disease in humans.

Lichens: a symbiotic association (mutually useful) between **algae** and **fungi**. The algal part is the **phycobiont** and the fungal part is the **mycobiont**. Algae make food for the fungus; the fungus gives shelter and absorbs water and minerals for the alga. They are so closely joined that a lichen looks like one organism. Lichens are very good **pollution indicators** – they do not grow in polluted areas.

Virus	Viroid
Nucleic acid (DNA or RNA) with protein coat	Free RNA without protein coat
Larger; nucleic acid of higher molecular weight	Smaller; RNA of low molecular weight
Example: TMV, HIV	Potato spindle tuber viroid

Chapter 3. Plant Kingdom

Kingdom Plantae includes algae, bryophytes, pteridophytes, gymnosperms and angiosperms. (Angiosperms as a group and alternation of generations are excluded this year.)

3.1 Types of classification systems

System	Basis	Example
Artificial	A few external (vegetative) characters such as habit, colour, number and shape of leaves; androecium structure	Linnaeus
Natural	Natural affinities using external and internal features (anatomy, embryology, phytochemistry)	Bentham and Hooker
Phylogenetic	Evolutionary relationships, assuming members of a taxon have a common ancestor	Engler and Prantl (in part), modern systems

Numerical taxonomy uses computers; all characters are given equal importance and coded as numbers. **Cytotaxonomy** uses chromosome number, structure and behaviour. **Chemotaxonomy** uses chemical constituents of the plant.

3.2 Algae

Algae are simple, chlorophyll-bearing, autotrophic, thalloid (body not divided into root, stem and leaf), largely aquatic organisms (fresh water and marine). Some occur on moist stones, soil and wood; some live with fungi (lichens) or animals (on sloth bear).

Form and size vary from colonial (*Volvox*) and filamentous (*Ulothrix*, *Spirogyra*) to massive marine forms such as kelps.

Reproduction:

- **Vegetative** – by fragmentation; each fragment grows into a thallus.
- **Asexual** – by spores, most commonly **zoospores** (flagellated, motile).
- **Sexual** – by fusion of two gametes: **isogamous** (similar gametes, flagellated as in *Chlamydomonas*, or non-flagellated as in *Spirogyra*); **anisogamous** (dissimilar in size, e.g. some *Chlamydomonas* species); **oogamous** (large non-motile female gamete and small motile male gamete, e.g. *Volvox*, *Fucus*).

Usefulness: algae fix at least half of the total carbon dioxide on Earth by photosynthesis and increase the dissolved oxygen in their surroundings. They are primary producers of aquatic food chains. *Porphyra*, *Laminaria* and *Sargassum* are eaten. **Algin** (brown algae) and **carrageen** (red algae) are hydrocolloids used commercially. **Agar** from *Gelidium* and *Gracilaria* is used to grow microbes and in ice-creams and jellies. *Chlorella* is a protein-rich food supplement used even by space travellers.

Feature	Chlorophyceae (green algae)	Phaeophyceae (brown algae)	Rhodophyceae (red algae)
Pigments	Chlorophyll a, b	Chlorophyll a, c, fucoxanthin	Chlorophyll a, d, phycoerythrin
Stored food	Starch	Mannitol, laminarin	Floridean starch
Cell wall	Cellulose (inner), pectose (outer)	Cellulose + algin	Cellulose, pectin, polysulphate esters
Flagella	2-8, equal, apical	2, unequal, lateral	Absent
Habitat	Fresh water, brackish, salt water	Mostly marine	Mostly marine, warmer areas; also deep water
Examples	<i>Chlamydomonas</i> , <i>Volvox</i> , <i>Ulothrix</i> , <i>Spirogyra</i> , <i>Chara</i>	<i>Ectocarpus</i> , <i>Dictyota</i> , <i>Laminaria</i> , <i>Sargassum</i> , <i>Fucus</i>	<i>Polysiphonia</i> , <i>Porphyra</i> , <i>Gracilaria</i> , <i>Gelidium</i>

Green algae have one or more storage bodies called **pyrenoids** in their chloroplasts (protein + starch). Brown algae have a plant body with a holdfast (attaches to substratum), a stalk called **stipe**, and a leaf-like **frond**. Red algae look red due to **r-phycoerythrin**; they can live at great depths where little light reaches.

3.3 Bryophyta

Bryophytes include liverworts and mosses. They are called the **amphibians of the plant kingdom** because they live on land but need water for sexual reproduction (sperm swim to the egg). They grow in moist, shaded areas, especially hills.

- Plant body is thallus-like, prostrate or erect, attached by unicellular or multicellular **rhizoids**. True roots, stems and leaves are absent; root-like, leaf-like or stem-like structures are present.
- The main plant body is **haploid** and called the **gametophyte** (it produces gametes).
- Male sex organ: **antheridium** (produces biflagellate antherozoids). Female sex organ: **archegonium** (flask-shaped; one egg).
- Antherozoids reach the archegonium through water; fusion forms a zygote which develops into a multicellular **sporophyte**. The sporophyte is **not free-living**; it is attached to the gametophyte and gets nourishment from it. Some cells undergo meiosis to make haploid spores, which germinate into gametophytes.

Economic importance: some mosses are food for herbaceous mammals, birds and other animals. *Sphagnum* (peat moss) provides **peat**, used as fuel and as packing material for transport of living material because of its water-holding capacity. Mosses, along with lichens, are the first organisms to colonise rocks (plant succession) and they decompose rocks; they form dense mats on soil and prevent soil erosion.

Liverworts	Mosses
Thalloid, dorsiventral, flat body closely appressed to substrate (e.g. <i>Marchantia</i>); leafy members have tiny leaf-like appendages	Gametophyte has two stages: protonema (creeping, green, branched, filamentous, develops from spore) and leafy stage (upright, slender axes with spirally arranged leaves)
Unicellular rhizoids	Multicellular, branched rhizoids
Asexual reproduction by fragmentation or gemmae (green, multicellular buds formed in gemma cups)	Vegetative reproduction by fragmentation and budding in the secondary protonema
Sporophyte: foot, seta and capsule	Sporophyte more elaborate: foot, seta and capsule; elaborate spore dispersal mechanism
<i>Marchantia</i> , <i>Riccia</i>	<i>Funaria</i> , <i>Polytrichum</i> , <i>Sphagnum</i>

3.4 Pteridophyta

Pteridophytes include horsetails and ferns. They are the **first terrestrial plants to have vascular tissues** (xylem and phloem). They are used for medicinal purposes, as soil binders and as ornamentals. They grow in cool, damp, shady places; some grow in sandy soil.

- The main plant body is a **sporophyte** (diploid), differentiated into true root, stem and leaves.
- Leaves may be small (**microphylls**, as in *Selaginella*) or large (**macrophylls**, as in ferns).
- Sporophytes bear **sporangia** on leaf-like appendages called **sporophylls**. In some (e.g. *Selaginella*, *Equisetum*) sporophylls form compact structures called **strobili** or cones.
- Spores germinate into small, multicellular, free-living, mostly photosynthetic thalloid gametophytes called **prothallus**. They need cool, damp, shady places, and water for fertilisation.
- Most pteridophytes are **homosporous** (one kind of spore). *Selaginella* and *Salvinia* are **heterosporous**: large **megaspores** (give female gametophytes) and small **microspores** (give male gametophytes). The female gametophyte stays on the parent sporophyte for a variable period; the zygote develops there. This is a precursor to the **seed habit** – an important step in evolution.

Class	Example
Psilopsida	<i>Psilotum</i>
Lycopsidea	<i>Selaginella</i> , <i>Lycopodium</i>
Sphenopsida	<i>Equisetum</i> (horsetail)
Pteropsida	<i>Dryopteris</i> , <i>Pteris</i> , <i>Adiantum</i> (ferns)

3.5 Gymnosperms

Gymnosperms (gymnos = naked, sperma = seed) are plants in which the **ovules are not enclosed by an ovary wall** and remain exposed before and after fertilisation. The seeds are therefore naked.

- Medium-sized trees or tall trees and shrubs. The giant redwood *Sequoia* is one of the tallest tree species.
- Roots are generally tap roots. Roots of some genera have fungal association (**mycorrhiza**, e.g. *Pinus*); small specialised roots of *Cycas* called **coralloid roots** are associated with N₂-fixing cyanobacteria.
- Stems are unbranched (*Cycas*) or branched (*Pinus*, *Cedrus*).
- Leaves are simple or compound. *Cycas* has pinnate leaves that persist for a few years. Needle-like leaves of conifers have thick cuticle and sunken stomata to reduce water loss – an adaptation to extremes of temperature, humidity and wind.
- They are **heterosporous**: microspores and megaspores, in sporangia borne on sporophylls arranged in cones (strobili). Male cones (microsporangiate) and female cones (megasporangiate) may be on the same tree (*Pinus*) or on different trees (*Cycas*).
- Male gametophyte is highly reduced and confined to a few cells – the **pollen grain**. The megaspore mother cell in the **nucellus** (protected by integuments) divides by meiosis to form four megaspores; one forms the female gametophyte with two or more archegonia.
- Pollen grains are carried by **air currents** to the ovule; a pollen tube carrying male gametes grows towards the archegonia. Water is not needed for fertilisation. After fertilisation the zygote forms an embryo and the ovule becomes a seed. Seeds are not covered.

3.6 Comparison of plant groups

Feature	Algae	Bryophytes	Pteridophytes	Gymnosperms
Habitat	Mostly aquatic	Moist land	Damp, shady land	Land, often cold/dry
Body	Thallus	Thallus-like; rhizoids	True root, stem, leaf	True root, stem, leaf
Vascular tissue	Absent	Absent	Present	Present (xylem without vessels, phloem without companion cells)
Dominant phase	Mostly gametophyte	Gametophyte	Sporophyte	Sporophyte
Water for fertilisation	Needed	Needed	Needed	Not needed
Seed	No	No	No	Naked seed

REMEMBER

Bryophytes = amphibians of plant kingdom; Pteridophytes = first vascular land plants ("vascular cryptogams"); Gymnosperms = naked seeds. Heterospory in *Selaginella* and *Salvinia* = first step towards seed habit.

Chapter 5. Morphology of Flowering Plants

Morphology is the study of the external form and features of plants. A typical flowering plant (angiosperm) has an underground **root system** and an aerial **shoot system** (stem, leaves, flowers and fruits).

5.1 The root

Type	Origin	Found in
Tap root system	Primary root develops directly from the radicle and grows deep; it bears lateral roots (secondary, tertiary)	Dicots, e.g. mustard, gram
Fibrous root system	Primary root is short-lived and replaced by many roots from the base of the stem	Monocots, e.g. wheat, rice
Adventitious roots	Roots arising from any part of the plant other than the radicle	Grass, Monstera, banyan tree

Functions: absorption of water and minerals, anchorage, storage of reserve food, and synthesis of plant growth regulators.

Regions of the root (from tip upward):

- **Root cap** – thimble-like covering that protects the tender apex as the root pushes through soil.
- **Region of meristematic activity** – a few mm above the cap; small, thin-walled cells with dense protoplasm that divide repeatedly.
- **Region of elongation** – cells elongate and enlarge; responsible for growth in length.
- **Region of maturation** – cells differentiate and mature; some epidermal cells form very fine thread-like **root hairs** which absorb water and minerals.

Modifications of root:

Modification	Function	Example
Storage tap roots	Store food	Carrot (conical), turnip (napiform), radish (fusiform)
Storage adventitious roots	Store food	Sweet potato (tuberous)
Prop roots	Support; hang down from branches and grow into soil	Banyan tree
Stilt roots	Support; arise from lower nodes of stem	Maize, sugarcane
Pneumatophores	Respiration; roots grow vertically upward out of swampy soil	<i>Rhizophora</i> (mangrove)
Epiphytic / velamen roots	Absorb moisture from air	Orchids (Vanda)

5.2 The stem

The stem is the ascending part of the axis bearing branches, leaves, flowers and fruits. It develops from the **plumule** of the embryo. It has **nodes** (where leaves arise) and **internodes** (portions between nodes). Young stems are green and photosynthetic. Functions: spreading out branches with leaves, flowers and fruits; conducting water, minerals and food; storage; support; perennation and vegetative propagation.

Modification	Function	Example
Underground stems: tuber, rhizome, corm, bulb	Store food; perennation (survive unfavourable season)	Potato (tuber), ginger and turmeric (rhizome), Colocasia (corm), onion (bulb)
Stem tendrils	Climbing; develop from axillary buds; slender and spirally coiled	Gourds (cucumber, pumpkin, watermelon), grapevine
Thorns	Protection from grazing animals; axillary buds modified into woody, straight, pointed thorns	<i>Citrus</i> , <i>Bougainvillea</i>
Phylloclade / cladode	Flattened (<i>Opuntia</i>) or fleshy cylindrical (<i>Euphorbia</i>) green stem that does photosynthesis in arid regions; leaves reduced to spines	<i>Opuntia</i> , <i>Euphorbia</i>
Sub-aerial: runner, stolon, offset, sucker	Vegetative propagation	Grass and strawberry (runner), Pistia and Eichhornia (offset), banana, pineapple, Chrysanthemum (sucker)

REMEMBER

Potato is a **stem**, not a root, because its "eyes" are nodes bearing buds. Sweet potato is a **root** because it has no nodes or buds. Thorn = modified stem (axillary bud); spine = modified leaf.

5.3 The leaf

The leaf is a lateral, generally flattened structure borne on the stem. It develops at the node and bears a bud in its axil. Leaves originate from shoot apical meristems and are arranged in an **acropetal** order. They are the most important vegetative organs for photosynthesis.

Parts of a typical leaf: **leaf base** (attaches leaf to stem; may bear two small lateral leaf-like structures called **stipules**; in monocots it expands into a sheath; in legumes it may become swollen, called **pulvinus**), **petiole** (holds the blade towards light; long thin flexible petioles allow blades to flutter in wind, cooling the leaf), and **lamina** or leaf blade (green expanded part with veins and veinlets; the prominent middle vein is the **midrib**).

Venation is the arrangement of veins and veinlets in the lamina.

- **Reticulate venation** – veinlets form a network; found in dicots.
- **Parallel venation** – veins run parallel to each other; found in most monocots.

Types of leaves: simple leaf – lamina entire or incised, but incisions do not touch the midrib. **Compound leaf** – incisions reach the midrib and break the lamina into a number of leaflets. A bud is present in the axil of the petiole of both simple and compound leaves, but never in the axil of leaflets.

- **Pinnately compound** – leaflets present on a common axis called **rachis** (the midrib), e.g. neem.
- **Palmately compound** – leaflets attached at a common point, the tip of the petiole, e.g. silk cotton.

Phyllotaxy is the pattern of arrangement of leaves on the stem or branch:

Type	Leaves per node	Example
Alternate	One, in alternate manner	China rose, mustard, sunflower
Opposite	A pair, opposite each other	<i>Calotropis</i> , guava
Whorled	More than two, forming a whorl	<i>Alstonia</i>

Modifications of leaf: tendrils for climbing (peas), spines for defence (cactus), fleshy food-storing leaves (onion and garlic), phyllode – flattened green petiole doing photosynthesis when leaves are short-lived (Australian *Acacia*), and insect-trapping leaves (pitcher plant, Venus fly trap).

5.4 The inflorescence

A flower is a modified shoot in which the shoot apical meristem changes to floral meristem. The arrangement of flowers on the floral axis is called **inflorescence**.

Racemose	Cymose
Main axis continues to grow	Main axis ends in a flower; growth is limited
Flowers borne laterally in acropetal succession (older flowers below, younger at top)	Flowers borne in basipetal order (older flower at top)
Example: mustard, radish	Example: jasmine, <i>Calotropis</i>

Other common types (useful for practicals): **spike** (sessile flowers on long axis, e.g. *Achyranthes*), **catkin** (spike of unisexual flowers, mulberry), **umbel** (flowers arise from one point, e.g. coriander), **head / capitulum** (sunflower, marigold – many small florets on a flat receptacle), **spadix** (fleshy axis covered by a large bract called spathe, e.g. banana, *Colocasia*), **cyathium** (*Euphorbia*), **hypanthodium** (fig), and **verticillaster** (*Ocimum/tulsi*).

5.5 The flower

The flower is the reproductive unit of angiosperms, meant for sexual reproduction. A typical flower has four whorls on a swollen end of the stalk (pedicel) called **thalamus** or receptacle: **calyx**, **corolla**, **androecium** and **gynoecium**. Calyx and corolla are

accessory organs; androecium and gynoecium are reproductive organs. If calyx and corolla are not distinct (as in lily) they are called **perianth**.

- **Bisexual** flower has both androecium and gynoecium; **unisexual** has only one.
- **Symmetry: actinomorphic** (radial; can be divided into two equal halves in any radial plane, e.g. mustard, datura, chilli); **zygomorphic** (can be divided into two similar halves only in one vertical plane, e.g. pea, gulmohur, bean, Cassia); **asymmetric** (cannot be divided by any plane, e.g. canna).
- Flowers may be **trimerous**, **tetramerous** or **pentamerous** when floral appendages are in multiples of 3, 4 or 5.
- **Bracteate** flowers have reduced leaves (bracts) at the base of the pedicel; **ebracteate** flowers do not.

Position of ovary on thalamus:

Type	Ovary	Example
Hypogynous	Gynoecium at highest position, other parts below it; ovary superior	Mustard, china rose, brinjal
Perigynous	Gynoecium in centre, other parts on rim of thalamus at almost the same level; ovary half-inferior	Plum, rose, peach
Epigynous	Margin of thalamus grows upward, enclosing and fusing with the ovary; other parts arise above the ovary; ovary inferior	Guava, cucumber, ray florets of sunflower

Parts of a flower

Calyx – outermost whorl; members are **sepals**, generally green and leaf-like; protect the flower in bud. **Gamosepalous** = sepals united; **polysepalous** = sepals free.

Corolla – made of **petals**, usually brightly coloured to attract insects. Gamopetalous (united) or polypetalous (free). Shape varies: tubular, bell-shaped, funnel-shaped, wheel-shaped.

Aestivation is the mode of arrangement of sepals or petals in the floral bud with respect to other members of the same whorl:

Type	Description	Example
Valvate	Margins just touch each other without overlapping	<i>Calotropis</i>
Twisted	One margin overlaps the next one and so on	China rose, lady's finger, cotton
Imbricate	Margins overlap but not in any particular direction	Cassia, gulmohur
Vexillary (papilionaceous)	Five petals: largest standard (vexillum) overlaps two lateral wings , which overlap two smallest anterior petals fused to form keel	Pea, bean

Androecium – made of **stamens**, the male reproductive organs. Each stamen has a stalk (**filament**) and an **anther** (usually bilobed, each lobe with two pollen sacs where pollen grains are produced). A sterile stamen is a **staminode**. Stamens attached to petals are

epipetalous (brinjal); attached to perianth are **epiphyllous** (lily). Free stamens = **polyandrous**. United stamens: one bundle = **monodelphous** (china rose), two bundles = **diadelphous** (pea), more than two = **polyadelphous** (citrus).

Gynoecium – female reproductive part, made of one or more **carpels**. A carpel has three parts: **stigma** (receptive surface for pollen), **style** (elongated tube) and **ovary** (enlarged basal part bearing ovules on a flattened cushion called **placenta**). More than one free carpel = **apocarpous** (lotus, rose); fused carpels = **syncarpous** (mustard, tomato). After fertilisation ovules become seeds and ovary becomes fruit.

Placentation – arrangement of ovules within the ovary:

Type	Description	Example
Marginal	Placenta forms a ridge along the ventral suture of a one-chambered ovary; ovules in two rows	Pea
Axile	Placenta is axial and ovules are attached to it in a multilocular ovary	China rose, tomato, lemon
Parietal	Ovules on inner wall of ovary or on peripheral part; ovary one-chambered but becomes two-chambered by a false septum	Mustard, Argemone
Free central	Ovules borne on central axis; septa absent	<i>Dianthus</i> , <i>Primrose</i>
Basal	Placenta at base of ovary; a single ovule attached	Sunflower, marigold

5.6 The fruit

The fruit is a characteristic feature of flowering plants. It is a mature or ripened ovary developed after fertilisation. A fruit formed without fertilisation is a **parthenocarpic fruit** (e.g. banana). A fruit has a wall called **pericarp** and seeds. The pericarp may be dry or fleshy. A thick fleshy pericarp is divided into outer **epicarp**, middle **mesocarp** and inner **endocarp**.

In **mango and coconut** the fruit is a **drupe**, developing from a monocarpellary superior ovary, one-seeded. In mango the pericarp is differentiated into thin epicarp, fleshy edible mesocarp and stony hard endocarp. In coconut the mesocarp is fibrous.

5.7 The seed

The ovules after fertilisation develop into seeds. A seed has a **seed coat** and an **embryo**. The embryo has a **radicle**, an **embryonal axis** and one (wheat, maize) or two (gram, pea) **cotyledons**.

Dicot seed (gram, bean)	Monocot seed (maize)
Seed coat has two layers: outer testa and inner tegmen	Seed coat membranous, generally fused with fruit wall
Hilum – scar where seed was attached to the fruit; micropyle – small pore above hilum	Endosperm bulky, stores food
Two fleshy cotyledons storing food; embryonal axis with radicle and plumule	Outer covering of endosperm separates embryo by a proteinous layer called aleurone layer
Endosperm absent in bean, gram, pea (non-endospermous); present in castor (endospermous)	One large shield-shaped cotyledon called scutellum ; short axis with plumule and radicle enclosed in sheaths called coleoptile and coleorhiza

5.8 Semi-technical description and floral formula

A flowering plant is described in scientific terms starting from habit, vegetative characters (root, stem, leaf) and then floral characters (inflorescence and flower parts). The flower is summarised by a **floral formula** and a **floral diagram**.

Symbol	Meaning
Br	Bracteate
⊕	Actinomorphic
% (or a single upward arrow)	Zygomorphic
♂	Bisexual
♂ / ♀	Male / female flower
K	Calyx (number of sepals as subscript; brackets when fused)
C	Corolla
P	Perianth
A	Androecium
G	Gynoecium. A line above G means inferior ovary; a line below G means superior ovary
Arc joining C and A	Epipetalous stamens

A **floral diagram** shows the number of parts, their arrangement and relation to each other. The mother axis is shown as a dot on top. Calyx, corolla, androecium and gynoecium are drawn in successive whorls, calyx being outermost and gynoecium in the centre.

5.9 Family Solanaceae (potato family)

A large family, commonly called the **potato family**. Widely distributed in tropics, subtropics and temperate zones.

Character	Description
Habit	Mostly herbs, shrubs, rarely small trees
Stem	Herbaceous, rarely woody, aerial, erect, cylindrical, branched, solid or hollow, hairy or glabrous; underground stem in potato (<i>Solanum tuberosum</i>)
Leaves	Alternate, simple, rarely pinnately compound, exstipulate; venation reticulate
Inflorescence	Solitary, axillary or cymose as in <i>Solanum</i>
Flower	Bisexual, actinomorphic
Calyx	Sepals five, united, persistent (remains with fruit); valvate aestivation
Corolla	Petals five, united; valvate aestivation
Androecium	Stamens five, epipetalous
Gynoecium	Bicarpellary, carpels obliquely placed, syncarpous; ovary superior, bilocular; placenta swollen with many ovules; axile placentation
Fruit	Berry or capsule
Seeds	Many, endospermous

Floral formula: $\oplus \varnothing K_{(5)} C_{(5)} A_5 G_{(2)}$ with an arc joining C and A (epipetalous) and a line under G (superior ovary).

Floral diagram (in words): five fused sepals in the outer circle, five fused petals inside them alternating with sepals, five stamens attached to the petals and alternating with them, and in the centre an obliquely placed two-chambered ovary with swollen axile placentae bearing many ovules.

Economic importance: Food – tomato, brinjal, potato; spice – chilli; medicine – belladonna, ashwagandha (*Withania*); fumigatory – tobacco; ornamentals – petunia.

REMEMBER

Solanaceae = "5-5-5-2, oblique ovary, epipetalous, persistent calyx". The **obliquely placed ovary** is the most special feature of this family.

Chapter 6. Anatomy of Flowering Plants

Anatomy is the study of the internal structure of plants. A **tissue** is a group of cells having a common origin and usually performing a common function. Plant tissues are of two main types: **meristematic** and **permanent**.

6.1 Meristematic tissues

Growth in plants is restricted to special regions of active cell division called **meristems** (Greek *meristos* = divided).

Meristem	Position	Role
Apical meristem	Tips of root and shoot	Primary growth – increase in length. Root apical meristem at root tip; shoot apical meristem at the top of stem axis
Intercalary meristem	Between masses of mature tissue, at base of leaves or internodes	Found in grasses; regenerates parts removed by grazing herbivores
Lateral meristem	Along the sides (cylindrical), in mature regions of roots and shoots	Secondary growth – increase in girth. E.g. fascicular vascular cambium, interfascicular cambium, cork cambium

Apical and intercalary meristems are **primary meristems** (appear early in life). Lateral meristems that appear later are **secondary meristems**. During formation of leaves and elongation of stem, some cells left behind from the shoot apical meristem form the **axillary bud**.

6.2 Permanent tissues

Cells formed by meristems become specialised and lose the ability to divide; they form permanent tissues. **Simple tissues** have one type of cell; **complex tissues** have more than one type.

Simple tissue	Cell wall	Living/dead	Function
Parenchyma	Thin, cellulose	Living	Major part of organs; photosynthesis, storage, secretion; cells isodiametric, closely packed or with small intercellular spaces
Collenchyma	Thickened at corners due to deposits of cellulose, hemicellulose and pectin	Living	Mechanical support to growing parts such as young stem and petiole; found below epidermis in dicots; absent in monocots; may contain chloroplasts
Sclerenchyma	Very thick, lignified, with pits	Dead, without protoplasm	Mechanical support. Two types: fibres (long, pointed, thick-walled, in groups) and sclereids (spherical, oval or cylindrical, narrow lumen; in fruit walls of nuts, pulp of guava, pear and sapota, seed coats of legumes, leaves of tea)

Complex tissues: xylem and phloem

Xylem conducts water and minerals from roots to stem and leaves, and gives mechanical strength. It has four elements:

- **Tracheids** – elongated or tube-like cells with thick lignified walls and tapering ends; dead and without protoplasm.
- **Vessels** – long cylindrical tube-like structures made of many cells (vessel members) joined by perforated walls; lignified; dead. Presence of vessels is a characteristic feature of angiosperms (absent in gymnosperms).
- **Xylem fibres** – highly thickened walls and obliterated central lumen; septate or aseptate.
- **Xylem parenchyma** – living, thin-walled; stores food (starch, fat) and tannins; radial conduction of water by ray parenchyma.

Primary xylem is of two types: **protoxylem** (first formed) and **metaxylem** (later formed). In stems protoxylem lies towards the centre (pith) and metaxylem towards the periphery – **endarch**. In roots protoxylem lies towards the periphery and metaxylem towards the centre – **exarch**.

Phloem transports food materials, usually from leaves to other parts. In angiosperms it has four elements:

- **Sieve tube elements** – long tube-like cells arranged end to end; end walls perforated in a sieve-like manner forming **sieve plates**. A mature sieve element has peripheral cytoplasm and a large vacuole but **no nucleus**.
- **Companion cells** – specialised parenchyma cells closely connected with sieve tube elements by pit fields; they keep the pressure gradient in sieve tubes and control their functions. Their death leads to death of the sieve tube.
- **Phloem parenchyma** – elongated, tapering, cylindrical; stores food, resins, latex, mucilage. Absent in most monocots.

- **Phloem fibres (bast fibres)** – sclerenchymatous; absent in primary phloem but present in secondary phloem; commercially used fibres from jute, flax and hemp.

Gymnosperms have **albuminous cells and sieve cells** instead of sieve tubes and companion cells. First-formed phloem is **protophloem** (narrow sieve tubes) and later-formed is **metaphloem** (bigger sieve tubes).

REMEMBER

The only **dead** element of phloem is the **phloem fibre**. The only **living** element of xylem is **xylem parenchyma**.

6.3 Tissue systems

Based on structure and location, there are three tissue systems: **epidermal**, **ground (fundamental)** and **vascular (conducting)**.

(a) Epidermal tissue system

Forms the outer covering of the whole plant body. It has epidermal cells, stomata and epidermal appendages (trichomes and hairs). The **epidermis** is usually a single layer of elongated, compactly arranged parenchyma cells with a large vacuole, covered outside by a waxy **cuticle** that prevents water loss. Cuticle is absent in roots.

Stomata regulate transpiration and gaseous exchange. Each stoma has two bean-shaped **guard cells** enclosing the stomatal pore. In grasses guard cells are **dumb-bell shaped**. The outer walls of guard cells (away from pore) are thin and inner walls (towards pore) are highly thickened. Guard cells have chloroplasts. Sometimes a few specialised epidermal cells around guard cells, called **subsidiary cells**, are present. The stomatal aperture, guard cells and surrounding subsidiary cells together are called the **stomatal apparatus**.

Root hairs are unicellular elongations of epidermal cells that absorb water and minerals. On the stem, epidermal hairs are called **trichomes**; they are usually multicellular, branched or unbranched, soft or stiff, and may be secretory; they help prevent water loss by transpiration.

(b) Ground tissue system

All tissues except epidermis and vascular bundles: simple tissues such as parenchyma, collenchyma and sclerenchyma. Parenchyma is present in cortex, pericycle, pith and medullary rays of stems and roots. In leaves the ground tissue is made of thin-walled chloroplast-containing cells called **mesophyll**.

(c) Vascular tissue system

Made of xylem and phloem forming **vascular bundles**.

Type of vascular bundle	Arrangement	Found in
Open	Cambium present between xylem and phloem; can form secondary tissues	Dicot stems
Closed	No cambium	Monocot stems
Radial	Xylem and phloem on different radii, alternating	Roots
Conjoint	Xylem and phloem on the same radius; phloem usually on outer side	Stems and leaves

6.4 Anatomy of dicot and monocot root

The T.S. of a dicot root (sunflower) shows, from outside to inside:

- **Epiblema** (epidermis) – outermost layer; many cells protrude as unicellular root hairs.
- **Cortex** – several layers of thin-walled parenchyma with intercellular spaces.
- **Endodermis** – innermost layer of cortex; single layer of barrel-shaped cells without intercellular spaces; tangential and radial walls have a band of water-impermeable waxy material, **suberin**, called **Casparian strips**.
- **Pericycle** – a few layers of thick-walled parenchyma next to endodermis. Lateral roots and vascular cambium (during secondary growth) start here.
- **Pith** – small or inconspicuous.
- **Vascular bundles** – radial; 2 to 4 xylem and phloem patches (diarch to tetrarch); exarch xylem. Parenchyma between xylem and phloem is **conjunctive tissue**.

All tissues inside the endodermis (pericycle, vascular bundles and pith) form the **stele**.

Feature	Dicot root	Monocot root
Number of xylem bundles	2-4 (diarch to tetrarch)	More than six (polyarch)
Pith	Small or absent	Large and well developed
Secondary growth	Present	Absent
Example	Sunflower, gram	Maize

6.5 Anatomy of dicot and monocot stem

The T.S. of a young dicot stem (sunflower) shows:

- **Epidermis** – outermost protective layer, covered with thin cuticle; may bear trichomes and a few stomata.
- **Cortex** – three sub-zones: **hypodermis** (a few layers of collenchyma below epidermis, gives mechanical strength to young stem), **cortical layers** (rounded thin-walled parenchyma with intercellular spaces), and innermost **endodermis** (cells rich in starch grains, called **starch sheath**).
- **Pericycle** – on the inner side of endodermis and above phloem in the form of semi-lunar patches of sclerenchyma.
- **Medullary rays** – a few layers of radially placed parenchyma between vascular bundles.

- **Vascular bundles** – a large number arranged in a **ring**; conjoint, open, with endarch protoxylem.
- **Pith** – large central part with rounded parenchyma and large intercellular spaces.

Feature	Dicot stem	Monocot stem
Hypodermis	Collenchymatous	Sclerenchymatous
Ground tissue	Differentiated into cortex, endodermis, pericycle, pith	Large, conspicuous parenchymatous ground tissue; not differentiated
Vascular bundles	Arranged in a ring; conjoint, open; fewer and of same size	Scattered; conjoint, closed; many, peripheral ones smaller than central
Bundle sheath	Absent	Each bundle surrounded by sclerenchymatous bundle sheath
Phloem parenchyma	Present	Absent
Water-containing cavities	Absent	Present within vascular bundles
Example	Sunflower	Maize

6.6 Anatomy of dicot and monocot leaf

A vertical section through the lamina of a **dorsiventral (dicot) leaf** shows three parts: epidermis, mesophyll and vascular system.

- **Epidermis** covers both upper (**adaxial**) and lower (**abaxial**) surfaces, with a conspicuous cuticle. The abaxial epidermis generally bears more stomata than the adaxial; the adaxial may even lack stomata.
- **Mesophyll** – tissue between upper and lower epidermis, does photosynthesis. It has two types of cells: **palisade parenchyma** (adaxially placed, elongated, arranged vertically and parallel to each other) and **spongy parenchyma** (below the palisade, oval or round, loosely arranged, with large spaces and air cavities).
- **Vascular system** – vascular bundles in veins and midrib; size depends on vein size. Veins vary in thickness in reticulate venation. Each bundle is surrounded by a layer of thick-walled **bundle sheath** cells.

Feature	Dicot (dorsiventral) leaf	Monocot (isobilateral) leaf
Stomata	More on lower surface	Almost equal on both surfaces
Mesophyll	Differentiated into palisade and spongy	Not differentiated
Bulliform cells	Absent	Present in grasses on adaxial epidermis along veins; large, empty, colourless; when turgid the leaf is exposed, when flaccid (water stress) the leaf rolls inward to reduce water loss
Vascular bundles	Of different sizes, reticulate venation	Nearly similar size (except main veins), parallel venation
Example	Mango, sunflower	Maize, grass

REMEMBER

How to identify a T.S. in the practical: **Root** – radial bundles, root hairs, no cuticle.

Stem – conjoint bundles; ring = dicot, scattered = monocot. **Leaf** – palisade + spongy = dicot; no palisade + bulliform cells = monocot.

Chapter 8. Cell: The Unit of Life

8.1 What is a cell?

The **cell** is the fundamental structural and functional unit of all living organisms. Anything less than a complete cell cannot live independently. Unicellular organisms (Amoeba, bacteria) are capable of independent existence and perform all essential functions of life within one cell.

Anton von Leeuwenhoek first saw and described a live cell. **Robert Brown** discovered the nucleus (1831). **Robert Hooke** (1665) first observed dead cork cells and coined the term "cell".

8.2 Cell theory

In 1838 the German botanist **Matthias Schleiden** observed that all plants are composed of different kinds of cells. In 1839 the zoologist **Theodore Schwann** found that animal cells have a thin outer layer (plasma membrane) and that plant cells have a cell wall as a unique character. He proposed that bodies of animals and plants are made of cells and products of cells. Schleiden and Schwann together formulated the **cell theory**, but they did not explain how new cells are formed. **Rudolf Virchow (1855)** explained that cells divide and new cells are formed from pre-existing cells: *Omnis cellula-e cellula*.

CELL THEORY (MODERN FORM)

(i) All living organisms are composed of cells and products of cells. (ii) All cells arise from pre-existing cells.

8.3 Overview of the cell

Every cell has a semi-fluid matrix called **cytoplasm**, the main arena of cellular activities. Cells with a membrane-bound nucleus are **eukaryotic**; cells without a membrane-bound nucleus are **prokaryotic**. Cells vary in size: Mycoplasma is the smallest cell (0.3 μm), bacteria are 3–5 μm , the largest isolated single cell is the egg of the ostrich, and human red blood cells are about 7.0 μm in diameter. Nerve cells are among the longest cells. Shapes vary: disc-like, polygonal, columnar, cuboid, thread-like or irregular, depending on function.

8.4 Prokaryotic cells

Bacteria, blue-green algae, mycoplasma and PPLO (pleuro-pneumonia-like organisms) are prokaryotes. They are generally smaller and multiply faster than eukaryotic cells.

- A cell wall surrounds the cell membrane (except in mycoplasma). Fluid matrix = cytoplasm. No well-defined nucleus; genetic material is a **naked** single circular chromosome (genomic DNA) in a region called **nucleoid**.
- Many bacteria have small circular DNA outside the genomic DNA, called **plasmids**. They give special characters such as resistance to antibiotics, and are used in genetic engineering.

- No membrane-bound organelles except ribosomes (70S). A special membranous structure called **mesosome** is formed by extension of the plasma membrane into the cell (vesicles, tubules, lamellae). It helps in cell wall formation, DNA replication and distribution to daughter cells, respiration, secretion, and increases surface area of plasma membrane.
- In cyanobacteria, membranous extensions called **chromatophores** contain pigments.

Cell envelope: most prokaryotic cells, especially bacteria, have a chemically complex cell envelope of three tightly bound layers: outermost **glycocalyx**, then **cell wall**, then **plasma membrane**. Each layer has a distinct function but together they act as a single protective unit. The glycocalyx may be a loose sheath called **slime layer** or thick and tough called **capsule**.

Gram staining: bacteria that take up the Gram stain are **Gram positive**; those that do not are **Gram negative**. This depends on differences in cell envelope.

Surface structures: **flagella** (motility; made of filament, hook and basal body), **pili** (elongated tubular structures of special protein) and **fimbriae** (small bristle-like fibres that help attach to rocks in streams and to host tissues).

Ribosomes and inclusion bodies: prokaryotic ribosomes are about 15 nm by 20 nm, made of 50S and 30S subunits which together form **70S**. Several ribosomes attached to one mRNA form a chain called **polyribosome** or **polysome**. Reserve materials are stored as **inclusion bodies** (not membrane-bound): phosphate granules, cyanophycean granules, glycogen granules; gas vacuoles in blue-green, purple and green photosynthetic bacteria.

8.5 Eukaryotic cells

All protists, plants, animals and fungi have eukaryotic cells. They have extensive compartmentalisation of cytoplasm by membrane-bound organelles, a well-organised nucleus with nuclear envelope, and genetic material organised into chromosomes.

Prokaryotic cell	Eukaryotic cell
Nucleus not well defined; nucleoid, no nuclear membrane	Well-defined nucleus with nuclear envelope
Single circular naked DNA, no histone	Many linear chromosomes with histone proteins
No membrane-bound organelles	Mitochondria, ER, Golgi, plastids etc. present
70S ribosomes	80S ribosomes in cytoplasm (70S in mitochondria and chloroplasts)
Size 1–10 μm	Size 10–100 μm
Bacteria, cyanobacteria	Plants, animals, fungi, protists

Plant cell	Animal cell
Cell wall of cellulose present	No cell wall
Plastids present	Plastids absent
Large central vacuole	Vacuoles small or absent
Centrioles absent (in higher plants)	Centrioles present
Usually regular shape	Usually irregular or round

8.6 Cell membrane

Detailed study of the membrane became possible after the electron microscope was invented in the 1950s. Studies on human RBC membrane showed it is mainly **lipids** (phospholipids arranged in a bilayer) and **proteins**. Lipids are arranged with polar heads towards the outside and hydrophobic tails towards the inside, so the non-polar tails are protected from the aqueous environment. Cholesterol is also present. In human RBC membrane about 52% is protein and 40% lipid.

Membrane proteins are **peripheral** (on the surface) or **integral** (partially or totally buried in the membrane).

Fluid mosaic model (Singer and Nicolson, 1972): the quasi-fluid nature of lipids allows lateral movement of proteins within the overall bilayer. This fluidity is important for cell growth, formation of intercellular junctions, secretion, endocytosis and cell division.

Transport: the membrane is **selectively permeable**. Movement without energy is **passive transport**: simple diffusion along concentration gradient; **osmosis** = movement of water by diffusion. Polar molecules need carrier proteins. Transport against the concentration gradient needs energy (ATP) and is **active transport**, e.g. Na^+/K^+ pump.

8.7 Cell wall

A non-living rigid structure that forms an outer covering for the plasma membrane of fungi and plants. It gives shape, protects from mechanical damage and infection, helps cell-to-cell interaction and acts as a barrier to undesirable macromolecules.

- Algae: cellulose, galactans, mannans and minerals like calcium carbonate.
- Other plants: cellulose, hemicellulose, pectins and proteins.
- Layers: **primary wall** (young cell, capable of growth; gradually diminishes as cell matures), **secondary wall** (formed on inner side, towards membrane), and **middle lamella** (mainly **calcium pectate**; holds neighbouring cells together).
- Cell wall and middle lamella are traversed by **plasmodesmata**, which connect the cytoplasm of neighbouring cells.

8.8 Endomembrane system

ER, Golgi complex, lysosomes and vacuoles are grouped as the **endomembrane system** because their functions are coordinated. Mitochondria, chloroplasts and peroxisomes are **not** part of it because their functions are not coordinated with these.

Endoplasmic reticulum (ER): a network of tiny tubular structures scattered in the cytoplasm. It divides the intracellular space into luminal (inside ER) and extra-luminal (cytoplasm) compartments.

Rough ER (RER)	Smooth ER (SER)
Ribosomes attached on outer surface	No ribosomes
Protein synthesis and secretion; extensive and continuous with outer nuclear membrane	Major site of lipid synthesis; in animal cells lipid-like steroidal hormones are made here
Abundant in cells active in protein synthesis	Abundant in cells making lipids

Golgi apparatus: first observed by **Camillo Golgi (1898)** near the nucleus as densely stained reticular structures. It has many flat, disc-shaped sacs or **cisternae** (0.5–1.0 μm in diameter), stacked parallel to each other. The cisternae are concentrically arranged near the nucleus with a convex **cis** (forming) face and a concave **trans** (maturing) face. Its main function is **packaging materials** to be delivered to intracellular targets or secreted outside. Proteins made by ribosomes on ER are modified in the cisternae before release from the trans face. It is the important site for formation of **glycoproteins and glycolipids**.

Lysosomes: membrane-bound vesicles formed by packaging in the Golgi. Rich in almost all types of **hydrolytic enzymes** (hydrolases – lipases, proteases, carbohydrases) which work best at **acidic pH**. They digest carbohydrates, proteins, lipids and nucleic acids. (Called "suicidal bags" because their enzymes can digest the cell itself.)

Vacuoles: membrane-bound space in the cytoplasm containing water, sap, excretory products and other unwanted materials. Bounded by a single membrane called **tonoplast**. In plant cells the vacuole can occupy up to 90% of the cell volume. The tonoplast actively transports many ions and other materials into the vacuole against concentration gradient, so their concentration is much higher in the vacuole than in cytoplasm. In Amoeba the **contractile vacuole** is important for excretion; in many protists **food vacuoles** are formed by engulfing food.

8.9 Mitochondria

Mitochondria (singular mitochondrion) are not easily seen under the light microscope unless specially stained. Number per cell varies with physiological activity. They are sausage-shaped or cylindrical, 0.2–1.0 μm in diameter and 1.0–4.1 μm long.

- Double membrane-bound. Outer membrane is smooth and forms the continuous limiting boundary; inner membrane forms a number of infoldings called **cristae** towards the matrix, which increase surface area.
- Two compartments: outer (inter-membrane space) and inner (**matrix**, dense and homogeneous).
- Sites of **aerobic respiration**; produce energy as ATP – called "**power houses**" of the cell.

- Matrix has a single circular DNA, a few RNA molecules, 70S ribosomes and components for protein synthesis. Mitochondria divide by fission, so they are called **semi-autonomous** organelles.

8.10 Plastids

Plastids are found in all plant cells and in euglenoids. They are easily seen under the microscope as they are large. They bear specific pigments giving particular colours. Based on pigments, plastids are of three types:

Plastid	Pigment / content	Function
Chloroplasts	Chlorophyll and carotenoids	Trap light energy for photosynthesis
Chromoplasts	Fat-soluble carotenoids - carotene, xanthophylls	Yellow, orange or red colour (petals, ripe fruits like tomato, carrot root)
Leucoplasts	Colourless; store nutrients	Amyloplasts store starch (potato); elaioplasts store oils and fats; aleuroplasts store proteins

Chloroplast structure: mostly found in mesophyll cells of leaves. Lens-shaped, oval, spherical, discoid or ribbon-like; 5–10 µm long and 2–4 µm wide. Number varies from one per cell in *Chlamydomonas* to 20–40 per cell in mesophyll. Double membrane. The space inside the inner membrane is the **stroma**. A number of flattened membranous sacs called **thylakoids** are present in the stroma, arranged in stacks like piles of coins called **grana** (singular granum). **Stroma lamellae** connect thylakoids of different grana. The space inside a thylakoid is the **lumen**. Stroma contains enzymes for synthesis of carbohydrates and proteins, small double-stranded circular DNA and 70S ribosomes. Chlorophyll pigments are present in the thylakoids.

8.11 Ribosomes

Granular structures first seen by **George Palade (1953)** as dense particles. Made of RNA and proteins; **not surrounded by any membrane**. Eukaryotic ribosomes are **80S** (60S + 40S) and prokaryotic are **70S** (50S + 30S). "S" (Svedberg unit) is the sedimentation coefficient – an indirect measure of density and size. Ribosomes are the sites of protein synthesis.

COMMON MISTAKE

60S + 40S = 80S, not 100S. Svedberg units are not simply added because sedimentation depends on shape and density, not just mass.

8.12 Cytoskeleton, cilia and flagella, centrosome

Cytoskeleton: an elaborate network of filamentous proteinaceous structures in the cytoplasm made of **microtubules, microfilaments and intermediate filaments**. Functions: mechanical support, motility, and maintaining the shape of the cell.

Cilia and flagella: hair-like outgrowths of the cell membrane. Cilia are small and work like oars, moving the cell or the surrounding fluid. Flagella are longer and responsible for cell movement. (Prokaryotic flagella are structurally different.) A eukaryotic cilium or flagellum is covered with plasma membrane. Its core, called **axoneme**, has a number of

microtubules running parallel to the long axis: nine pairs of doublets of radially arranged peripheral microtubules and a pair of centrally located microtubules – the **9 + 2 array**. The central tubules are connected by bridges and enclosed by a central sheath connected to each peripheral doublet by a **radial spoke**. Peripheral doublets are interconnected by linkers. Cilia and flagella arise from centriole-like structures called **basal bodies**.

Centrosome and centrioles: the centrosome usually contains two cylindrical structures called **centrioles**, surrounded by amorphous pericentriolar material. Both centrioles lie perpendicular to each other. Each has a cartwheel organisation: nine evenly spaced peripheral fibrils of tubulin protein, each a **triplet** (9 + 0 arrangement). The central part is a proteinaceous **hub**, connected to the triplets by radial spokes. Centrioles form the basal body of cilia or flagella and the spindle fibres that form the spindle apparatus during cell division in animal cells.

8.13 Nucleus

First described by **Robert Brown (1831)**. Later the material of the nucleus stained by basic dyes was named **chromatin** by **Flemming**.

- The interphase nucleus has highly extended, elaborate nucleoprotein fibres called **chromatin**, the nuclear matrix and one or more spherical bodies called **nucleoli**.
- The **nuclear envelope** has two parallel membranes with a space of 10–50 nm between them (perinuclear space), forming a barrier between materials in the nucleus and the cytoplasm. The outer membrane is usually continuous with ER and bears ribosomes. At many places the envelope is interrupted by minute **nuclear pores**, through which RNA and protein molecules move in both directions.
- Normally there is one nucleus per cell. Some cells have more than one; some mature cells lack a nucleus, e.g. mammalian RBCs and sieve tube cells of vascular plants.
- **Nucleolus** – spherical, not membrane-bound; its content is continuous with nucleoplasm. Site of active **ribosomal RNA synthesis**. Larger and more numerous in cells actively making proteins.
- Chromatin contains DNA and basic proteins called **histones**, some non-histone proteins and RNA. A single human cell has approximately two metre long DNA distributed among 46 chromosomes (23 pairs).
- Every chromosome has a primary constriction, the **centromere**, on whose sides are disc-shaped structures called **kinetochores**. Based on centromere position, chromosomes are **metacentric** (middle; two equal arms), **sub-metacentric** (slightly away from middle; one shorter arm), **acrocentric** (close to end; one extremely short arm) and **telocentric** (terminal centromere). Some chromosomes have a non-staining secondary constriction; it gives a small fragment called **satellite**.

8.14 Microbodies

Many membrane-bound minute vesicles containing various enzymes, present in both plant and animal cells, are called **microbodies**. Examples are **peroxisomes** (involved in photorespiration in plants; contain catalase) and **glyoxysomes** (in fat-rich germinating seeds; convert fats to carbohydrates).

Organelle	Membrane	Main function	Nickname
Mitochondria	Double	Aerobic respiration, ATP	Power house
Chloroplast	Double	Photosynthesis	Kitchen of the cell
Nucleus	Double	Controls activities; heredity	Brain / control centre
Golgi body	Single	Packaging, secretion, glycoproteins	Post office / packaging centre
Lysosome	Single	Intracellular digestion	Suicidal bag
ER	Single	Protein (RER), lipid (SER) synthesis; transport	Cell's transport system
Ribosome	None	Protein synthesis	Protein factory
Vacuole	Single (tonoplast)	Storage, turgidity	Storage sac
Centriole	None	Spindle formation, basal bodies	-

REMEMBER

Organelles with their own DNA and 70S ribosomes: **mitochondria and chloroplasts** (semi-autonomous). Non-membranous organelles: **ribosomes, centrioles, cytoskeleton, nucleolus.**

Chapter 9. Biomolecules

9.1 How to analyse chemical composition

Living tissue (e.g. a piece of liver or a vegetable) is ground in **trichloroacetic acid** (Cl_3CCOOH) and the slurry is strained through cheesecloth. Two fractions are obtained: the filtrate, called **acid-soluble pool** (small molecules of molecular weight 18 to about 800 Da – sugars, amino acids, nucleotides), and the retentate, called **acid-insoluble fraction** (macromolecules – proteins, nucleic acids, polysaccharides; and lipids). Lipids have molecular weight below 800 Da but come in the acid-insoluble fraction because, when tissue is ground, cell membranes break into vesicles that are not water-soluble.

All carbon compounds obtained from living tissues are called **biomolecules**. Water is the most abundant chemical in living organisms (70–90% of total cellular mass).

9.2 Primary and secondary metabolites

Primary metabolites have identifiable functions and play known roles in normal physiological processes, e.g. amino acids, sugars. **Secondary metabolites** are found in plant, fungal and microbial cells; their role in the host is not fully understood but many are useful to humans: pigments (carotenoids, anthocyanins), alkaloids (morphine, codeine), terpenoids (monoterpenes, diterpenes), essential oils (lemon grass oil), toxins (abrin, ricin), lectins (concanavalin A), drugs (vinblastine, curcumin), polymeric substances (rubber, gums, cellulose).

9.3 Carbohydrates (polysaccharides)

Carbohydrates are compounds of C, H and O, generally with the formula $(\text{CH}_2\text{O})_n$. Simple sugars are **monosaccharides**: glucose ($\text{C}_6\text{H}_{12}\text{O}_6$, aldohexose), fructose (ketohexose), ribose ($\text{C}_5\text{H}_{10}\text{O}_5$, pentose) and galactose. Two monosaccharides join by a **glycosidic bond** (formed by dehydration) to form **disaccharides** such as sucrose (glucose + fructose), maltose (glucose + glucose) and lactose (glucose + galactose).

Polysaccharides are long chains of monosaccharides:

- **Cellulose** – a homopolymer of glucose; main component of plant cell wall; does not contain complex helices, so it cannot hold iodine and gives no colour with iodine. Cotton fibre is cellulose; paper is made from plant pulp.
- **Starch** – storage polysaccharide in plants; forms helical secondary structures that can hold I_2 , giving **blue colour**.
- **Glycogen** – storage polysaccharide in animals (and fungi); highly branched.
- **Inulin** – a polymer of fructose.
- **Chitin** – a complex polysaccharide (contains amino sugars, e.g. glucosamine, N-acetyl galactosamine); forms the exoskeleton of arthropods and fungal cell walls. These are homopolymers.

In a polysaccharide chain (say glycogen) the right end is the **reducing end** and the left end is the **non-reducing end**.

9.4 Proteins

Proteins are **polypeptides** – linear chains of **amino acids** linked by **peptide bonds**. A peptide bond forms when the carboxyl group ($-\text{COOH}$) of one amino acid reacts with the amino group ($-\text{NH}_2$) of the next amino acid with elimination of a water molecule (dehydration).

Amino acids are organic compounds with an amino group and an acidic group as substituents on the same carbon, the **α -carbon**; hence α -amino acids. They differ in the R group: R = H in **glycine**, CH_3 in **alanine**, hydroxymethyl (CH_2OH) in **serine**. There are 20 types of amino acids in proteins. They can be acidic (glutamic acid), basic (lysine), or neutral (valine); aromatic amino acids are tyrosine, phenylalanine and tryptophan. Amino acids exist as **zwitterions** (both positive and negative charges) at a particular pH. **Essential amino acids** must be obtained through diet; **non-essential** ones the body can make.

Levels of protein structure:

Level	Description
Primary	Sequence of amino acids, i.e. positional information – which is first, second and so on. The left end is the N-terminal (first amino acid) and the right end is the C-terminal (last amino acid).
Secondary	Folding of the chain into a helix (right-handed helices only in proteins) or sheet, held by hydrogen bonds
Tertiary	The long chain folds upon itself like a hollow woollen ball; gives 3-D shape essential for biological activity
Quaternary	Arrangement of two or more polypeptides (subunits). Example: adult human haemoglobin has 4 subunits – two α and two β

Functions of proteins: transport of nutrients across membranes, fighting infections (antibodies), hormones (insulin), enzymes (trypsin), receptors, structural (collagen, the most abundant protein in the animal world). **RuBisCO** (Ribulose biphosphate carboxylase-oxygenase) is the most abundant protein in the whole biosphere.

9.5 Lipids

Lipids are generally water-insoluble. **Fatty acids** have a carboxyl group attached to an R group (methyl, ethyl or higher number of $-\text{CH}_2$ groups, 1 to 19 carbons). Palmitic acid has 16 carbons including the carboxyl carbon; arachidonic acid has 20 carbons. Fatty acids are **saturated** (without double bonds) or **unsaturated** (with one or more $\text{C}=\text{C}$ double bonds).

- **Glycerol** is trihydroxy propane. Many lipids have both glycerol and fatty acids: fatty acids esterified with glycerol form **monoglycerides, diglycerides and triglycerides**. These are called fats and oils based on melting point; oils (e.g. gingelly oil) have lower melting point and remain liquid in winter.
- **Phospholipids** have phosphorus and a phosphorylated organic compound, e.g. **lecithin**; found in cell membranes.

- Some tissues, especially neural tissues, have lipids with more complex structures.
- **Steroids** such as cholesterol are also grouped with lipids.

9.6 Nucleic acids

Nucleic acids (DNA and RNA) are polymers of **nucleotides**. A nucleotide has three chemically distinct components: a **nitrogenous base** (heterocyclic compound), a **sugar** (monosaccharide) and a **phosphate group**.

- Nitrogen bases: **purines** – adenine, guanine; **pyrimidines** – cytosine, uracil, thymine.
- **Nucleoside** = base + sugar (adenosine, guanosine, thymidine, uridine, cytidine).
Nucleotide = nucleoside + phosphate (adenylic acid, thymidylic acid, guanylic acid, uridylic acid, cytidylic acid).
- Sugar in RNA is **ribose**; in DNA it is **2'-deoxyribose**. Nucleic acids with deoxyribose are DNA; with ribose are RNA.
- In a polynucleotide, a phosphate moiety links the 3'-carbon of one sugar of one nucleotide to the 5'-carbon of the sugar of the next nucleotide. The bond between phosphate and hydroxyl group of sugar is an ester bond; as there is one such ester bond on either side it is called a **phosphodiester bond**.
- **DNA double helix** (Watson and Crick model): two strands are antiparallel; backbone of sugar and phosphate; bases project inside. A pairs with T by **two hydrogen bonds**; G pairs with C by **three hydrogen bonds**. One full turn of the helix is 34 Å and has 10 base pairs; the pitch rises 3.4 Å per base pair. This is the **B-DNA** form.

DNA	RNA
Sugar: deoxyribose	Sugar: ribose
Bases: A, G, C, T	Bases: A, G, C, U
Usually double-stranded	Usually single-stranded
Genetic material in most organisms	Genetic material in some viruses; helps in protein synthesis (mRNA, tRNA, rRNA)

9.7 Concept of metabolism and dynamic state

Biomolecules are constantly being changed into other biomolecules and also made from other biomolecules. This breaking down and building up through chemical reactions is called **metabolism**. Each metabolic reaction is catalysed by an enzyme (no uncatalysed metabolic conversion in living systems). Metabolic pathways can be linear or circular and are linked. Pathways leading to a more complex structure from simpler ones are **anabolic** (biosynthetic, consume energy, e.g. protein from amino acids); pathways leading to simpler structures from complex ones are **catabolic** (release energy, e.g. glucose to lactic acid in muscle). The most important energy currency in living systems is **ATP** (adenosine triphosphate). The living state is a **non-equilibrium steady state** able to do work; living process is a constant effort to prevent falling into equilibrium.

9.8 Enzymes

Almost all enzymes are **proteins**. Some nucleic acids behave like enzymes; they are called **ribozymes**. An enzyme, like any protein, has primary to tertiary structure. In the tertiary structure the backbone folds into crevices or pockets; one such pocket is the **active site**, into which the substrate fits.

Enzymes differ from inorganic catalysts: inorganic catalysts work efficiently at high temperature and pressure, while enzymes get damaged at high temperature (above 40°C). However, enzymes from organisms living in very high temperatures (hot vents, sulphur springs) are stable up to 80–90°C. This **thermal stability** is an important quality of such enzymes.

How enzymes work

Chemical reactions involve breaking and making of bonds. Without an enzyme, the formation of carbonic acid from $\text{CO}_2 + \text{H}_2\text{O}$ is very slow (about 200 molecules per hour). With the enzyme **carbonic anhydrase** in the cytoplasm, the rate increases to about 600,000 molecules per second – about 10 million times faster.

The substrate binds to the active site forming an **enzyme-substrate complex (ES)**. This complex is short-lived and passes through a high-energy **transition state**. The enzyme lowers the **activation energy** needed to reach the transition state. The product is released and the enzyme is free to bind another substrate.



Steps of catalytic cycle: (1) substrate binds to the active site, fitting into it; (2) binding induces the enzyme to change shape, fitting more tightly around the substrate (**induced fit**); (3) the active site, now near the substrate, breaks the chemical bonds of the substrate and forms the enzyme-product complex; (4) enzyme releases the products and the free enzyme is ready to bind another substrate.

Factors affecting enzyme activity

- **Temperature and pH:** each enzyme shows the highest activity at a particular temperature and pH called the **optimum**. Activity declines above and below. Low temperature keeps the enzyme in a temporarily inactive state; high temperature destroys enzyme activity because proteins are **denatured** by heat.
- **Substrate concentration:** with increasing substrate concentration, velocity rises at first and then reaches a maximum velocity (V_{max}), which is not exceeded by further rise in substrate because enzyme molecules are fewer than substrate molecules; after saturation there are no free enzyme molecules.
- **Inhibitors:** when an inhibitor closely resembles the substrate in molecular structure and competes for the active site, it is a **competitive inhibitor**. Example: inhibition of **succinic dehydrogenase** by **malonate**, which resembles the substrate succinate. Competitive inhibitors are used to control bacterial pathogens.

Classification of enzymes (six classes)

Class	Reaction catalysed
1. Oxidoreductases / dehydrogenases	Oxidation-reduction between two substrates: S reduced + S' oxidised → S oxidised + S' reduced
2. Transferases	Transfer of a group G (other than hydrogen) between a pair of substrates: S-G + S' → S + S'-G
3. Hydrolases	Hydrolysis of ester, ether, peptide, glycosidic, C-C, C-halide or P-N bonds
4. Lyases	Removal of groups from substrates by mechanisms other than hydrolysis, leaving double bonds
5. Isomerases	Inter-conversion of optical, geometric or positional isomers
6. Ligases	Linking together of two compounds, e.g. joining of C-O, C-S, C-N, P-O bonds

REMEMBER

Six classes in order: "**Over The Hill Lives Indian Lion**" = Oxidoreductase, Transferase, Hydrolase, Lyase, Isomerase, Ligase.

Co-factors

Many enzymes need non-protein constituents called **co-factors** for activity. The protein part is then called the **apoenzyme**. Three kinds of co-factors:

- **Prosthetic groups** – organic compounds tightly bound to the apoenzyme. Example: in peroxidase and catalase (which break hydrogen peroxide into water and oxygen), **haem** is the prosthetic group and part of the active site.
- **Co-enzymes** – organic compounds whose association with apoenzyme is transient, during catalysis. Many co-enzymes contain vitamins: **NAD** and **NADP** contain the vitamin **niacin**.
- **Metal ions** – form coordination bonds with side chains at the active site and with the substrate. Example: **zinc** is a co-factor for the proteolytic enzyme **carboxypeptidase**.

Catalytic activity is lost when the co-factor is removed from the enzyme.

Chapter 11. Photosynthesis in Higher Plants

11.1 What is photosynthesis?

DEFINITION

Photosynthesis is a physico-chemical process by which green plants use light energy to synthesise organic compounds (carbohydrates) from carbon dioxide and water, releasing oxygen. $6\text{CO}_2 + 12\text{H}_2\text{O} \xrightarrow{\text{light, chlorophyll}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} + 6\text{O}_2$

It is important because (i) it is the primary source of all food on Earth, and (ii) it releases oxygen into the atmosphere.

11.2 Early experiments

Scientist	Discovery
Joseph Priestley (1770)	A candle burning or a mouse in a closed bell jar soon dies, but a mint plant kept in the jar restores the air. Plants restore what breathing animals and burning candles remove (oxygen).
Jan Ingenhousz	Showed that sunlight is essential; only the green parts of plants release oxygen (using an aquatic plant, bubbles formed in bright light, none in dark).
Julius von Sachs (1854)	Green parts make glucose, usually stored as starch; chlorophyll is located in special bodies (chloroplasts) in cells.
T.W. Engelmann	Using a prism and the green alga <i>Cladophora</i> with aerobic bacteria, found bacteria accumulated mainly in blue and red light – first action spectrum of photosynthesis.
Cornelius van Niel	Using purple and green sulphur bacteria, showed that photosynthesis is a light-dependent reaction in which hydrogen from a suitable oxidisable compound reduces CO_2 . In green plants H_2O is the hydrogen donor and is oxidised to O_2 . Therefore O_2 evolved comes from water , not CO_2 (later proved by radioisotope techniques).

11.3 Site of photosynthesis

Photosynthesis takes place in green leaves (and other green parts) inside the **chloroplasts** of mesophyll cells. Chloroplasts align along the walls of mesophyll cells to get optimum light. Inside the chloroplast there is a clear **division of labour**: the membrane system (grana / thylakoids) traps light energy and makes ATP and NADPH – the **light reaction**; the **stroma** contains enzymes that reduce CO_2 to carbohydrates – the **dark reaction** (better called biosynthetic or carbon reactions; they are light-driven indirectly, not literally done in the dark).

11.4 Pigments

Paper chromatography of leaf pigments separates four pigments:

Pigment	Colour on chromatogram	Role
Chlorophyll a	Bright or blue-green	Chief pigment; reaction centre
Chlorophyll b	Yellow-green	Accessory pigment
Xanthophylls	Yellow	Accessory pigment
Carotenoids (carotene)	Yellow to yellow-orange	Accessory pigment; protect chlorophyll a from photo-oxidation

Absorption spectrum shows the wavelengths a pigment absorbs; chlorophyll a absorbs most in the blue and red regions. The **action spectrum** shows the rate of photosynthesis at different wavelengths; it closely matches the absorption spectrum of chlorophyll a, showing that most photosynthesis occurs in blue and red light. Accessory pigments absorb light of other wavelengths and transfer energy to chlorophyll a, making a wider range of light usable.

11.5 Light reaction (photochemical phase)

Light reactions include light absorption, water splitting, oxygen release, and formation of high-energy chemical intermediates ATP and NADPH. Pigments are organised into two discrete photochemical **light harvesting complexes (LHC)** within **Photosystem I (PS I)** and **Photosystem II (PS II)**, named in the order of discovery, not the order in which they work.

The LHCs are made of hundreds of pigment molecules bound to proteins. Each photosystem has all pigments (except one molecule of chlorophyll a) forming a light harvesting system called **antennae**. The single chlorophyll a molecule forms the **reaction centre**. In PS I the reaction centre chlorophyll a has an absorption peak at 700 nm (**P700**); in PS II it absorbs at 680 nm (**P680**).

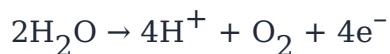
Electron transport (Z scheme)

In PS II, the reaction centre chlorophyll a absorbs 680 nm red light; electrons get excited and jump to an orbit farther from the nucleus. They are picked up by an electron acceptor and passed to an electron transport system of **cytochromes**. Electrons move downhill in terms of redox potential and are passed to PS I. At the same time, electrons in PS I reaction centre are excited by 700 nm light and transferred to another acceptor with greater redox potential. These electrons are finally used to reduce **NADP⁺ to NADPH + H⁺**. The whole scheme of transfer of electrons, from PS II uphill to the acceptor, down the ETS to PS I, excitation of electrons, transfer to another acceptor and finally down hill to NADP⁺, gives a shape like the letter Z when drawn on a redox scale – the **Z scheme**.



Splitting of water (photolysis)

PS II continuously loses electrons which are replaced by electrons from splitting of water. The water-splitting complex is associated with PS II, physically located on the inner side of the thylakoid membrane:



Protons are retained in the lumen; oxygen is released as a by-product.

Photophosphorylation

Synthesis of ATP from ADP and inorganic phosphate in the presence of light is called **photophosphorylation**.

Non-cyclic photophosphorylation	Cyclic photophosphorylation
Both PS II and PS I work in series	Only PS I works
Electrons do not return to the same photosystem; they go to NADP^+	Electrons circulate back to PS I through the ETS (cyclic flow)
ATP and NADPH both formed	Only ATP formed; no NADPH
Photolysis of water and O_2 evolution occur	No photolysis; no O_2 release
Occurs in grana thylakoids	Occurs in stroma lamellae (lack PS II and NADP reductase); also when only light above 680 nm is available

11.6 Chemiosmotic hypothesis

Proposed by **Peter Mitchell**, it explains how ATP is made. ATP synthesis is linked to development of a **proton gradient** across the thylakoid membrane. Protons accumulate inside the membrane (in the lumen). The gradient is created by three events:

1. Splitting of water on the inner side of the membrane releases protons into the lumen.
2. As electrons move through the photosystems, protons are carried across the membrane by the primary electron acceptor located on the outer side; they are released into the lumen.
3. The NADP reductase enzyme is on the stroma side; protons needed to reduce NADP^+ to NADPH are removed from the stroma.

So the stroma has fewer protons and the lumen more: a proton gradient and a fall in pH in the lumen. The gradient is broken down when protons move back to the stroma through the transmembrane channel of the **F₀** part of the enzyme **ATP synthase**. The other part, **F₁**, protrudes into the stroma; it undergoes a conformational change that allows synthesis of ATP. Chemiosmosis needs a membrane, a proton pump, a proton gradient and ATP synthase. ATP and NADPH are used in the stroma for fixing CO_2 .

11.7 Dark reaction - Calvin cycle (C_3 pathway)

Melvin Calvin used radioactive ^{14}C in algae and found that the first CO_2 fixation product is a 3-carbon organic acid, **3-phosphoglyceric acid (PGA)**. Plants in which the first product is PGA are called **C_3 plants**. The primary CO_2 acceptor is a 5-carbon ketose sugar, **ribulose biphosphate (RuBP)**. The cycle has three stages:

1. **Carboxylation** – fixation of CO_2 into a stable organic intermediate. $RuBP + CO_2 \rightarrow 2$ molecules of 3-PGA, catalysed by **RuBisCO** (RuBP carboxylase-oxygenase). This is the most crucial step.
2. **Reduction** – a series of reactions forming glucose. Uses 2 ATP and 2 NADPH for each CO_2 fixed. Fixation of 6 CO_2 and 6 turns of the cycle are needed to remove one glucose molecule.
3. **Regeneration** – regeneration of RuBP so the cycle continues; needs one ATP per CO_2 for phosphorylation.

	In	Out
CO_2	6	One glucose
ATP	18	18 ADP
NADPH	12	12 NADP

REMEMBER

For each CO_2 : **3 ATP + 2 NADPH**. For one glucose (6 CO_2): **18 ATP + 12 NADPH**.

This is why cyclic photophosphorylation is needed – to supply the extra ATP.

11.8 C_4 pathway (Hatch and Slack pathway)

Plants adapted to dry tropical regions (maize, sugarcane, sorghum) have the **C_4 pathway**. The first CO_2 fixation product is a 4-carbon compound, **oxaloacetic acid (OAA)**. They use the Calvin cycle as the main biosynthetic pathway too, but have special features:

- **Kranz anatomy** ("kranz" = wreath): large cells around vascular bundles of leaves, called **bundle sheath cells**, arranged in a wreath-like manner. They have a large number of chloroplasts, thick walls impervious to gas exchange, and no intercellular spaces.
- Tolerate higher temperatures, respond to high light intensities, lack photorespiration and have greater productivity of biomass.

Steps: in **mesophyll cells** the primary CO_2 acceptor is a 3-carbon molecule **phosphoenol pyruvate (PEP)**, and the enzyme is **PEP carboxylase (PEPcase)**. Mesophyll cells lack RuBisCO. OAA (C_4 acid) is formed and changed to other 4-carbon acids like **malic acid** or **aspartic acid**, which are transported to bundle sheath cells. In **bundle sheath cells** the C_4 acids are broken down to release CO_2 and a 3-carbon

molecule. The 3-carbon molecule goes back to mesophyll and is converted to PEP again. The released CO_2 enters the Calvin cycle in bundle sheath cells, which are rich in RuBisCO but lack PEPcase.

Mesophyll: $\text{PEP} + \text{CO}_2 \rightarrow \text{OAA} \rightarrow \text{malic acid} \rightarrow (\text{to bundle sheath}) \rightarrow \text{CO}_2 + \text{pyruvate}$; $\text{CO}_2 \rightarrow \text{Calvin cycle}$; $\text{pyruvate} \rightarrow \text{back to mesophyll} \rightarrow \text{PEP}$

11.9 Photorespiration

RuBisCO is the most abundant enzyme in the world. Its active site can bind both CO_2 and O_2 - hence the name carboxylase-oxygenase. RuBisCO has a much greater affinity for CO_2 when the $\text{CO}_2:\text{O}_2$ ratio is nearly equal. When O_2 is higher (at high temperature and when stomata close), RuBisCO binds O_2 .

In C_3 plants some O_2 binds RuBisCO and so CO_2 fixation decreases. RuBP, instead of becoming 2 PGA, binds O_2 forming **one PGA and one phosphoglycolate**. This pathway is **photorespiration**. It has no sugar formation, no ATP or NADPH formation; instead it releases CO_2 with use of ATP. Hence it is a **wasteful process**. It involves three organelles: chloroplast, **peroxisome** and mitochondria.

In C_4 plants photorespiration does not occur because they have a mechanism that increases CO_2 concentration at the enzyme site (in bundle sheath cells). This is why C_4 plants are more productive.

Feature	C_3 plants	C_4 plants
First stable product	3-PGA (3-carbon)	OAA (4-carbon)
Primary CO_2 acceptor	RuBP (5C)	PEP (3C)
Carboxylating enzyme	RuBisCO	PEPcase (mesophyll) and RuBisCO (bundle sheath)
Kranz anatomy	Absent	Present
Cells involved	Mesophyll only	Mesophyll and bundle sheath
Photorespiration	Present	Absent (negligible)
Optimum temperature	20-25°C	30-40°C
Examples	Rice, wheat, potato, mango	Maize, sugarcane, sorghum, Amaranthus

11.10 Factors affecting photosynthesis

Blackman's Law of Limiting Factors (1905): "If a chemical process is affected by more than one factor, its rate will be determined by the factor which is nearest to its minimal value: it is the factor which directly affects the process if its quantity is

changed." For example, even with optimal light and CO_2 , a plant may not photosynthesise if temperature is very low; giving optimal temperature then increases the rate.

- **Internal (plant) factors:** number, size, age and orientation of leaves; mesophyll cells and chloroplasts; internal CO_2 concentration; amount of chlorophyll.
- **Light:** rate of photosynthesis is linearly related to light intensity at low intensities. At higher intensity the rate does not increase further, as other factors become limiting. Only about 10% of leaves in a canopy receive full sunlight, so light is rarely limiting in nature except in shade and dense forests. Very high light intensity causes breakdown of chlorophyll and decrease in photosynthesis.
- **Carbon dioxide:** the major limiting factor. Atmospheric CO_2 is very low (0.03–0.04%). Increase up to 0.05% increases fixation; beyond this level it can be damaging over longer periods. C_3 and C_4 plants respond differently: C_4 plants show saturation at about 360 $\mu\text{l/L}$, while C_3 plants respond to increased CO_2 beyond 450 $\mu\text{l/L}$. Hence C_3 plants benefit from high CO_2 – used in greenhouse crops such as tomato and bell pepper.
- **Temperature:** dark reactions are enzymatic and temperature-controlled; light reactions are less sensitive. C_4 plants respond to higher temperatures and have higher temperature optimum than C_3 plants.
- **Water:** water stress causes stomata to close, reducing CO_2 availability; leaves wilt, reducing surface area and metabolic activity. Effect of water is more through the plant than directly on photosynthesis.

Chapter 12. Respiration in Plants

12.1 Introduction

DEFINITION

Cellular respiration is the breaking of C-C bonds of complex organic compounds through oxidation within cells, leading to release of a considerable amount of energy. The compounds oxidised are called **respiratory substrates** (usually carbohydrates; also proteins, fats and organic acids).

The energy is not released all at once but slowly in a series of steps controlled by enzymes, and is trapped as chemical energy in the form of **ATP**, the **energy currency** of the cell. Plants have no special organs for gas exchange; they use stomata and lenticels. Each part takes care of its own gas exchange; there is little transport of gases from one part to another.



12.2 Glycolysis (EMP pathway)

The term comes from Greek *glycos* = sugar and *lysis* = splitting. The scheme was given by **Gustav Embden, Otto Meyerhof and J. Parnas**, so it is called the **EMP pathway**. It occurs in the **cytoplasm** of all living organisms and is the only process of respiration in anaerobic organisms. Glucose is partially oxidised to form two molecules of **pyruvic acid**.

In plants glucose comes from sucrose (broken by **invertase** into glucose and fructose). Main steps:

1. Glucose is phosphorylated to glucose-6-phosphate by **hexokinase** (uses 1 ATP).
2. Glucose-6-phosphate isomerises to fructose-6-phosphate.
3. Fructose-6-phosphate is phosphorylated to fructose-1,6-bisphosphate (uses 1 ATP; enzyme phosphofructokinase).
4. Fructose-1,6-bisphosphate splits into two 3-carbon molecules: dihydroxyacetone phosphate (DHAP) and 3-phosphoglyceraldehyde (PGAL). DHAP converts to PGAL.
5. Each PGAL is oxidised (with inorganic phosphate) to 1,3-bisphosphoglycerate (BPGA); NAD^+ is reduced to **$\text{NADH} + \text{H}^+$** .
6. BPGA is converted to 3-phosphoglyceric acid (PGA); 1 ATP formed (energy-yielding step).
7. $\text{PGA} \rightarrow 2\text{-PGA} \rightarrow \text{phosphoenol pyruvate (PEP)} \rightarrow \text{pyruvic acid}$; 1 ATP formed.

Net gain per glucose: 4 ATP formed – 2 ATP used = **2 ATP + 2 NADH + 2 pyruvate**.

Pyruvic acid is the key product. Its fate depends on cellular need: lactic acid fermentation, alcoholic fermentation, or aerobic respiration (Krebs cycle).

12.3 Fermentation (anaerobic respiration)

In fermentation (e.g. by yeast) incomplete oxidation of glucose occurs under anaerobic conditions. Pyruvic acid is converted to CO_2 and **ethanol** by enzymes **pyruvic acid**

decarboxylase and **alcohol dehydrogenase**. Some bacteria produce **lactic acid** from pyruvic acid. In animal muscles during exercise, when oxygen is inadequate, pyruvic acid is reduced to lactic acid by **lactate dehydrogenase**. In both cases the reducing agent is $\text{NADH} + \text{H}^+$, which is re-oxidised to NAD^+ .

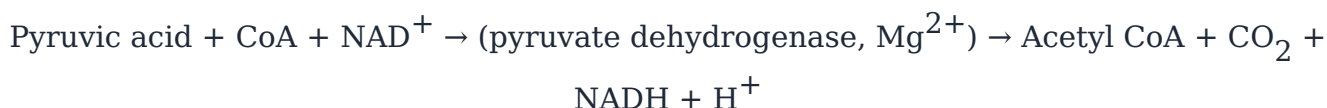
- Less than 7% of the energy in glucose is released and not all of it is trapped as high-energy bonds of ATP.
- Products are hazardous – acid or alcohol. Yeasts poison themselves to death when alcohol concentration reaches about 13%.
- Net ATP: only **2 ATP** per glucose (from glycolysis).

Aerobic respiration	Anaerobic respiration / fermentation
Needs oxygen	No oxygen needed
Complete oxidation to CO_2 and H_2O	Incomplete oxidation; ethanol + CO_2 or lactic acid
Cytoplasm + mitochondria	Cytoplasm only
Net 38 ATP (theoretical; 36 in eukaryotes in some books)	Net 2 ATP

12.4 Aerobic respiration

Occurs within mitochondria. The final product of glycolysis, pyruvate, is transported from cytoplasm into mitochondria. Two crucial events: (1) complete oxidation of pyruvate by stepwise removal of all hydrogen atoms, leaving three molecules of CO_2 (in the **matrix**); (2) passing of electrons removed as part of the hydrogen atoms to O_2 with simultaneous synthesis of ATP (on the **inner membrane**).

Link reaction (oxidative decarboxylation of pyruvate):



Two molecules of NADH are produced from the two pyruvates of one glucose.

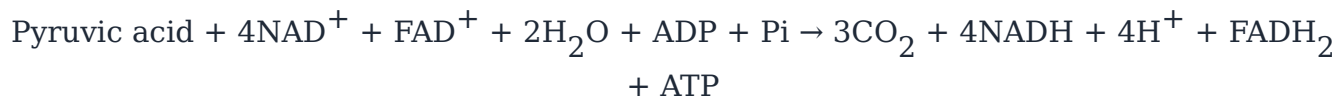
12.5 Tricarboxylic acid cycle (TCA / Krebs / citric acid cycle)

First explained by **Hans Krebs**. Occurs in the mitochondrial matrix.

1. Acetyl group condenses with **oxaloacetic acid (OAA, 4C)** and water to form **citric acid (6C)**, catalysed by **citrate synthase**; CoA is released.
2. Citrate isomerises to isocitrate.
3. Two successive **decarboxylations** lead to α -ketoglutaric acid (5C) and then succinyl-CoA (4C).
4. Succinyl-CoA is oxidised to OAA through succinic acid, fumaric acid and malic acid, allowing the cycle to continue. During conversion of succinyl-CoA to succinic acid, one GTP is synthesised (**substrate-level phosphorylation**); GTP converts to ATP in a coupled reaction.

5. At three points NAD^+ is reduced to $\text{NADH} + \text{H}^+$ and at one point FAD^+ is reduced to FADH_2 .

Summary per pyruvate (one turn):



(The 4 NADH include 1 from the link reaction and 3 from the cycle.)

Flowchart of TCA cycle (in words): Acetyl CoA (2C) + OAA (4C) $\rightarrow$ Citric acid (6C) $\rightarrow$ Isocitric acid (6C) $\rightarrow$ $[-\text{CO}_2, \text{NADH}]$ α -Ketoglutaric acid (5C) $\rightarrow$ $[-\text{CO}_2, \text{NADH}]$ Succinyl CoA (4C) $\rightarrow$ $[\text{GTP/ATP}]$ Succinic acid (4C) $\rightarrow$ $[\text{FADH}_2]$ Fumaric acid (4C) $\rightarrow$ Malic acid (4C) $\rightarrow$ $[\text{NADH}]$ OAA (4C), which again accepts acetyl CoA.

12.6 Electron transport system (ETS) and oxidative phosphorylation

The metabolic pathway through which electrons pass from one carrier to another is the **electron transport system**, present in the **inner mitochondrial membrane**.

- Electrons from NADH (produced in matrix) are oxidised by **NADH dehydrogenase (complex I)** and transferred to **ubiquinone**. Ubiquinone also receives electrons from FADH_2 via **complex II (succinate dehydrogenase)**.
- Reduced ubiquinone (ubiquinol) is oxidised by transfer of electrons to **cytochrome c** via the **cytochrome bc_1 complex (complex III)**. Cytochrome c is a small protein attached to the outer surface of the inner membrane and acts as a mobile carrier between complex III and complex IV.
- **Complex IV** is **cytochrome c oxidase** (cytochromes a and a_3 with two copper centres).
- When electrons pass from one carrier to another via complexes I to IV, they are coupled to **ATP synthase (complex V)** for production of ATP from ADP and Pi.
- Oxidation of one NADH gives **3 ATP**; one FADH_2 gives **2 ATP**.
- **Oxygen** is the **final hydrogen (electron) acceptor**; it combines with hydrogen to form water. Its role is limited to the terminal stage, but it is vital because it drives the whole process by removing hydrogen from the system.

Unlike photophosphorylation (light energy creates the proton gradient), in respiration the energy of oxidation-reduction is used to create the gradient; hence the process is called **oxidative phosphorylation**. Complex V has two parts: **F_1** headpiece (peripheral membrane protein complex; site of ATP synthesis) and **F_0** (integral membrane protein complex forming the channel through which protons cross the inner membrane). For each ATP produced, about 2H^+ pass through F_0 from the inter-membrane space to the matrix down the electrochemical proton gradient.

12.7 Respiratory balance sheet

The calculation assumes: sequential orderly pathway; NADH from glycolysis enters mitochondria and undergoes oxidative phosphorylation; no intermediates are used for other compounds; only glucose is respired. (These assumptions are not fully valid in a living system, so this is a theoretical exercise.)

Stage	Direct ATP	NADH	FADH ₂	ATP total
Glycolysis	2 (net)	2 ($\times 3 = 6$)	–	8
Link reaction (2 pyruvate)	–	2 ($\times 3 = 6$)	–	6
Krebs cycle (2 turns)	2	6 ($\times 3 = 18$)	2 ($\times 2 = 4$)	24
Total				38 ATP

REMEMBER

Net gain of **38 ATP** per glucose in aerobic respiration (theoretical). Fermentation gives only **2 ATP**. Per glucose: 10 NADH, 2 FADH₂, 4 direct ATP (2 net from glycolysis + 2 from Krebs), 6 CO₂.

12.8 Amphibolic pathway

Glucose is the favoured substrate, but fats and proteins can also be respired. Fats break down into glycerol and fatty acids; fatty acids are converted to acetyl CoA and enter the pathway; glycerol enters as PGAL (after conversion to DHAP). Proteins are degraded by proteases into amino acids; each amino acid (after deamination) enters at a stage in the Krebs cycle or as pyruvate or acetyl CoA.

In synthesis, the reverse happens: when the organism needs fatty acids, acetyl CoA is withdrawn from the respiratory pathway. Hence the respiratory pathway is involved in both breakdown (catabolism) and synthesis (anabolism). Therefore it is better called an **amphibolic pathway** rather than a catabolic one.

12.9 Respiratory quotient (RQ)

DEFINITION

Respiratory quotient (RQ) or respiratory ratio = volume of CO₂ evolved ÷ volume of O₂ consumed during respiration.

Substrate	RQ	Reason / example
Carbohydrate	1	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$; $RQ = 6/6 = 1.0$
Fat	Less than 1	Tripalmitin: $2(C_{51}H_{98}O_6) + 145O_2 \rightarrow 102CO_2 + 98H_2O$; $RQ = 102/145 = 0.7$
Protein	About 0.9	Proteins have less oxygen relative to C and H
Organic acids	More than 1	E.g. malic acid (oxygen-rich)
Anaerobic respiration	Infinity	CO_2 released but no O_2 consumed

In living organisms respiratory substrates are often more than one; pure proteins or fats are never used as substrates.

Chapter 13. Plant Growth and Development

13.1 Introduction and seed germination

Development is the sum of two processes: **growth and differentiation**. The development of a mature plant starts from the zygote. Plants follow different pathways in response to environment or phases of life to form different kinds of structures.

Seed germination: the process by which the embryo of a seed resumes growth and develops into a seedling. A dry seed absorbs water (**imbibition**), swells, and the seed coat bursts. Enzymes become active and convert stored food into soluble forms. The **radicle** comes out first and forms the root; the **plumule** forms the shoot. Conditions needed: water, suitable temperature, oxygen (aerobic respiration), and in some seeds light. In **epigeal** germination the cotyledons come above the soil (bean, castor); in **hypogeal** germination they remain below the soil (pea, maize, gram). Many seeds do not germinate even under favourable conditions; this is **dormancy**, caused by a hard seed coat, chemical inhibitors such as abscisic acid, phenolic acids and para-ascorbic acid, or immature embryos. Dormancy can be broken by scarification (mechanical abrasion with knives, sandpaper), vigorous shaking, chilling, gibberellic acid and nitrates.

13.2 Growth

DEFINITION

Growth is an irreversible permanent increase in size of an organ or its parts or even of an individual cell. It is accompanied by metabolic processes (both anabolic and catabolic) that occur at the expense of energy.

Plant growth is generally indeterminate – plants retain the capacity for unlimited growth throughout life due to meristems. This form of growth, where new cells are always added by meristems, is called the **open form of growth**.

- **Primary growth** – by root and shoot apical meristems; elongation along the axis.
- **Secondary growth** – by lateral meristems (vascular cambium and cork cambium) in dicots and gymnosperms; increase in girth.

Measurement of growth: at cellular level growth is increase in protoplasm. It can be measured by increase in fresh weight, dry weight, length, area, volume and cell number. A single maize root apical meristem can give rise to more than 17,500 new cells per hour; cells in a watermelon may increase in size by up to 3,50,000 times. Growth of a pollen tube is measured in length; growth of a dorsiventral leaf is measured as increase in surface area.

13.3 Phases of growth

Phase	Location (root tip)	Features
Meristematic	Root apex and shoot apex	Constantly dividing cells; rich protoplasm, large conspicuous nuclei; cellulosic primary walls, thin, with abundant plasmodesmata
Elongation	Zone just behind meristematic zone	Increased vacuolation, cell enlargement, new cell wall deposition
Maturation	Further away from apex, proximal to elongation zone	Cells attain maximal size in terms of wall thickening and protoplasmic modifications

13.4 Growth rates

The increased growth per unit time is the **growth rate**. It can be arithmetic or geometric.

- **Arithmetic growth:** after mitosis only one daughter cell continues to divide while the other differentiates and matures. Example: a root elongating at a constant rate. Plotting length against time gives a **linear curve**. Equation: $L_t = L_0 + rt$ (L_t = length at time t, L_0 = length at time zero, r = growth rate per unit time).
- **Geometric growth:** both daughter cells divide repeatedly. Initial growth is slow (**lag phase**), then rapid at an exponential rate (**log or exponential phase**), then slows down with limited nutrients and becomes stationary (**stationary phase**). Plotting growth against time gives a **sigmoid (S-shaped) curve**, characteristic of all cells, tissues and organs in natural environments. Exponential growth: $W_1 = W_0 e^{rt}$ (W_1 = final size, W_0 = initial size, r = relative growth rate, also called **efficiency index**, t = time, e = base of natural logarithms).

Absolute growth rate is the total growth per unit time; **relative growth rate** is the growth per unit time per unit initial parameter. Example: two leaves A and B each grow 5 cm² in a given time; if A started at 5 cm² and B at 50 cm², both have the same absolute rate but A has a much higher relative growth rate.

Sigmoid curve (described in words): the x-axis shows time and the y-axis size/weight. The curve starts flat (lag phase), then rises steeply (log phase), then bends and becomes flat again (stationary phase), giving an "S" shape.

13.5 Conditions for growth

- **Water** – cell enlargement needs water; turgidity helps extension growth; water is the medium for enzymatic activities.
- **Oxygen** – releases metabolic energy (respiration) essential for growth.
- **Nutrients** – macro and micro essential elements for synthesis of protoplasm and as energy source.
- **Optimum temperature** – deviation is harmful.
- Environmental signals such as **light and gravity** also affect some phases of growth.

13.6 Differentiation, dedifferentiation and redifferentiation

Process	Meaning	Example
Differentiation	Cells from root and shoot apical meristems and cambium mature to perform specific functions; major changes in cell walls and protoplasm	Tracheary elements lose protoplasm and develop strong, elastic lignocellulosic secondary walls to carry water
Dedifferentiation	Living differentiated cells that had lost the ability to divide regain it under certain conditions	Formation of interfascicular cambium and cork cambium from fully differentiated parenchyma cells
Redifferentiation	Cells produced by dedifferentiated meristems lose the ability to divide again and mature to perform specific functions	Secondary xylem and secondary phloem formed from interfascicular cambium

Final structure at maturity of a cell or tissue is also determined by its location: e.g. cells positioned away from the root apical meristem differentiate as root-cap cells, while those pushed to the periphery mature as epidermis. Plants show **plasticity** – the ability to follow different pathways in response to environment to form different structures. Example: **heterophylly** – different leaf shapes in juvenile and mature plants of cotton, coriander and larkspur; in buttercup leaves differ in air and in water.

13.7 Plant growth regulators (PGRs)

PGRs are small, simple molecules of diverse chemical composition. They may be indole compounds (indole-3-acetic acid, IAA), adenine derivatives (N^6 -furfurylamino purine, kinetin), derivatives of carotenoids (abscisic acid, ABA), terpenes (gibberellic acid, GA_3) or gases (ethylene, C_2H_4). They are also called plant hormones or phytohormones.

Group	PGRs	Role
Plant growth promoters	Auxins, gibberellins, cytokinins	Cell division, enlargement, pattern formation, tropic growth, flowering, fruiting, seed formation
Plant growth inhibitors	Absciscic acid (ABA)	Response to wounds and stresses; dormancy and abscission
Both	Ethylene	Largely an inhibitor but also promotes some processes

Discovery

- **Auxin:** Charles Darwin and his son Francis Darwin observed that coleoptiles of canary grass bend towards light (phototropism); the tip of the coleoptile sensed light. **F.W. Went** isolated auxin from tips of oat (*Avena*) coleoptiles.
- **Gibberellin:** "bakanae" (foolish seedling) disease of rice caused by the fungus *Gibberella fujikuroi*. **E. Kurosawa** reported that uninfected rice seedlings showed the symptoms when treated with sterile filtrate of the fungus; the active substance was later identified as gibberellic acid.
- **Cytokinin:** **F. Skoog** and co-workers found that callus from tobacco stem internodes proliferated only if, in addition to auxin, the medium had extracts of vascular tissues,

yeast extract, coconut milk or DNA. **Skoog and Miller** later crystallised the cytokinesis-promoting substance and named it **kinetin**.

- **Abscisic acid:** in the mid-1960s three independent researchers purified and characterised three inhibitors: inhibitor-B, abscission II and dormin. They were later found to be chemically identical and named abscisic acid.
- **Ethylene: H.H. Cousins** confirmed release of a volatile substance from ripened oranges that hastened ripening of stored unripe bananas; it was later identified as ethylene.

Physiological effects

1. Auxins (Greek *auxein* = to grow). First isolated from human urine. Natural: IAA and indole butyric acid (IBA). Synthetic: NAA (naphthalene acetic acid) and 2,4-D (2,4-dichlorophenoxyacetic acid).

- Initiate rooting in stem cuttings (used for plant propagation).
- Promote flowering (e.g. in pineapples).
- Prevent fruit and leaf drop at early stages but promote abscission of older, mature leaves and fruits.
- **Apical dominance:** the growing apical bud inhibits growth of lateral (axillary) buds. Removal of shoot tips (**decapitation**) results in growth of lateral buds; used in tea plantations and hedge-making.
- Induce **parthenocarpy** (e.g. in tomatoes).
- Used as **herbicides:** 2,4-D kills dicotyledonous weeds but does not affect mature monocots; used to prepare weed-free lawns.
- Control **xylem differentiation** and help in cell division.

2. Gibberellins – more than 100 gibberellins (GA_1 , GA_2 , GA_3 and so on) from fungi and higher plants. All are acidic. **GA_3** was one of the first discovered and is the most intensively studied.

- Increase in **axis length**; used to increase length of grape stalks.
- Cause fruits like apple to elongate and improve their shape; delay senescence, so fruits can be left on the tree longer to extend the market period.
- Used in brewing industry to speed up **malting**.
- Sugarcane stores sugar in stems; spraying GA increases stem length and yield by as much as 20 tonnes per acre.
- Spraying juvenile conifers with GA hastens maturity, leading to early seed production.
- Promote **bolting** (internode elongation just before flowering) in beet, cabbage and many plants with rosette habit.

3. Cytokinins – specific effects on **cytokinesis**. Kinetin (a modified form of adenine, a purine) was discovered from autoclaved herring sperm DNA; it does not occur naturally in plants. **Zeatin** is a natural cytokinin from corn kernels and coconut milk. Natural

cytokinins are synthesised in regions of rapid cell division: root apices, developing shoot buds, young fruits.

- Help produce new leaves, chloroplasts in leaves, lateral shoot growth and adventitious shoot formation.
- Help overcome apical dominance.
- Promote nutrient mobilisation, which helps **delay leaf senescence**.

4. Ethylene – a simple gaseous PGR. Synthesised in large amounts by tissues undergoing senescence and by ripening fruits.

- Influences horizontal growth of seedlings, swelling of the axis and **apical hook** formation in dicot seedlings.
- Promotes senescence and abscission of plant organs, especially leaves and flowers.
- Highly effective in **fruit ripening**; enhances respiration rate during ripening (**respiratory climacteric**).
- Breaks seed and bud dormancy; initiates germination in peanut seeds and sprouting of potato tubers.
- Promotes rapid internode/petiole elongation in deep-water rice plants, helping leaves and upper parts stay above water.
- Promotes root growth and root hair formation, increasing absorption surface.
- Used to initiate flowering and synchronise fruit-set in pineapples; induces flowering in mango.
- The most widely used compound as a source of ethylene is **ethephon**. In aqueous solution it is readily absorbed and slowly releases ethylene. It hastens ripening of tomatoes and apples, accelerates abscission in flowers and fruits (thinning of cotton, cherry, walnut), and promotes female flowers in cucumbers, increasing yield.

5. Abscissic acid (ABA) – regulates abscission and dormancy, but has other wide-ranging effects; acts as a general **plant growth inhibitor** and inhibitor of plant metabolism.

- Inhibits seed germination.
- Stimulates **closure of stomata** in the epidermis and increases tolerance of plants to various stresses; hence called the **stress hormone**.
- Important role in seed development, maturation and dormancy; by inducing dormancy, ABA helps seeds withstand desiccation and other unfavourable factors.
- In most situations ABA acts as an **antagonist to GAs**.

REMEMBER

Auxin – **Apical** dominance, rooting; Gibberellin – **Giant** (stem elongation, bolting);
Cytokinin – **Cell** division, delays ageing; Ethylene – **Eats** (ripens) fruits; ABA –
Antagonist, stress, closes stomata, dormancy.

PGRs often act together: several events in a plant (dormancy in seeds/buds, abscission, senescence, apical dominance) are controlled by interaction of more than one PGR. Both intrinsic and extrinsic factors affect them. Extrinsic factors include light (photoperiodism) and temperature (vernalisation).

QUESTION BANK

Botany · +2 1st Year

QB-1. The Living World

Key points

- Defining features of life: metabolism, cellular organisation, consciousness. Growth and reproduction are not defining features.
- Three domains (Carl Woese): Archaea, Bacteria, Eukarya.
- Taxonomy = characterisation, identification, nomenclature, classification. Systematics also includes evolutionary relationships.
- Hierarchy: Kingdom, Division, Class, Order, Family, Genus, Species. Species is the basic unit.
- Binomial nomenclature by Linnaeus; plant names follow ICBN. Genus capital, epithet small, italics or underlined separately.
- Herbarium = dried pressed plants on sheets; key = pairs of contrasting characters (couplets).

A. Multiple choice questions

1. Which of the following is a defining feature of living organisms? (a) Growth (b) Reproduction (c) Metabolism (d) Movement

(c) Metabolism

2. The basic unit of classification is (a) genus (b) species (c) family (d) order

(b) species

3. Binomial nomenclature was introduced by (a) Darwin (b) Whittaker (c) Linnaeus (d) Aristotle

(c) Linnaeus

4. The three-domain system was proposed by (a) Carl Woese (b) Whittaker (c) Copeland (d) Haeckel

(a) Carl Woese

5. Which category includes related orders? (a) Family (b) Class (c) Division (d) Genus

(b) Class

6. In *Mangifera indica*, "indica" is the (a) genus (b) family (c) specific epithet (d) author name

(c) specific epithet

7. Mango belongs to the family (a) Poaceae (b) Anacardiaceae (c) Solanaceae (d) Malvaceae

(b) Anacardiaceae

8. The Indian Botanical Garden is located at (a) Lucknow (b) Kew (c) Howrah (d) Bhubaneswar

(c) Howrah

B. Very short answer questions

1. What is a taxon?

A concrete group of organisms at any rank of classification, e.g. Poaceae or Mangifera.

2. Name the code that governs the naming of plants.

International Code of Botanical Nomenclature (ICBN).

3. Why is reproduction not a defining feature of life?

Because many living organisms such as mules, worker bees and infertile individuals do not reproduce.

4. What is a herbarium?

A store-house of dried, pressed and preserved plant specimens on sheets, arranged according to a classification system.

5. What is a couplet in a taxonomic key?

A pair of contrasting characters; each statement of the pair is called a lead.

6. Write the scientific name of wheat.

Triticum aestivum.

C. Short answer questions**1. Write the rules of binomial nomenclature.**

(i) Names are in Latin or Latinised and printed in italics. (ii) The first word is the genus and the second is the specific epithet. (iii) When handwritten, the two words are underlined separately. (iv) The genus starts with a capital letter and the epithet with a small letter. (v) The author's name in short form is written at the end, e.g. *Mangifera indica* Linn.

2. Distinguish between taxonomy and systematics.

Taxonomy deals with characterisation, identification, nomenclature and classification of organisms based on their characters. **Systematics** is broader: it deals with the diversity of organisms and also their evolutionary (phylogenetic) relationships. All taxonomy is part of systematics.

3. Why is classification needed?

Millions of organisms cannot be studied one by one. Classification groups them on easily observable characters, which makes study easy, shows relationships among organisms, helps in identification and naming, and gives a basis for applied sciences like agriculture and medicine.

4. What are the three domains of life? Give one feature of each.

Archaea – prokaryotes living in extreme habitats; cell wall lacks peptidoglycan. **Bacteria** – true prokaryotes with peptidoglycan cell walls. **Eukarya** – organisms with a membrane-bound nucleus and organelles (protists, fungi, plants, animals).

D. Long answer questions**1. What is taxonomic hierarchy? Describe the obligate categories with an example.**

The arrangement of taxonomic categories in a definite order from the highest to the lowest is called taxonomic hierarchy. Each rank is a category. The obligate categories are: **Species** – group of individuals with fundamental similarities that interbreed to give fertile young (*indica* for mango). **Genus** – group of related species (*Mangifera*). **Family** – group of related genera (Anacardiaceae). **Order** – group of related families (Sapindales).

Class – group of related orders (Dicotyledonae). **Division** – group of related classes (Angiospermae). **Kingdom** – the highest category (Plantae).

From species to kingdom the number of common characters decreases while the number of organisms increases. Lower categories show more similarity among their members, so identification at the species level is most precise.

2. Describe any four taxonomical aids.

(1) **Herbarium**: dried pressed specimens on sheets, with labels giving name, family, collector, date and place; a quick reference for identification. (2) **Botanical gardens**: living plants grown for reference, labelled with botanical name and family, e.g. Kew, Howrah, Lucknow. (3) **Museums**: preserved specimens in jars or as dry specimens, skeletons, insect boxes. (4) **Keys**: analytical tools based on contrasting characters in pairs; used for identifying families, genera and species. Flora, manuals, monographs and catalogues are also useful aids.

QB-2. Biological Classification

Key points

- Whittaker (1969): Monera, Protista, Fungi, Plantae, Animalia; criteria – cell structure, body organisation, nutrition, reproduction, phylogeny.
- Archaeobacteria: halophiles, thermoacidophiles, methanogens (methane in cattle gut). Cyanobacteria: heterocysts fix N_2 (Nostoc, Anabaena). Mycoplasma: no cell wall, smallest cell.
- Protista: chrysophytes (diatomaceous earth), dinoflagellates (red tide), euglenoids (pellicle), slime moulds (plasmodium), protozoans.
- Fungi: chitin wall; Phycomycetes (aseptate, zygospore), Ascomycetes (ascospores, Neurospora), Basidiomycetes (basidiospores, mushroom), Deuteromycetes (no sexual stage).
- Virus: protein capsid + DNA or RNA; TMV discovered by Ivanowsky; viroid = free RNA (Diener, potato spindle tuber); lichen = alga (phycobiont) + fungus (mycobiont).

A. Multiple choice questions

1. Five-kingdom classification was proposed by (a) Linnaeus (b) Whittaker (c) Woese (d) Haeckel
(b) Whittaker
2. Methanogens belong to (a) eubacteria (b) archaeobacteria (c) fungi (d) protista
(b) archaeobacteria
3. Red tide is caused by (a) diatoms (b) Gonyaulax (c) Euglena (d) Nostoc
(b) Gonyaulax
4. Cell wall of fungi is made of (a) cellulose (b) chitin (c) peptidoglycan (d) pectin
(b) chitin
5. Which is called "fungi imperfecti"? (a) Phycomycetes (b) Ascomycetes (c) Basidiomycetes (d) Deuteromycetes
(d) Deuteromycetes
6. Viroids were discovered by (a) Ivanowsky (b) Stanley (c) Diener (d) Beijerinck
(c) Diener
7. The organism without a cell wall is (a) Mycoplasma (b) Nostoc (c) yeast (d) Euglena
(a) Mycoplasma
8. Lichens are good indicators of (a) soil fertility (b) air pollution (c) water depth (d) temperature
(b) air pollution
9. Euglena has a flexible body because of (a) cell wall (b) pellicle (c) capsule (d) cuticle
(b) pellicle
10. Bread mould is (a) Rhizopus (b) Agaricus (c) Puccinia (d) Ustilago
(a) Rhizopus

B. Very short answer questions

1. What are heterocysts?

Special thick-walled cells in filamentous cyanobacteria (Nostoc, Anabaena) that fix atmospheric nitrogen.

2. What is diatomaceous earth?

Deposits of silica-rich cell walls of dead diatoms, used in polishing and filtration of oils and syrups.

3. What is dikaryon?

A cell with two haploid nuclei ($n + n$) formed after plasmogamy but before karyogamy in ascomycetes and basidiomycetes.

4. What is capsid?

The protein coat of a virus, made of subunits called capsomeres, that protects the nucleic acid.

5. Name the fungus used in genetic research.

Neurospora.

6. What are mycorrhizae?

Symbiotic associations of fungi with roots of higher plants.

C. Short answer questions

1. What were the drawbacks of the two-kingdom classification?

It did not distinguish between prokaryotes and eukaryotes, unicellular and multicellular organisms, or photosynthetic (green algae) and non-photosynthetic (fungi) organisms. Bacteria, fungi and algae with very different structures were all placed in Plantae.

2. Give the economic importance of heterotrophic bacteria.

They are decomposers that recycle nutrients; help in making curd from milk; produce antibiotics; fix nitrogen in legume roots (*Rhizobium*). Some are harmful and cause cholera, typhoid, tetanus and citrus canker.

3. Write a short note on lichens.

Lichens are symbiotic associations between algae (phycobiont) and fungi (mycobiont). The alga makes food by photosynthesis; the fungus gives shelter and absorbs water and minerals. They are so closely joined that they appear to be one organism. They grow on rocks and tree bark, are pioneers of succession on bare rocks, and are sensitive to sulphur dioxide, so they do not grow in polluted areas.

4. Distinguish between virus and viroid.

A virus has nucleic acid (DNA or RNA) enclosed in a protein coat and is larger. A viroid is a free low-molecular-weight RNA without any protein coat, e.g. the agent of potato spindle tuber disease.

D. Long answer questions

1. Describe the salient features of Kingdom Fungi and classify it with examples.

Fungi are eukaryotic, heterotrophic, mostly multicellular organisms (yeast is unicellular). The body consists of hyphae forming a mycelium; hyphae may be coenocytic (aseptate,

multinucleate) or septate. The cell wall is of chitin and polysaccharides. They are saprophytes, parasites or symbionts (lichens, mycorrhiza). They reproduce vegetatively (fragmentation, fission, budding), asexually (conidia, sporangiospores, zoospores) and sexually (oospores, ascospores, basidiospores). The sexual cycle involves plasmogamy, karyogamy and meiosis; a dikaryotic stage occurs in ascomycetes and basidiomycetes.

Classes: (1) Phycomycetes – aseptate coenocytic mycelium, zoospores or aplanospores, zygospore; Mucor, Rhizopus, Albugo. (2) Ascomycetes – septate mycelium, conidia, ascospores in asci, ascocarp; yeast, Penicillium, Aspergillus, Claviceps, Neurospora, morels, truffles. (3) Basidiomycetes – septate mycelium, no sex organs, basidiospores on basidia in basidiocarp; Agaricus, Ustilago, Puccinia. (4) Deuteromycetes – only asexual conidia known; Alternaria, Colletotrichum, Trichoderma.

2. Describe the major groups of Kingdom Protista.

Protista includes unicellular eukaryotes, mostly aquatic. (1) **Chrysophytes:** diatoms and desmids; silica-impregnated walls in two overlapping halves; chief producers of oceans; diatomaceous earth. (2) **Dinoflagellates:** marine, photosynthetic, cellulose plates, two flagella in grooves; Gonyaulax causes red tide. (3) **Euglenoids:** fresh water, pellicle instead of wall, two flagella; photosynthetic in light and heterotrophic in dark (Euglena). (4) **Slime moulds:** saprophytic; form plasmodium; resistant spores in fruiting bodies. (5) **Protozoans:** heterotrophic; amoeboid (Amoeba), flagellated (Trypanosoma), ciliated (Paramecium), sporozoans (Plasmodium).

3. Diagram description: Structure of a bacteriophage and TMV.

Bacteriophage: a polyhedral head (capsid) containing double-stranded DNA; a collar; a hollow tail sheath; a base plate with tail fibres used for attachment to the bacterium. **TMV:** a long rod; single-stranded RNA coiled helically in the centre, surrounded by many protein capsomeres arranged in a helix. Label: capsid, capsomere, nucleic acid, tail fibre, base plate.

QB-3. Plant Kingdom

Key points

- Artificial (Linnaeus), natural (Bentham and Hooker), phylogenetic systems; numerical taxonomy, cytotaxonomy, chemotaxonomy.
- Algae: thalloid, aquatic; isogamy, anisogamy, oogamy. Green (chl a, b; starch), brown (chl a, c, fucoxanthin; laminarin, mannitol), red (chl a, d, r-phycoerythrin; floridean starch).
- Agar from *Gelidium* and *Gracilaria*; algin from brown algae; carrageen from red algae; *Chlorella* is protein-rich.
- Bryophytes: amphibians of plant kingdom; gametophyte dominant; sporophyte dependent. Liverworts (*Marchantia*, gemmae), mosses (*Funaria*, protonema). *Sphagnum* gives peat.
- Pteridophytes: first vascular land plants; sporophyte dominant; prothallus; heterospory in *Selaginella* and *Salvinia* leads to seed habit.
- Gymnosperms: naked ovules; coralloid roots of *Cycas* with cyanobacteria; *Pinus* mycorrhiza; wind pollination; no water for fertilisation.

A. Multiple choice questions

1. Agar is obtained from (a) *Gelidium* (b) *Laminaria* (c) *Chlorella* (d) *Spirogyra*

(a) *Gelidium*

2. Stored food in brown algae is (a) starch (b) floridean starch (c) laminarin and mannitol (d) glycogen

(c) laminarin and mannitol

3. "Amphibians of the plant kingdom" are (a) algae (b) bryophytes (c) pteridophytes (d) gymnosperms

(b) bryophytes

4. Protonema is found in (a) *Marchantia* (b) *Funaria* (c) *Selaginella* (d) *Cycas*

(b) *Funaria*

5. The first vascular land plants are (a) bryophytes (b) pteridophytes (c) gymnosperms (d) angiosperms

(b) pteridophytes

6. Coralloid roots are found in (a) *Pinus* (b) *Cycas* (c) *Selaginella* (d) *Funaria*

(b) *Cycas*

7. Heterosporous pteridophyte is (a) *Dryopteris* (b) *Selaginella* (c) *Pteris* (d) *Equisetum*

(b) *Selaginella*

8. Oogamy is found in (a) *Spirogyra* (b) *Ulothrix* (c) *Volvox* (d) *Chlamydomonas* (isogamous species)

(c) *Volvox*

9. Pigment that gives red colour to red algae is (a) fucoxanthin (b) r-phycoerythrin (c) carotene (d) chlorophyll d

(b) r-phycoerythrin

10. Gemmae are asexual buds of (a) Marchantia (b) Funaria (c) Pinus (d) Fern
(a) Marchantia

B. Very short answer questions**1. What are pyrenoids?**

Storage bodies in chloroplasts of green algae containing protein and starch.

2. What is a prothallus?

The small, multicellular, free-living, photosynthetic, thalloid gametophyte of pteridophytes.

3. Why are gymnosperms called "naked-seeded"?

Because their ovules are not enclosed in an ovary and remain exposed before and after fertilisation.

4. Name an alga used as food supplement by space travellers.

Chlorella.

5. What are strobili?

Compact cone-like structures formed by sporophylls, e.g. in *Selaginella*, *Equisetum* and gymnosperms.

6. What is the use of Sphagnum?

It provides peat used as fuel and as packing material for living material because of its water-holding capacity.

C. Short answer questions**1. Why are bryophytes called amphibians of the plant kingdom?**

They live on land (soil, rocks, bark) but depend on water for sexual reproduction, because the flagellated antherozoids must swim through water to reach the egg in the archegonium. Like amphibian animals they need both land and water.

2. Give the economic importance of algae.

They fix half of the world's CO₂ and add oxygen; primary producers in water; *Porphyra*, *Laminaria* and *Sargassum* are eaten; algin and carrageen are hydrocolloids; agar (*Gelidium*, *Gracilaria*) is used in culture media, ice-creams and jellies; *Chlorella* is protein-rich food.

3. What is heterospory? Why is it important?

Production of two kinds of spores – large megaspores and small microspores – as in *Selaginella* and *Salvinia*. Megaspores give female and microspores give male gametophytes. Female gametophytes are retained on the parent sporophyte, and the zygote develops into an embryo there. This is the precursor to the seed habit, an important step in evolution.

4. Distinguish between liverworts and mosses.

Liverworts have thalloid, dorsiventral bodies (*Marchantia*) with unicellular rhizoids and reproduce asexually by gemmae. Mosses have a protonema stage and a leafy stage with

spirally arranged leaves and multicellular rhizoids (Funaria); their sporophyte is more elaborate with a spore-dispersal mechanism.

D. Long answer questions

1. Compare the three classes of algae.

Chlorophyceae (green algae): pigments chlorophyll a and b; stored food starch; wall of inner cellulose and outer pectose; 2–8 equal apical flagella; mostly fresh water; e.g. Chlamydomonas, Volvox, Ulothrix, Spirogyra, Chara. Phaeophyceae (brown algae): chlorophyll a, c and fucoxanthin; food stored as laminarin and mannitol; wall of cellulose and algin; two unequal lateral flagella; mostly marine; body has holdfast, stipe and frond; e.g. Ectocarpus, Dictyota, Laminaria, Sargassum, Fucus. Rhodophyceae (red algae): chlorophyll a, d and r-phycoerythrin; floridean starch; wall of cellulose, pectin and polysulphate esters; no flagella; mostly marine, grow even in deep water; e.g. Polysiphonia, Porphyra, Gracilaria, Gelidium.

2. Describe the salient features of gymnosperms.

Gymnosperms are seed plants with naked ovules. They are medium to tall trees and shrubs (Sequoia is among the tallest). Roots are tap roots; Pinus has mycorrhiza and Cycas has coralloid roots with N_2 -fixing cyanobacteria. Stems are unbranched (Cycas) or branched (Pinus, Cedrus). Leaves are simple or compound; needle-like leaves in conifers have thick cuticle and sunken stomata. They are heterosporous; microsporophylls form male cones and megasporophylls form female cones, on the same tree (Pinus) or different trees (Cycas). The pollen grain is the reduced male gametophyte. The ovule has a nucellus protected by integuments; the female gametophyte has archegonia. Pollination is by wind, and a pollen tube carries male gametes to the archegonium, so water is not needed. The zygote forms an embryo and the ovule becomes a naked seed.

3. Diagram description: Thallus of Marchantia (female) and plant of Funaria.

Marchantia: flat, dichotomously branched green thallus with a midrib; rhizoids on lower surface; gemma cups on upper surface; female thallus bears stalked umbrella-like archegoniophores. **Funaria:** erect leafy gametophyte with small spirally arranged leaves and multicellular rhizoids at base; the sporophyte on top has a foot (in gametophyte), a long seta and a capsule. Labels: rhizoid, leaf, axis, seta, capsule, operculum.

QB-4. Morphology of Flowering Plants

Key points

- Tap root (dicots) from radicle; fibrous root (monocots); adventitious roots from other parts.
- Root modifications: storage (carrot, radish, turnip, sweet potato), prop (banyan), stilt (maize, sugarcane), pneumatophores (Rhizophora).
- Stem modifications: tuber (potato), rhizome (ginger), corm (Colocasia), bulb (onion), tendrils (gourds), thorn (Citrus, Bougainvillea), phylloclade (Opuntia), runner, stolon, offset, sucker.
- Phyllotaxy: alternate (china rose), opposite (Calotropis, guava), whorled (Alstonia). Reticulate venation in dicots; parallel in monocots.
- Racemose (acropetal, axis grows) and cymose (basipetal, axis ends in flower).
- Aestivation: valvate (Calotropis), twisted (china rose, cotton), imbricate (Cassia), vexillary (pea).
- Placentation: marginal (pea), axile (china rose, tomato), parietal (mustard), free central (Dianthus), basal (sunflower).
- Solanaceae: $\oplus \text{ } \ominus \text{ } K_{(5)} C_{(5)} A_5 G_{(2)}$, epipetalous, superior oblique ovary, axile placentation, berry or capsule.

A. Multiple choice questions

- Pneumatophores are found in (a) Rhizophora (b) banyan (c) maize (d) carrot
(a) Rhizophora
- Potato is a modified (a) root (b) stem (c) leaf (d) inflorescence
(b) stem
- Phylloclade is found in (a) Opuntia (b) pea (c) onion (d) ginger
(a) Opuntia
- Twisted aestivation is seen in (a) pea (b) Calotropis (c) china rose (d) Cassia
(c) china rose
- Parietal placentation is found in (a) pea (b) mustard (c) tomato (d) sunflower
(b) mustard
- The edible part of mango is (a) epicarp (b) mesocarp (c) endocarp (d) seed
(b) mesocarp
- Aleurone layer is found in (a) gram seed (b) maize grain (c) pea seed (d) bean seed
(b) maize grain
- In Solanaceae the ovary is (a) inferior (b) half-inferior (c) superior and obliquely placed (d) monocarpellary
(c) superior and obliquely placed
- Stamens attached to petals are (a) epiphyllous (b) epipetalous (c) diadelphous (d) polyandrous
(b) epipetalous

10. Perigynous flower is found in (a) mustard (b) guava (c) rose (d) cucumber
(c) rose

B. Very short answer questions

1. Define phyllotaxy.

The pattern of arrangement of leaves on the stem or branch.

2. What is a parthenocarpic fruit?

A fruit formed without fertilisation; it is seedless, e.g. banana.

3. What is pulvinus?

The swollen leaf base found in leguminous plants.

4. Name the scutellum.

The single large shield-shaped cotyledon of a grass (maize) embryo.

5. What is a staminode?

A sterile stamen that does not produce pollen.

6. Give one example of a leaf tendril.

Pea.

C. Short answer questions

1. Distinguish between racemose and cymose inflorescence.

In racemose inflorescence the main axis continues to grow and flowers are borne laterally in acropetal order (older at base, younger at top), e.g. mustard. In cymose inflorescence the main axis ends in a flower so growth is limited, and flowers are in basipetal order (oldest at top), e.g. jasmine.

2. Explain hypogynous, perigynous and epigynous flowers.

Hypogynous: ovary at the highest point of thalamus, other parts below; ovary superior (mustard, brinjal). Perigynous: other parts arise from the rim of a cup-shaped thalamus at about the level of the ovary; ovary half-inferior (rose, plum). Epigynous: thalamus grows up and fuses with the ovary; other parts arise above it; ovary inferior (guava, cucumber).

3. Why is potato a stem and sweet potato a root?

Potato has nodes ("eyes") bearing axillary buds and scale leaves, which are stem characters. Sweet potato is a swollen adventitious root and has no nodes, internodes or buds.

4. Describe the structure of a dicot seed.

The seed has a seed coat of two layers, outer testa and inner tegmen. The hilum is the scar of attachment and the micropyle a small pore above it. Inside, the embryo has an embryonal axis with radicle and plumule and two fleshy cotyledons storing food. Endosperm is absent in gram and pea and present in castor.

D. Long answer questions

1. Describe the family Solanaceae with floral formula and economic importance.

Vegetative: herbs or shrubs; stem herbaceous, erect, branched, hairy or smooth; underground tuber in potato; leaves alternate, simple, exstipulate, reticulate venation.

Floral: inflorescence solitary, axillary or cymose; flower bisexual, actinomorphic; calyx of

five united persistent sepals, valvate; corolla of five united petals, valvate; androecium of five epipetalous stamens; gynoecium bicarpellary, syncarpous, ovary superior, bilocular, carpels obliquely placed, placenta swollen with many ovules, axile placentation; fruit berry or capsule; seeds many, endospermous.

Floral formula: $\oplus \varnothing K_{(5)} C_{(5)} A_5 G_{(2)}$ (C and A joined by an arc; line below G).

Economic importance: potato, tomato, brinjal (food); chilli (spice); belladonna and ashwagandha (medicine); tobacco (fumigatory); petunia (ornamental).

2. Describe the modifications of stem with examples.

(1) Underground for storage and perennation: tuber (potato), rhizome (ginger, turmeric), corm (Colocasia), bulb (onion). (2) Stem tendrils from axillary buds for climbing (cucumber, pumpkin, grapevine). (3) Thorns from axillary buds for protection (Citrus, Bougainvillea). (4) Phylloclade, a flattened green photosynthetic stem with leaves reduced to spines (Opuntia) or a fleshy cylindrical one (Euphorbia). (5) Sub-aerial stems for vegetative propagation: runner (grass, strawberry), stolon (jasmine), offset (Pistia, Eichhornia), sucker (banana, pineapple, Chrysanthemum).

3. Diagram description: L.S. of a typical flower.

Draw the pedicel at the bottom with a swollen thalamus. On the thalamus show outermost green sepals (calyx), then coloured petals (corolla), then stamens each with filament and bilobed anther, and in the centre the pistil with ovary at base containing ovules on placenta, a long style and a stigma at top. Labels: pedicel, thalamus, sepal, petal, filament, anther, stigma, style, ovary, ovule.

QB-5. Anatomy of Flowering Plants

Key points

- Meristems: apical (length), intercalary (grasses), lateral (girth: cambium, cork cambium).
- Parenchyma (living, thin wall), collenchyma (living, corner thickening, absent in monocots), sclerenchyma (dead, lignified: fibres and sclereids).
- Xylem: tracheids, vessels, fibres, parenchyma (only living). Phloem: sieve tubes (no nucleus), companion cells, parenchyma, fibres (only dead).
- Endarch xylem in stem; exarch in root. Open bundles (dicot stem), closed (monocot stem), radial (root), conjoint (stem, leaf).
- Endodermis with Casparian strips (suberin). Pericycle gives lateral roots.
- Dicot root 2–4 xylem bundles; monocot root polyarch with large pith.
- Dicot stem: collenchymatous hypodermis, ring of bundles, starch sheath. Monocot stem: scattered bundles with bundle sheath and water cavities.
- Dicot leaf dorsiventral, palisade and spongy; monocot leaf isobilateral, bulliform cells.

A. Multiple choice questions

1. Intercalary meristem is found in (a) grasses (b) mango (c) Pinus (d) fern
(a) grasses
2. Casparian strips occur in (a) pericycle (b) endodermis (c) epidermis (d) cortex
(b) endodermis
3. The only living element of xylem is (a) tracheid (b) vessel (c) xylem fibre (d) xylem parenchyma
(d) xylem parenchyma
4. Bulliform cells are present in (a) dicot leaf (b) grass leaf (c) dicot stem (d) monocot root
(b) grass leaf
5. Vascular bundles in monocot stem are (a) radial (b) conjoint open (c) conjoint closed (d) concentric
(c) conjoint closed
6. Lateral roots arise from (a) endodermis (b) pericycle (c) cortex (d) pith
(b) pericycle
7. Guard cells in grasses are (a) bean-shaped (b) dumb-bell shaped (c) kidney-shaped (d) round
(b) dumb-bell shaped
8. Sieve tubes lack (a) cytoplasm (b) nucleus (c) cell wall (d) vacuole
(b) nucleus

B. Very short answer questions

1. What is a tissue?

A group of cells with a common origin usually performing a common function.

2. What is the starch sheath?

The endodermis of the dicot stem, whose cells are rich in starch grains.

3. What is stele?

All tissues inside the endodermis: pericycle, vascular bundles and pith.

4. What is conjunctive tissue?

Parenchyma present between xylem and phloem bundles in roots.

5. Where are sclereids found?

In fruit walls of nuts, pulp of guava, pear and sapota, seed coats of legumes and leaves of tea.

6. Define endarch condition.

Protoxylem lies towards the centre (pith) and metaxylem towards the periphery, as in stems.

C. Short answer questions**1. Distinguish between parenchyma, collenchyma and sclerenchyma.**

Parenchyma: living, thin cellulose walls, isodiametric; photosynthesis and storage. Collenchyma: living, walls thickened at corners with cellulose, hemicellulose and pectin; support to young stems and petioles; absent in monocots. Sclerenchyma: dead, thick lignified walls with pits; fibres and sclereids; mechanical support.

2. Describe the structure of stomata.

A stoma is a pore surrounded by two bean-shaped guard cells (dumb-bell shaped in grasses). Outer walls of guard cells are thin and inner walls thick. Guard cells have chloroplasts and regulate opening and closing. Specialised epidermal cells around them are subsidiary cells. Pore, guard cells and subsidiary cells together form the stomatal apparatus. Stomata regulate transpiration and gaseous exchange.

3. Distinguish between dicot root and monocot root.

Dicot root has 2–4 xylem bundles (diarch to tetrarch), small or no pith and shows secondary growth, e.g. sunflower. Monocot root has more than six xylem bundles (polyarch), a large well-developed pith and no secondary growth, e.g. maize.

4. What are bulliform cells? Give their role.

Large, empty, colourless cells present on the upper (adaxial) epidermis along veins of grass leaves. When turgid they keep the leaf open; during water stress they become flaccid and the leaf rolls inward, reducing water loss.

D. Long answer questions**1. Describe the internal structure of a dicot stem (T.S. of sunflower stem).**

(1) Epidermis: single outer layer with thin cuticle, trichomes and few stomata. (2) Cortex: hypodermis of a few layers of collenchyma for strength; cortical parenchyma with intercellular spaces; endodermis or starch sheath. (3) Pericycle: semilunar patches of sclerenchyma above phloem. (4) Medullary rays: radial parenchyma between bundles. (5) Vascular bundles: many, arranged in a ring; conjoint, collateral, open with cambium between xylem and phloem; xylem endarch. (6) Pith: large central parenchyma with intercellular spaces.

2. Compare dicot and monocot stems.

Dicot stem has collenchymatous hypodermis while monocot stem has sclerenchymatous hypodermis. In dicots the ground tissue is differentiated into cortex, endodermis, pericycle and pith, but in monocots it is an undifferentiated mass of parenchyma. Dicot vascular bundles are few, of equal size, in a ring, conjoint and open; monocot bundles are many, scattered, conjoint and closed, with sclerenchymatous bundle sheath, and peripheral bundles are smaller. Phloem parenchyma is present in dicots and absent in monocots. Water-containing cavities occur in monocot bundles.

3. Describe the T.S. of a dicot (dorsiventral) leaf.

Upper (adaxial) and lower (abaxial) epidermis with cuticle; more stomata on the lower surface. Mesophyll between them has palisade parenchyma (elongated, vertical, compact cells below upper epidermis) and spongy parenchyma (round, loosely arranged with large air spaces) towards the lower surface. Vascular bundles in the midrib and veins are conjoint and closed, xylem towards the upper side and phloem towards the lower side, each surrounded by a bundle sheath.

QB-6. Cell: The Unit of Life

Key points

- Cell theory: Schleiden and Schwann; Virchow – omnis cellula-e cellula.
- Prokaryotes: nucleoid, plasmids, mesosome, 70S ribosomes; envelope = glycocalyx + wall + membrane.
- Fluid mosaic model (Singer and Nicolson, 1972). Middle lamella = calcium pectate.
- Endomembrane system: ER, Golgi, lysosomes, vacuoles. Mitochondria, chloroplasts, peroxisomes are not part of it.
- Mitochondria and chloroplasts: double membrane, own DNA and 70S ribosomes – semi-autonomous.
- Ribosomes: 80S (60S + 40S) in eukaryotes; discovered by Palade. Cilia 9 + 2; centriole 9 + 0 triplets.
- Chromosomes: metacentric, sub-metacentric, acrocentric, telocentric.

A. Multiple choice questions

1. "Omnis cellula-e cellula" was stated by (a) Schleiden (b) Schwann (c) Virchow (d) Brown

(c) Virchow

2. Mesosomes are found in (a) plant cells (b) animal cells (c) bacteria (d) fungi

(c) bacteria

3. Middle lamella is mainly made of (a) cellulose (b) calcium pectate (c) lignin (d) suberin

(b) calcium pectate

4. Which is not a part of the endomembrane system? (a) ER (b) Golgi (c) lysosome (d) mitochondrion

(d) mitochondrion

5. Site of lipid synthesis is (a) RER (b) SER (c) Golgi (d) ribosome

(b) SER

6. Arrangement of microtubules in a cilium is (a) 9 + 0 (b) 9 + 2 (c) 9 + 3 (d) 8 + 2

(b) 9 + 2

7. Amyloplasts store (a) proteins (b) oils (c) starch (d) pigments

(c) starch

8. Chromosome with centromere at the tip is (a) metacentric (b) acrocentric (c) telocentric (d) sub-metacentric

(c) telocentric

9. Membrane of vacuole is called (a) tonoplast (b) plasmalemma (c) cristae (d) thylakoid

(a) tonoplast

10. Smallest living cell is (a) bacterium (b) Mycoplasma (c) yeast (d) virus

(b) Mycoplasma

B. Very short answer questions

1. What are plasmids?

Small circular extra-chromosomal DNA in bacteria that give characters like antibiotic resistance.

2. What are cristae?

Infoldings of the inner mitochondrial membrane that increase surface area.

3. What is a polysome?

Several ribosomes attached to a single mRNA strand.

4. Name the cells that lack a nucleus at maturity.

Mammalian red blood cells and sieve tube cells of plants.

5. What is the function of the nucleolus?

Synthesis of ribosomal RNA.

6. What is plasmodesmata?

Cytoplasmic connections passing through cell walls of neighbouring plant cells.

C. Short answer questions

1. State the cell theory and its modification.

Schleiden and Schwann stated that all plants and animals are composed of cells and products of cells. Virchow added that new cells arise from pre-existing cells. Modern cell theory: (i) all living organisms are composed of cells and their products; (ii) all cells arise from pre-existing cells.

2. Describe the fluid mosaic model.

Proposed by Singer and Nicolson (1972). The membrane is a lipid bilayer with polar heads facing outside and hydrophobic tails inside. Proteins are peripheral (on surface) or integral (buried). The lipid is quasi-fluid, so proteins can move laterally – like icebergs in a sea of lipids. Fluidity helps growth, secretion, endocytosis, cell division and formation of junctions.

3. Write the functions of the Golgi apparatus.

Packaging of materials for intracellular targets or secretion; modification of proteins received from ER; formation of glycoproteins and glycolipids; formation of lysosomes; formation of cell plate during plant cell division.

4. Why are mitochondria called semi-autonomous?

They contain their own circular DNA, RNA and 70S ribosomes and can synthesise some of their own proteins; they multiply by fission. But most of their proteins are coded by nuclear genes, so they are only partly independent.

D. Long answer questions

1. Describe the structure and function of the chloroplast.

Chloroplasts are lens-shaped or discoid, 5–10 μm long and 2–4 μm wide, mostly in mesophyll cells. They are bounded by a double membrane. Inside is the stroma, containing enzymes for carbohydrate and protein synthesis, circular DNA and 70S ribosomes. Flattened sacs called thylakoids are stacked into grana; stroma lamellae connect grana. The space inside a thylakoid is the lumen. Chlorophyll and other pigments are located in thylakoid membranes. Function: photosynthesis – light reactions in thylakoids (ATP and NADPH formation, O_2 release) and dark reactions in stroma (CO_2 fixation to sugar).

2. Describe the structure of the nucleus.

The nucleus, discovered by Robert Brown, is enclosed by a nuclear envelope of two membranes with a perinuclear space of 10–50 nm. The outer membrane is continuous with ER and bears ribosomes. Nuclear pores allow movement of RNA and proteins. The nucleoplasm contains the nucleolus (site of rRNA synthesis) and chromatin (DNA, histones, non-histone proteins and RNA). During division chromatin condenses into chromosomes, each with a centromere and kinetochores; chromosomes are metacentric, sub-metacentric, acrocentric or telocentric. Functions: controls cell activities, carries hereditary information, forms ribosomes.

3. Diagram description: Structure of a typical plant cell.

Draw a rectangular cell with an outer cell wall and plasma membrane just inside it. Show a large central vacuole surrounded by tonoplast, pushing cytoplasm to the edge; a nucleus with nucleolus near the wall; several oval chloroplasts with grana; sausage-shaped mitochondria; ER network; Golgi stack; ribosomes as dots; plasmodesmata passing through the wall; middle lamella between adjacent walls. Labels: cell wall, plasma membrane, middle lamella, plasmodesmata, vacuole, tonoplast, nucleus, nucleolus, chloroplast, mitochondrion, ER, Golgi, ribosomes.

QB-7. Biomolecules

Key points

- Acid-soluble pool: small molecules; acid-insoluble: proteins, nucleic acids, polysaccharides, lipids.
- Peptide bond (amino acids), glycosidic bond (sugars), phosphodiester bond (nucleotides), ester bond (lipids).
- Starch gives blue colour with iodine (helical); cellulose does not. Inulin = polymer of fructose. Chitin = exoskeleton and fungal wall.
- Haemoglobin: 4 subunits ($2\alpha + 2\beta$) – quaternary structure. RuBisCO most abundant protein in biosphere; collagen in animals.
- B-DNA: 10 bp per turn, pitch 34 Å; A=T (2 H-bonds), G≡C (3 H-bonds).
- Enzymes lower activation energy; malonate competitively inhibits succinic dehydrogenase; six classes; co-factors: prosthetic group (haem), co-enzyme (NAD – niacin), metal ion (Zn in carboxypeptidase).

A. Multiple choice questions

1. The bond between two amino acids is (a) glycosidic (b) peptide (c) ester (d) phosphodiester
(b) peptide
2. Most abundant protein in the biosphere is (a) collagen (b) haemoglobin (c) RuBisCO (d) insulin
(c) RuBisCO
3. Inulin is a polymer of (a) glucose (b) fructose (c) galactose (d) ribose
(b) fructose
4. Malonate inhibits (a) amylase (b) succinic dehydrogenase (c) catalase (d) pepsin
(b) succinic dehydrogenase
5. NAD contains the vitamin (a) riboflavin (b) niacin (c) thiamine (d) biotin
(b) niacin
6. Zinc is the co-factor of (a) carboxypeptidase (b) catalase (c) peroxidase (d) hexokinase
(a) carboxypeptidase
7. Pyrimidine absent in DNA is (a) cytosine (b) thymine (c) uracil (d) adenine
(c) uracil
8. Lecithin is a (a) phospholipid (b) protein (c) steroid (d) sugar
(a) phospholipid

B. Very short answer questions

1. Why do lipids appear in the acid-insoluble fraction?

Because cell membranes break into water-insoluble vesicles when tissue is ground.

2. What is a zwitterion?

A form of amino acid carrying both positive and negative charges at a particular pH.

3. What are ribozymes?

Nucleic acids (RNA) that act as enzymes.

4. What is a nucleoside?

A nitrogen base joined to a sugar, e.g. adenosine.

5. Name two secondary metabolites.

Morphine (alkaloid) and rubber (polymer); also curcumin, anthocyanins.

6. What is apoenzyme?

The protein part of an enzyme that needs a co-factor for activity.

C. Short answer questions**1. Explain the levels of protein structure.**

Primary – sequence of amino acids from N-terminal to C-terminal. Secondary – folding into helix (right-handed) or sheets held by hydrogen bonds. Tertiary – further folding into a 3-D globular shape needed for activity. Quaternary – association of two or more polypeptide subunits, e.g. haemoglobin with two α and two β chains.

2. Distinguish between DNA and RNA.

DNA has deoxyribose sugar, bases A, G, C and T, is usually double-stranded and is the genetic material. RNA has ribose sugar, bases A, G, C and U, is usually single-stranded and helps in protein synthesis (genetic material only in some viruses).

3. How does temperature affect enzyme activity?

Activity rises with temperature up to the optimum. At low temperature the enzyme becomes temporarily inactive; at high temperature it is denatured because the protein loses its 3-D shape, and activity is lost permanently.

4. What is competitive inhibition?

When an inhibitor resembles the substrate in structure, it competes for the active site and blocks the substrate, reducing enzyme activity. Example: malonate inhibits succinic dehydrogenase because it resembles succinate.

D. Long answer questions**1. Explain the mechanism of enzyme action.**

An enzyme has an active site, a pocket into which a specific substrate fits. (1) The substrate binds to the active site forming the enzyme-substrate complex. (2) The enzyme changes shape to fit more tightly (induced fit). (3) The active site breaks bonds of the substrate, forming the enzyme-product complex. (4) The product is released and the enzyme is free for another substrate. $E + S \rightarrow ES \rightarrow EP \rightarrow E + P$. The ES complex passes through a transition state; the enzyme lowers the activation energy needed, so the reaction is much faster. Carbonic anhydrase increases the rate of carbonic acid formation about 10 million times.

2. Classify enzymes and explain co-factors.

Six classes: oxidoreductases (oxidation-reduction), transferases (group transfer), hydrolases (hydrolysis of bonds), lyases (removal of groups without hydrolysis, forming double bonds), isomerases (inter-conversion of isomers), ligases (joining two compounds). Co-factors are non-protein parts needed for activity: prosthetic groups are tightly bound

organic compounds (haem in catalase and peroxidase); co-enzymes are loosely and transiently bound organic compounds, often containing vitamins (NAD, NADP contain niacin); metal ions form coordination bonds (zinc in carboxypeptidase). Removing the co-factor destroys activity.

3. Diagram description: Watson-Crick model of DNA.

Draw two parallel spiral ribbons twisting to the right (right-handed helix), running in opposite directions ($5' \rightarrow 3'$ and $3' \rightarrow 5'$). Each ribbon is the sugar-phosphate backbone. Horizontal rungs between them are base pairs: A-T with two dotted lines and G-C with three dotted lines. Mark one complete turn as $34 \text{ \AA}$ containing 10 base pairs and the distance between pairs as $3.4 \text{ \AA}$; width $20 \text{ \AA}$. Labels: sugar, phosphate, base pair, hydrogen bonds, major groove, minor groove.

QB-8. Photosynthesis in Higher Plants

Key points

- O_2 evolved comes from water (van Niel). Engelmann – first action spectrum with *Cladophora*.
- PS I – P700; PS II – P680; water splitting complex with PS II on lumen side.
- Non-cyclic: PS II + PS I, ATP + NADPH + O_2 . Cyclic: PS I only, ATP only, in stroma lamellae.
- Chemiosmosis (Mitchell): H^+ gradient across thylakoid; ATP synthase F_0 (channel) + F_1 (makes ATP).
- Calvin cycle: carboxylation, reduction, regeneration; 18 ATP + 12 NADPH per glucose.
- C_4 : $PEP + CO_2$ (PEPcase) $\rightarrow$ OAA in mesophyll; Kranz anatomy; no photorespiration.
- Photorespiration: $RuBisCO + O_2 \rightarrow PGA +$ phosphoglycolate; chloroplast, peroxisome, mitochondria; wasteful.
- Blackman's law of limiting factors; CO_2 is the major limiting factor.

A. Multiple choice questions

1. Reaction centre of PS II is (a) P700 (b) P680 (c) P670 (d) P720

(b) P680

2. The first stable product of C_4 pathway is (a) PGA (b) OAA (c) malic acid (d) PEP

(b) OAA

3. Kranz anatomy is found in (a) wheat (b) rice (c) maize (d) potato

(c) maize

4. The oxygen released in photosynthesis comes from (a) CO_2 (b) H_2O (c) glucose (d) chlorophyll

(b) H_2O

5. Cyclic photophosphorylation produces (a) ATP only (b) NADPH only (c) ATP and NADPH (d) O_2

(a) ATP only

6. Chemiosmotic hypothesis was given by (a) Calvin (b) Mitchell (c) Hatch (d) Blackman

(b) Mitchell

7. Photorespiration involves (a) chloroplast, peroxisome, mitochondria (b) chloroplast only (c) ribosome, Golgi (d) nucleus, ER

(a) chloroplast, peroxisome, mitochondria

8. Number of ATP needed to fix one CO_2 in Calvin cycle is (a) 2 (b) 3 (c) 5 (d) 18

(b) 3

9. CO_2 acceptor in mesophyll of C_4 plants is (a) RuBP (b) PEP (c) OAA (d) PGA

(b) PEP

10. Law of limiting factors was given by (a) Blackman (b) Liebig (c) Priestley (d) Sachs

(a) Blackman**B. Very short answer questions****1. What is photophosphorylation?**

Synthesis of ATP from ADP and inorganic phosphate in the presence of light.

2. What is Kranz anatomy?

Wreath-like arrangement of large chloroplast-rich bundle sheath cells around vascular bundles in leaves of C_4 plants.

3. Name the primary CO_2 acceptor of C_3 plants.

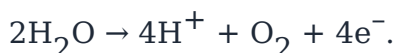
Ribulose-1,5-bisphosphate (RuBP), a 5-carbon compound.

4. Why is RuBisCO called carboxylase-oxygenase?

Because it can bind both CO_2 (carboxylation) and O_2 (oxygenation).

5. What is an action spectrum?

A graph showing the rate of photosynthesis at different wavelengths of light.

6. Write the equation of photolysis of water.**C. Short answer questions****1. Distinguish between cyclic and non-cyclic photophosphorylation.**

Non-cyclic: both photosystems work, electrons go from water to $NADP^+$, ATP and NADPH are formed, water splits and O_2 is released; occurs in grana. Cyclic: only PS I works, electrons return to PS I, only ATP is formed, no water splitting or O_2 ; occurs in stroma lamellae.

2. What is photorespiration? Why is it absent in C_4 plants?

Photorespiration is the light-dependent uptake of O_2 and release of CO_2 when RuBisCO binds O_2 instead of CO_2 , giving one PGA and one phosphoglycolate; no sugar, ATP or NADPH is formed, so it is wasteful. In C_4 plants, malic acid releases CO_2 inside bundle sheath cells, raising CO_2 concentration around RuBisCO, so it acts as a carboxylase and oxygenation is minimised.

3. State Blackman's law of limiting factors with an example.

If a chemical process is affected by more than one factor, its rate is determined by the factor nearest to its minimal value. Example: on a cold winter morning a plant in bright light and normal CO_2 photosynthesises slowly because temperature is limiting; increasing temperature increases the rate until another factor becomes limiting.

4. Why do C_3 plants benefit from increased CO_2 ?

C_3 plants saturate only above 450 $\mu\text{L/L}$ CO_2 , while current levels are lower. Extra CO_2 increases carboxylation and reduces photorespiration, giving higher yields. Hence tomatoes and bell peppers are grown in CO_2 -enriched greenhouses.

D. Long answer questions

1. Describe the light reaction of photosynthesis (Z scheme).

Light is absorbed by antenna pigments of PS II and PS I and passed to reaction centres. In PS II, P680 absorbs red light; its electrons are excited and accepted by a primary acceptor, then passed through the cytochrome chain (ETS) downhill to PS I. Electrons lost by PS II are replaced by splitting of water ($2\text{H}_2\text{O} \rightarrow 4\text{H}^+ + \text{O}_2 + 4\text{e}^-$), releasing O_2 . In PS I, P700 is excited and its electrons are passed through another acceptor to NADP^+ , reducing it to $\text{NADPH} + \text{H}^+$. Electrons lost by PS I are replaced from PS II via the ETS. On a redox scale the path looks like the letter Z. ATP is produced by chemiosmosis as protons accumulate in the lumen and flow through ATP synthase. The products ATP and NADPH are used in the Calvin cycle.

2. Describe the Calvin cycle.

Occurs in stroma; discovered by Calvin using ^{14}C . (1) Carboxylation: $\text{RuBP (5C)} + \text{CO}_2 \rightarrow 2 \times 3\text{-PGA}$, catalysed by RuBisCO. (2) Reduction: PGA is reduced to triose phosphate using 2 ATP and 2 NADPH per CO_2 ; some triose phosphate forms glucose. (3) Regeneration: RuBP is regenerated using 1 ATP per CO_2 . For one glucose, 6 turns are needed: 6 CO_2 , 18 ATP and 12 NADPH are used.

3. Describe the C_4 pathway and compare C_3 and C_4 plants.

In C_4 plants (maize, sugarcane) leaves have Kranz anatomy. In mesophyll cells PEP (3C) accepts CO_2 using PEP carboxylase, forming OAA (4C), which becomes malic or aspartic acid and moves to bundle sheath cells. There it is decarboxylated, releasing CO_2 that enters the Calvin cycle (RuBisCO present only here). The 3C pyruvate returns to mesophyll and is converted back to PEP. Comparison: C_3 - first product PGA, acceptor RuBP, no Kranz anatomy, photorespiration present, optimum 20–25°C (rice, wheat). C_4 - first product OAA, acceptor PEP, Kranz anatomy, no photorespiration, optimum 30–40°C, higher productivity.

QB-9. Respiration in Plants

Key points

- Glycolysis (EMP) in cytoplasm: glucose $\rightarrow$ 2 pyruvate; net 2 ATP + 2 NADH.
- Fermentation: yeast $\rightarrow$ ethanol + CO_2 (pyruvate decarboxylase, alcohol dehydrogenase); muscle $\rightarrow$ lactic acid (lactate dehydrogenase).
- Link reaction: pyruvate $\rightarrow$ acetyl CoA + CO_2 + NADH (pyruvate dehydrogenase).
- Krebs cycle in matrix: OAA + acetyl CoA $\rightarrow$ citric acid; 3 NADH, 1 FADH_2 , 1 ATP (GTP), 2 CO_2 per turn.
- ETS on inner membrane: complexes I-V; O_2 final acceptor; $\text{NADH} \rightarrow 3 \text{ ATP}$, $\text{FADH}_2 \rightarrow 2 \text{ ATP}$. Net 38 ATP.
- Amphibolic pathway; RQ carbohydrate 1, fat 0.7, protein 0.9, anaerobic infinity.

A. Multiple choice questions

1. Glycolysis occurs in (a) mitochondria (b) cytoplasm (c) chloroplast (d) nucleus
(b) cytoplasm
2. Net ATP from glycolysis per glucose (a) 2 (b) 4 (c) 8 (d) 36
(a) 2
3. First product of Krebs cycle is (a) OAA (b) citric acid (c) succinic acid (d) malic acid
(b) citric acid
4. Final electron acceptor in aerobic respiration is (a) NAD (b) FAD (c) oxygen (d) cytochrome c
(c) oxygen
5. RQ of fat is about (a) 1 (b) 0.7 (c) 1.3 (d) infinity
(b) 0.7
6. Complex IV of ETS is (a) NADH dehydrogenase (b) cytochrome bc_1 (c) cytochrome c oxidase (d) ATP synthase
(c) cytochrome c oxidase
7. Substrate-level phosphorylation in Krebs cycle occurs at (a) succinyl CoA → succinic acid (b) citrate → isocitrate (c) malate → OAA (d) fumarate → malate
(a) succinyl CoA → succinic acid
8. Yeast stops fermenting when alcohol reaches about (a) 5% (b) 13% (c) 30% (d) 50%
(b) 13%

B. Very short answer questions

1. What is the energy currency of the cell?

ATP (adenosine triphosphate).

2. Define RQ.

Ratio of volume of CO_2 evolved to volume of O_2 consumed in respiration.

3. Name the enzyme that converts sucrose into glucose and fructose.

Invertase.

4. How many ATP are formed from one NADH in ETS?

Three.

5. Where does the Krebs cycle occur?

In the mitochondrial matrix.

6. What is the RQ of anaerobic respiration?

Infinity, because CO_2 is released without O_2 consumption.

C. Short answer questions

1. Why is the respiratory pathway called amphibolic?

Because it is used for both breaking down and building up. Fats, proteins and carbohydrates are broken down and enter the pathway at different points (catabolism), and intermediates such as acetyl CoA are withdrawn to synthesise fatty acids, amino acids and other compounds (anabolism).

2. Distinguish between aerobic respiration and fermentation.

Aerobic respiration needs oxygen, occurs in cytoplasm and mitochondria, oxidises glucose completely to CO_2 and H_2O , and gives 38 ATP. Fermentation occurs without oxygen in cytoplasm only, oxidises glucose incompletely to ethanol and CO_2 or lactic acid, and gives only 2 ATP.

3. What is the role of oxygen in respiration?

Oxygen acts as the final acceptor of electrons and hydrogen at the end of the ETS, forming water. Though it acts only at the last step, it drives the whole process by removing electrons and hydrogen from the system; without oxygen the ETS and Krebs cycle stop.

4. Calculate RQ for tripalmitin.

$2\text{C}_{51}\text{H}_{98}\text{O}_6 + 145\text{O}_2 \rightarrow 102\text{CO}_2 + 98\text{H}_2\text{O}$. $\text{RQ} = 102 \div 145 = 0.7$.

D. Long answer questions**1. Describe glycolysis.**

Glycolysis (EMP pathway) occurs in the cytoplasm. Glucose is phosphorylated by hexokinase to glucose-6-phosphate (1 ATP used), isomerised to fructose-6-phosphate, and phosphorylated to fructose-1,6-bisphosphate (1 ATP used). This splits into DHAP and PGAL; DHAP becomes PGAL. Each PGAL is oxidised with phosphate to 1,3-bisphosphoglycerate, forming NADH. BPGA gives 3-PGA with formation of ATP. 3-PGA becomes 2-PGA, then PEP, and PEP gives pyruvic acid with formation of ATP. Per glucose: 4 ATP formed, 2 used, net 2 ATP, 2 NADH and 2 pyruvate.

2. Describe the Krebs cycle.

Pyruvate entering mitochondria is converted by pyruvate dehydrogenase into acetyl CoA, CO_2 and NADH. Acetyl CoA (2C) joins OAA (4C) to form citric acid (6C) through citrate synthase. Citrate isomerises to isocitrate, which is decarboxylated to α -ketoglutarate (5C) with NADH; this is decarboxylated to succinyl CoA (4C) with NADH. Succinyl CoA forms succinic acid, giving GTP (ATP). Succinic acid is oxidised to fumaric acid, forming FADH_2 ; fumaric acid becomes malic acid, and malic acid is oxidised to OAA, forming NADH. OAA is regenerated. Per turn: 2 CO_2 , 3 NADH, 1 FADH_2 , 1 ATP.

3. Explain ETS and calculate the net ATP gain per glucose.

The ETS on the inner mitochondrial membrane passes electrons from NADH through complex I (NADH dehydrogenase) and from FADH_2 through complex II to ubiquinone, then through complex III (cytochrome bc_1) to cytochrome c, then to complex IV (cytochrome c oxidase) and finally to O_2 , forming water. Energy released pumps protons into the inter-membrane space; protons return through complex V (ATP synthase, $\text{F}_0\text{-F}_1$), forming ATP - oxidative phosphorylation. Balance: glycolysis 2 ATP + 2 NADH (6) = 8; link reaction 2 NADH = 6; Krebs cycle 2 ATP + 6 NADH (18) + 2 FADH_2 (4) = 24. Total = 38 ATP.

QB-10. Plant Growth and Development

Key points

- Growth: irreversible permanent increase in size; indeterminate (open) in plants.
- Phases: meristematic, elongation, maturation. Arithmetic $L_t = L_0 + rt$ (linear); geometric $W_1 = W_0 e^{rt}$ (sigmoid: lag, log, stationary).
- Differentiation, dedifferentiation (interfascicular cambium, cork cambium), redifferentiation.
- Auxin (Went; apical dominance, rooting, 2,4-D weedicide), gibberellin (Kurosawa; bolting, malting, sugarcane), cytokinin (Skoog and Miller; kinetin; delay senescence), ethylene (ripening, ethephon), ABA (stress hormone; stomatal closure, dormancy).
- Germination: epigeal (bean, castor), hypogeal (pea, maize).

A. Multiple choice questions

1. Apical dominance is due to (a) auxin (b) cytokinin (c) ABA (d) ethylene
(a) auxin
2. Bolting is caused by (a) auxin (b) gibberellin (c) ethylene (d) ABA
(b) gibberellin
3. Stress hormone is (a) IAA (b) GA (c) ABA (d) kinetin
(c) ABA
4. A gaseous hormone is (a) ethylene (b) auxin (c) zeatin (d) GA_3
(a) ethylene
5. Geometric growth gives (a) linear curve (b) sigmoid curve (c) bell curve (d) straight line
(b) sigmoid curve
6. Kinetin was first isolated from (a) coconut milk (b) herring sperm DNA (c) corn (d) urine
(b) herring sperm DNA
7. Bakanae disease of rice led to the discovery of (a) auxin (b) gibberellin (c) cytokinin (d) ethylene
(b) gibberellin
8. Hypogeal germination occurs in (a) bean (b) castor (c) pea (d) cotton
(c) pea

B. Very short answer questions

1. What is dedifferentiation?

Regaining of the capacity to divide by living differentiated cells, e.g. formation of cork cambium.

2. Name a natural cytokinin.

Zeatin.

3. Name a synthetic auxin used as weedicide.

2,4-D.

4. What is heterophylly?

Occurrence of different shapes of leaves on the same plant, e.g. cotton, coriander, larkspur, buttercup.

5. Which hormone delays senescence?

Cytokinin.

6. Name the compound used as ethylene source.

Ethephon.

C. Short answer questions

1. Distinguish between absolute and relative growth rate.

Absolute growth rate is the total growth per unit time. Relative growth rate is the growth per unit time per unit initial size. Two leaves gaining 5 cm² each have the same absolute rate, but the smaller leaf has a higher relative rate.

2. What is apical dominance? How is it used?

Suppression of lateral bud growth by the apical bud, caused by auxin. When the shoot tip is removed (decapitation), lateral buds grow and the plant becomes bushy. Used in tea plantations and hedges.

3. Write any four uses of gibberellins.

Increase length of grape stalks; elongate and improve shape of apples; speed up malting in breweries; increase sugarcane yield by stem elongation; hasten maturity in conifers; cause bolting in cabbage and beet.

4. Describe the phases of growth in a root.

Meristematic phase at the tip: constantly dividing cells with dense protoplasm and large nuclei. Elongation phase behind it: cells vacuolate and enlarge with new wall deposition. Maturation phase further back: cells reach maximum size and differentiate.

D. Long answer questions

1. Describe the physiological effects of auxin and ethylene.

Auxin: initiates rooting in cuttings; promotes flowering in pineapple; prevents premature drop of leaves and fruits; causes apical dominance; induces parthenocarpy in tomato; 2,4-D kills dicot weeds; controls xylem differentiation and cell division. **Ethylene:** causes horizontal growth, swelling of axis and apical hook in seedlings; promotes senescence and abscission; ripens fruits and increases respiration (climacteric); breaks seed and bud dormancy (peanut, potato); elongates internodes in deep-water rice; promotes root hairs; induces flowering in pineapple and mango; ethephon increases female flowers in cucumber.

2. Explain arithmetic and geometric growth with equations.

Arithmetic growth: after mitosis only one daughter cell keeps dividing; growth is constant. $L_t = L_0 + rt$; graph of length vs time is a straight line (e.g. root elongating at constant rate). Geometric growth: both daughter cells keep dividing. $W_1 = W_0 e^{rt}$, where r is the relative growth rate or efficiency index. Growth is slow at first (lag), then

exponential (log), then slows to a stationary phase as nutrients become limited, giving a sigmoid curve.

3. Describe the role of cytokinin and abscisic acid.

Cytokinin: promotes cell division; helps produce new leaves, chloroplasts, lateral shoots and adventitious shoots; overcomes apical dominance; promotes nutrient mobilisation and delays leaf senescence. **ABA:** general growth inhibitor; inhibits seed germination; closes stomata during water stress; increases stress tolerance; promotes seed maturation and dormancy, helping seeds survive desiccation; acts as antagonist to gibberellins.

PRACTICAL & VIVA GUIDE

Botany · +2 1st Year

Botany Practical Guide

PRACTICAL RECORD TIPS

For every experiment write: Aim, Materials required, Procedure, Observation, Result/ Inference and Precautions. Draw neat, labelled pencil diagrams on the left-hand page. Label lines must be parallel and must not cross.

P1. Parts of a dissecting and a compound microscope

Dissecting microscope	Compound microscope
Base (heavy, stable foot)	Base and pillar
Vertical limb with adjustment screw (rack and pinion)	Arm (handle) and inclination joint
Folding arm carrying a single lens (magnification 5x-20x)	Body tube with eyepiece (ocular, 10x) at top
Glass stage with two leaf rests (hand rests) on sides	Revolving nosepiece with objectives (10x low power, 45x high power)
Concave mirror below the stage	Stage with clips and central hole; condenser and diaphragm below; plane/concave mirror
Use: dissection of flowers and small specimens; simple microscope	Coarse and fine adjustment knobs for focusing; total magnification = eyepiece $\times$ objective (10 $\times$ 45 = 450x)

P2. Study of a typical angiosperm plant

Observation: the plant has an underground root system (tap root with lateral branches) and an aerial shoot system. The stem has nodes and internodes; leaves arise at nodes with axillary buds; each leaf has leaf base, petiole and lamina with reticulate venation; flowers and fruits are borne on branches. **Result:** it is a typical dicotyledonous flowering plant showing root, stem, leaf, flower and fruit.

P3. Description of plant families

Character	Malvaceae (china rose)	Fabaceae (pea, bean)	Solanaceae (Datura, brinjal)	Liliaceae (onion, lily)
Leaf	Simple, alternate, stipulate	Pinnately compound, alternate, stipulate, pulvinate; leaflet tendrils in pea	Simple, alternate, exstipulate	Mostly basal, linear, parallel venation
Flower	Bracteate, epicalyx present, actinomorphic, bisexual	Zygomorphic, bisexual	Actinomorphic, bisexual	Actinomorphic, bisexual, trimerous
Calyx / perianth	K(5), valvate	K(5), gamosepalous	K(5), persistent	P(3+3), tepals in two whorls
Corolla	C5, polypetalous, twisted	C5: standard, 2 wings, keel (2 fused); vexillary	C(5), valvate	Perianth (no separate corolla)
Androecium	Numerous, monadelphous (staminal tube), monothecous kidney-shaped anthers	Ten, diadelphous (9)+1	Five, epipetalous	Six (3+3), epiphyllous
Gynoecium	Pentacarpellary, syncarpous, superior, axile	Monocarpellary, superior, marginal	Bicarpellary, syncarpous, oblique, superior, axile	Tricarpellary, syncarpous, superior, trilocular, axile
Fruit	Capsule	Legume (pod)	Berry or capsule	Capsule, rarely berry
Floral formula	Br $\oplus$ $\varnothing$ Epi ₅₋₈ K ₍₅₎ C ₅ A _(∞) G ₍₅₎	Br $\% \varnothing$ K ₍₅₎ C ₁₊₂₊₍₂₎ A ₍₉₎₊₁ G ₁	$\oplus \varnothing$ K ₍₅₎ C ₍₅₎ A ₅ G ₍₂₎	Br $\oplus \varnothing$ P ₍₃₊₃₎ A ₃₊₃ G ₍₃₎

In each formula, the ovary is superior (line drawn below G). In Solanaceae, the C and A are joined by an arc (epipetalous); in Liliaceae, P and A are joined (epiphyllous).

P4. T.S. of dicot and monocot root, stem and leaf

Procedure: take a fresh piece of root/stem (or leaf held in potato pith), cut thin transverse sections with a sharp razor, keep them in water in a watch glass, select the thinnest, stain with **safranin** (1–2 minutes), wash, mount in **glycerine** on a slide, cover with a cover slip and observe under the microscope.

Section	Identifying features (Observation)
Dicot root (gram/sunflower)	Epiblema with root hairs; no cuticle; cortex; endodermis with Casparian strips; radial bundles, 2-4 xylem, exarch; little or no pith
Monocot root (maize)	As above but xylem bundles many (polyarch); large pith
Dicot stem (sunflower)	Cuticle, multicellular hairs; collenchymatous hypodermis; starch sheath; bundles conjoint, collateral, open, in a ring; endarch; large pith
Monocot stem (maize)	Sclerenchymatous hypodermis; ground tissue undifferentiated; many scattered closed bundles with bundle sheath and water cavity; no pith
Dicot leaf (mango)	Palisade and spongy mesophyll; more stomata on lower side; dorsiventral
Monocot leaf (maize/grass)	Isobilateral; mesophyll undifferentiated; bulliform cells on upper epidermis; stomata on both surfaces

Precautions: sections should be thin and complete; avoid over-staining; avoid air bubbles under the cover slip; keep sections wet.

P5. Mitosis in onion root tip

Procedure: grow onion bulbs in water; cut 1-2 cm long root tips in the morning (9-11 a.m., when division is maximum); fix in **Carnoy's fluid** or acetic alcohol (1:3); hydrolyse in 1N HCl at about 60°C for a few minutes; stain with **acetocarmine** or aceto-orcein; place the tip on a slide, add a drop of stain, put a cover slip and gently tap/squash; observe.

Observation: Prophase – chromatin condensed into thread-like chromosomes; nuclear membrane and nucleolus disappearing. **Metaphase** – chromosomes arranged at the equator (metaphase plate) attached to spindle fibres. **Anaphase** – sister chromatids separate and move to opposite poles (V, J, L shapes). **Telophase** – chromosomes reach poles, nuclear membrane reforms, cell plate formation begins. **Result:** different stages of mitosis are seen in onion root tip cells.

P6. Onion peel and Rhoeo leaf cells; plasmolysis

Procedure: peel the thin inner epidermis of an onion scale leaf (or lower epidermis of Rhoeo leaf), stain onion peel with safranin or iodine, mount in water or glycerine and observe. **Observation:** onion cells are rectangular, closely packed, with a distinct cell wall, a nucleus near the wall and a large vacuole. Rhoeo cells show purple cell sap (anthocyanin in vacuole) and stomata with guard cells. When Rhoeo peel is placed in strong salt or sugar solution, the protoplast shrinks away from the wall (**plasmolysis**); in water it swells again (deplasmolysis). **Result:** plant cells have a cell wall, nucleus and vacuole; living cells show plasmolysis in hypertonic solution.

P7. Tests for starch, protein and fat

Test	Procedure	Observation	Inference
Starch (iodine test)	Add a few drops of dilute iodine solution to potato extract or starch solution	Blue-black colour	Starch present
Protein (biuret test)	To 2 mL of sample (gram or egg albumin) add 2 mL 10% NaOH and 2-3 drops of 1% CuSO ₄	Violet / purple colour	Protein present
Protein (xanthoproteic)	Add conc. HNO ₃ and heat; cool and add ammonia	Yellow, turning orange	Protein present
Fat (Sudan III)	Add a few drops of Sudan III to oil or groundnut paste in water	Red-stained oil droplets	Fat present
Fat (paper test)	Rub groundnut seed on paper	Translucent greasy spot	Fat present

P8. Starch grains and raphides

Starch grains: scrape a little cut potato on a slide, add a drop of water (or dilute iodine) and observe. Grains are oval and show eccentric layers (**striations**) around a point called **hilum**; they turn blue-black with iodine. **Raphides:** crush a petiole of Colocasia or Pistia, or a piece of Eichhornia, mount and observe: bundles of needle-shaped crystals of **calcium oxalate** in cells. **Result:** starch grains are reserve food (ergastic substances); raphides are excretory crystals and cause itching when Colocasia is eaten raw.

P9. Catalase activity (leaf disc / potato disc)

Principle: catalase breaks hydrogen peroxide into water and oxygen: $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$. **Procedure:** take three test tubes with 5 mL of 3% H₂O₂. Add fresh potato discs (or leaf discs) to tube A, boiled discs to tube B and nothing to tube C (control). Observe the rate of bubble formation; the discs may float upward due to oxygen. **Observation:** brisk effervescence in A; no bubbles in B and C. **Result:** catalase in living tissue decomposes H₂O₂ releasing O₂; boiling denatures the enzyme. Activity can be compared by counting bubbles per minute or by the time taken for discs to rise.

P10. Modifications and flower parts (specimens)

Specimen	Identification	Key feature to write
Carrot / radish / turnip	Storage tap root	No nodes; swollen primary root; conical / fusiform / napiform
Banyan / maize	Prop / stilt root	Adventitious; support
Rhizophora	Pneumatophore	Negatively geotropic roots with pores for gas exchange
Potato / ginger / onion / Colocasia	Tuber / rhizome / bulb / corm	Nodes, buds and scale leaves – stem nature
Opuntia	Phylloclade	Green flat stem; leaves as spines
Bougainvillea / cucumber	Thorn / stem tendril	Arise from axillary bud
Pea / cactus / pitcher plant	Leaf tendril / leaf spine / insectivorous leaf	Modified leaflets / leaves
Mustard, sunflower, coriander, fig, Euphorbia	Raceme, capitulum, umbel, hypanthodium, cyathium	Arrangement of flowers on axis

Viva-voce questions

1. What is the magnification of a compound microscope with 10x eyepiece and 40x objective?

400x.

2. Why is safranin used?

It stains lignified walls (xylem, sclerenchyma) red and makes tissues clearly visible.

3. Why are onion root tips cut in the morning?

Cell division (mitotic index) is maximum at that time.

4. Why is HCl used in the mitosis experiment?

To hydrolyse and soften the middle lamella so cells separate and spread on squashing.

5. What are raphides made of?

Calcium oxalate.

6. What gives purple colour to Rhoeo cells?

Anthocyanin in the cell sap of the vacuole.

7. Why do boiled potato discs show no bubbles in H_2O_2 ?

Boiling denatures the enzyme catalase.

8. How do you identify a monocot stem section?

Scattered closed vascular bundles with bundle sheath; no distinct cortex or pith.

9. What is the identifying character of Fabaceae flowers?

Zygomorphic papilionaceous corolla with vexillary aestivation and diadelphous stamens.

10. Which family has epiphyllous stamens?

Liliaceae.

MODEL PAPERS

Botany · +2 1st Year

Model Paper 1 (Botany, Full Marks 35)

PATTERN

Group A: MCQ and very short answers (1 mark each). Group B: short answers (2–3 marks). Group C: long answers with diagram (5–7 marks). Check the latest CHSE blueprint for your session; mark distribution may change slightly.

Group A (1 × 7 = 7)

1. (a) Heterocysts occur in: (i) *Nostoc* (ii) *Mucor* (iii) *Euglena* (iv) *Funaria*

(i) *Nostoc*

(b) Twisted aestivation is found in: (i) pea (ii) china rose (iii) *Calotropis* (iv) *Cassia*

(ii) china rose

(c) The first stable product of Calvin cycle is: (i) OAA (ii) 3-PGA (iii) RuBP (iv) PEP

(ii) 3-PGA

(d) Who gave the five-kingdom classification?

R.H. Whittaker (1969)

(e) Name the hormone that closes stomata.

Abscisic acid

(f) What is the RQ of carbohydrates?

1

(g) Which organelle is called "suicidal bag"?

Lysosome

Group B (answer any four, 3 × 4 = 12)

2. Distinguish between C_3 and C_4 plants (any three points).

C_3 : first product 3-PGA; acceptor RuBP; no Kranz anatomy; photorespiration present (rice, wheat). C_4 : first product OAA; acceptor PEP; Kranz anatomy; no photorespiration; higher temperature optimum (maize, sugarcane).

3. Write a short note on lichens.

Symbiotic association of alga (phycobiont, makes food) and fungus (mycobiont, gives shelter and absorbs water and minerals). Grow on rocks and bark; pioneers on bare rock; sensitive to SO_2 , hence pollution indicators.

4. Why is the respiratory pathway called amphibolic?

It breaks down carbohydrates, fats and proteins (catabolism) and also supplies intermediates such as acetyl CoA for synthesis of fatty acids and amino acids (anabolism); so it is both catabolic and anabolic.

5. Give the floral formula of Solanaceae and explain the symbols.

$\oplus \varnothing K_{(5)} C_{(5)} A_5 G_{(2)}$: actinomorphic, bisexual; five united sepals; five united petals; five stamens epipetalous (arc joining C and A); bicarpellary syncarpous superior ovary (line under G).

6. Differentiate between prokaryotic and eukaryotic cells.

Prokaryotic: no nuclear membrane (nucleoid), single circular DNA, no membrane-bound organelles, 70S ribosomes (bacteria). Eukaryotic: true nucleus, linear chromosomes with histones, membrane-bound organelles, 80S ribosomes (plants, animals).

Group C (answer any two, $8 \times 2 = 16$)**7. Describe the Krebs cycle and calculate the ATP produced from one glucose in aerobic respiration.**

See QB-9, long answers 2 and 3. Key steps: pyruvate $\rightarrow$ acetyl CoA; acetyl CoA + OAA $\rightarrow$ citrate $\rightarrow$ isocitrate $\rightarrow$ α -ketoglutarate $\rightarrow$ succinyl CoA $\rightarrow$ succinate $\rightarrow$ fumarate $\rightarrow$ malate $\rightarrow$ OAA; per turn 3 NADH, 1 FADH₂, 1 ATP, 2 CO₂. Balance: 8 (glycolysis) + 6 (link) + 24 (Krebs) = 38 ATP.

8. Describe the internal structure of a monocot stem with a labelled diagram.

Epidermis with cuticle; sclerenchymatous hypodermis; large undifferentiated parenchymatous ground tissue; numerous scattered vascular bundles, peripheral ones smaller; each bundle conjoint, collateral, closed, surrounded by sclerenchymatous bundle sheath; phloem parenchyma absent; water-containing cavity in xylem. Diagram: circle with scattered oval bundles, each showing sheath, phloem at top, Y-shaped xylem below with cavity.

9. Describe the salient features and classes of fungi.

See QB-2, long answer 1.

Model Paper 2 (Botany, Full Marks 35)

Group A ($1 \times 7 = 7$)

1. (a) Agar is obtained from: (i) Laminaria (ii) Gelidium (iii) Ulothrix (iv) Volvox

(ii) Gelidium

(b) Sieve tube elements lack: (i) cytoplasm (ii) nucleus (iii) cell wall (iv) vacuole

(ii) nucleus

(c) Bolting is induced by: (i) auxin (ii) gibberellin (iii) ethylene (iv) ABA

(ii) gibberellin

(d) Name the reaction centre of PS I.

P700

(e) What is the cell wall of fungi made of?

Chitin

(f) Give the arrangement of microtubules in a centriole.

9 + 0 (nine triplets)

(g) Name the bond joining nucleotides.

Phosphodiester bond

Group B (answer any four, $3 \times 4 = 12$)

2. What is chemiosmotic hypothesis?

Mitchell's explanation of ATP synthesis: during light reaction protons accumulate in the thylakoid lumen (from water splitting, carrier transport, and removal of H^+ from stroma for NADPH). The proton gradient drives H^+ back to the stroma through the F_0 channel of ATP synthase, and the F_1 part makes ATP from ADP and P_i .

3. Write the rules of binomial nomenclature.

Latin names in italics; genus first with capital letter, epithet second with small letter; underlined separately when handwritten; author's name abbreviated at the end (e.g. *Mangifera indica* Linn.).

4. Describe the structure of a mitochondrion.

Double membrane; smooth outer membrane; inner membrane folded into cristae; inter-membrane space and matrix; matrix contains circular DNA, RNA, 70S ribosomes and Krebs cycle enzymes; F_0 - F_1 particles on cristae; site of aerobic respiration.

5. Distinguish between dicot and monocot leaf.

Dicot: dorsiventral, palisade and spongy mesophyll, more stomata below, no bulliform cells. Monocot: isobilateral, undifferentiated mesophyll, stomata equal on both sides, bulliform cells present.

6. Write three features of pteridophytes.

First vascular land plants; dominant sporophyte with true root, stem and leaves; sporangia on sporophylls, often in strobili; free-living gametophyte prothallus; water needed for fertilisation; heterospory in Selaginella.

Group C (answer any two, $8 \times 2 = 16$)

7. Describe the light reaction of photosynthesis with the Z scheme.

See QB-8, long answer 1. Include: PS II (P680) and PS I (P700); photolysis of water; electron flow PS II $\rightarrow$ cytochromes $\rightarrow$ PS I $\rightarrow$ $NADP^+$; ATP by chemiosmosis; cyclic flow in PS I only. Flowchart: $H_2O \rightarrow$ PS II $\rightarrow$ acceptor $\rightarrow$ ETS $\rightarrow$ PS I $\rightarrow$ acceptor $\rightarrow$ NADPH.

8. Describe the physiological effects of any three plant growth regulators.

See QB-10, long answers 1 and 3 (auxin, ethylene, cytokinin, ABA). Write at least four effects of each hormone with examples.

9. What are enzymes? Explain their mechanism of action and the factors affecting their activity.

Enzymes are biological catalysts, mostly proteins (ribozymes are RNA). Mechanism: substrate binds active site, ES complex, induced fit, transition state with lowered activation energy, product released. Factors: temperature (optimum; denaturation at high temperature), pH (optimum), substrate concentration (rate rises to V_{max}), inhibitors (competitive – malonate and succinic dehydrogenase).

Model Paper 3 (Short Practice Set)

Group A

1. (a) Who coined the term "cell"? (b) Name the site of rRNA synthesis. (c) Name a C_4 plant. (d) What is the primary acceptor of CO_2 in C_3 plants? (e) Which hormone causes fruit ripening? (f) Which plant gives peat? (g) What is the RQ of fat?

(a) Robert Hooke (b) Nucleolus (c) Maize (d) RuBP (e) Ethylene (f) Sphagnum (g) About 0.7

Group B

2. Distinguish between meristematic and permanent tissue.

Meristematic tissue has small, thin-walled, actively dividing cells with dense cytoplasm, large nuclei and no intercellular spaces or vacuoles; found at tips and cambium. Permanent tissue has cells that have stopped dividing, become specialised, have vacuoles and may be living or dead.

3. What is photorespiration? Why is it wasteful?

When RuBisCO binds O_2 instead of CO_2 , RuBP forms PGA and phosphoglycolate; through chloroplast, peroxisome and mitochondria CO_2 is released. No sugar, ATP or NADPH is formed and ATP is consumed, so fixed carbon is lost.

4. Name the types of placentation with examples.

Marginal (pea), axile (china rose, tomato, lemon), parietal (mustard, Argemone), free central (Dianthus, Primrose), basal (sunflower, marigold).

Group C

5. Describe the structure of a eukaryotic cell membrane and the cell wall of plants.

Membrane: lipid bilayer with phospholipid heads outside and tails inside, cholesterol, peripheral and integral proteins; fluid mosaic model (Singer and Nicolson); selectively permeable; passive and active transport. Cell wall: non-living rigid layer of cellulose, hemicellulose, pectins and proteins; primary wall in young cells, secondary wall inside it in mature cells; middle lamella of calcium pectate cements cells; plasmodesmata connect neighbouring cells; gives shape, protection and support.

MCQ BANK & REVISION

Zoology · +2 1st Year

MCQ Bank – 105 Questions with Answers

These questions are additional to the chapter-wise MCQs. Cover the answer column and test yourself; aim for at least 90 correct.

No.	Question (choose one)	Answer
1	Sponges belong to the level of organisation: (cellular / tissue / organ / organ-system)	cellular
2	Choanocytes are found in: (Porifera / Cnidaria / Ctenophora / Annelida)	Porifera
3	Comb plates help in locomotion in: (Hydra / Pleurobrachia / Aurelia / Sycon)	Pleurobrachia
4	Diploblastic animals include: (flatworms / coelenterates / annelids / molluscs)	coelenterates
5	Acoelomate animals are: (Platyhelminthes / Aschelminthes / Annelida / Arthropoda)	Platyhelminthes
6	Ancylostoma is the: (tapeworm / hookworm / filaria worm / liver fluke)	hookworm
7	Parapodia are found in: (earthworm / leech / Nereis / Ascaris)	Nereis
8	The largest animal phylum is: (Mollusca / Chordata / Arthropoda / Annelida)	Arthropoda
9	Silkworm is: (Apis / Bombyx / Laccifer / Locusta)	Bombyx
10	Pearl oyster is: (Pila / Pinctada / Sepia / Loligo)	Pinctada
11	Sea urchin is: (Asterias / Echinus / Antedon / Ophiura)	Echinus
12	Stomochord is found in: (Balanoglossus / Amphioxus / Ascidia / Petromyzon)	Balanoglossus
13	Jawless vertebrates belong to class: (Cyclostomata / Chondrichthyes / Amphibia / Reptilia)	Cyclostomata
14	Electric organ is found in: (Trygon / Torpedo / Pristis / Scoliodon)	Torpedo
15	Sea horse is: (Hippocampus / Exocoetus / Betta / Clarias)	Hippocampus
16	Limbless amphibian is: (Hyla / Ichthyophis / Bufo / Salamandra)	Ichthyophis
17	Crop and gizzard are found in: (reptiles / birds / mammals / fishes)	birds
18	Blue whale is: (Delphinus / Balaenoptera / Macropus / Pteropus)	Balaenoptera
19	Cloaca is absent in: (frog / lizard / pigeon / man)	man
20	Penguin is: (Aptenodytes / Struthio / Neophron / Psittacula)	Aptenodytes
21	Epithelium lining fallopian tubes is: (squamous / ciliated / cuboidal / compound)	ciliated
22	Fibroblasts, macrophages and mast cells occur in: (areolar tissue / bone / cartilage / blood)	areolar tissue
23	Muscle fibres that are spindle-shaped and unstriated are: (skeletal / smooth / cardiac / red)	smooth
24	The unit of neural system is: (neuroglia / neuron / nerve / synapse)	neuron
25	Scientific name of Indian bullfrog is: (Rana tigrina / Bufo / Hyla / Rana hexadactyla)	Rana tigrina
26		skin

	Frog never drinks water but absorbs it through: (mouth / skin / cloaca / gills)	
27	Tympanum in frog helps in: (vision / hearing / smell / taste)	hearing
28	Sinus venosus in frog joins the: (left atrium / right atrium / ventricle / conus)	right atrium
29	Frog RBCs are: (non-nucleated / nucleated / biconcave / absent)	nucleated
30	Optic lobes in frog are part of: (forebrain / midbrain / hindbrain / spinal cord)	midbrain
31	A typical human cell divides once in about: (90 min / 24 h / 12 h / 48 h)	24 h
32	Centriole duplicates during: (G1 / S / G2 / M)	S
33	Best stage to study chromosome morphology is: (prophase / metaphase / anaphase / telophase)	metaphase
34	Terminalisation of chiasmata occurs in: (pachytene / diplotene / diakinesis / zygotene)	diakinesis
35	Sister chromatids separate in: (anaphase I / anaphase II / metaphase I / telophase I)	anaphase II
36	Meiosis results in: (2 diploid / 4 haploid / 2 haploid / 4 diploid cells)	4 haploid
37	Interphase occupies more than ___ of cell cycle: (50% / 75% / 95% / 25%)	95%
38	Cell plate formation is seen in: (animal cells / plant cells / both / bacteria)	plant cells
39	Insects respire by: (gills / tracheal tubes / lungs / skin)	tracheal tubes
40	The trachea divides at the level of the: (3rd / 5th / 7th / 10th thoracic vertebra)	5th
41	Inspiratory capacity equals: (TV + ERV / TV + IRV / ERV + RV / VC + RV)	TV + IRV
42	pO ₂ of alveolar air is: (159 / 104 / 95 / 40 mm Hg)	104
43	Solubility of CO ₂ compared with O ₂ is: (same / 20-25 times higher / lower / double)	20-25 times higher
44	Respiratory rhythm centre is in: (pons / medulla / cerebrum / hypothalamus)	medulla
45	Role of O ₂ in regulating respiratory rhythm is: (major / insignificant / absent / main)	insignificant
46	Silicosis is an example of: (asthma / occupational disorder / emphysema / bronchitis)	occupational disorder
47	Respiratory organs of earthworm are: (gills / skin / lungs / tracheae)	skin
48	Normal breathing rate of man is: (12-16 / 20-25 / 30-40 / 72 per min)	12-16
49	Plasma forms about ___ of blood: (45% / 55% / 90% / 10%)	55%
50	Albumins help in: (clotting / defence / osmotic balance / transport of O ₂)	osmotic balance

51	Life span of human RBC is: (20 / 60 / 120 / 365 days)	120
52	Allergic reactions are associated with: (neutrophils / eosinophils / monocytes / lymphocytes)	eosinophils
53	Rh+ve people form about ___ of humans: (20% / 50% / 80% / 100%)	80%
54	Thrombin converts fibrinogen into: (prothrombin / fibrin / thrombokinase / plasmin)	fibrin
55	The heart of fish is: (2 / 3 / 4 / 1-chambered)	2
56	AV node is located in: (left atrium / right atrium / left ventricle / septum)	right atrium
57	Second heart sound 'dub' is due to closure of: (AV valves / semilunar valves / mitral valve / tricuspid valve)	semilunar valves
58	Stroke volume is about: (50 / 70 / 120 / 5000 mL)	70
59	T-wave represents: (atrial depolarisation / ventricular depolarisation / ventricular repolarisation / atrial systole)	ventricular repolarisation
60	Atherosclerosis affects: (veins / coronary arteries / lymph vessels / capillaries)	coronary arteries
61	Parasympathetic stimulation ___ heart rate: (increases / decreases / does not change / stops)	decreases
62	Lymph lacks: (lymphocytes / RBCs / water / proteins)	RBCs
63	Ammonotelic animals include: (birds / bony fishes / mammals / reptiles)	bony fishes
64	Malpighian tubules are excretory organs of: (earthworm / cockroach / prawn / Planaria)	cockroach
65	Glomerulus is formed by the: (efferent arteriole / afferent arteriole / renal vein / vasa recta)	afferent arteriole
66	Brush border epithelium is found in: (PCT / DCT / collecting duct / ureter)	PCT
67	Medullary osmolarity reaches about: (300 / 600 / 1200 / 2000 mOsmol/L)	1200
68	Urine output per day in an adult is: (180 L / 1-1.5 L / 15 L / 0.1 L)	1-1.5 L
69	pH of human urine is about: (4 / 6 / 8 / 10)	6
70	Aldosterone is secreted by: (adrenal medulla / adrenal cortex / kidney / pituitary)	adrenal cortex
71	Anticoagulant used in haemodialysis is: (hirudin / heparin / thrombin / fibrin)	heparin
72	Ketonuria indicates: (diabetes insipidus / diabetes mellitus / gout / uraemia)	diabetes mellitus
73	Movement of sperm is: (amoeboid / ciliary / flagellar / muscular)	flagellar
74	Muscles form about ___ of adult body weight: (10-20% / 40-50% / 60-70% / 80%)	40-50%

75	Heavy meromyosin forms the myosin: (tail / head and short arm / Z-line / M-line)	head and short arm
76	Neurotransmitter at the neuromuscular junction is: (adrenaline / acetylcholine / dopamine / serotonin)	acetylcholine
77	Number of bones in human skeleton is: (200 / 206 / 212 / 180)	206
78	Number of cervical vertebrae in man is: (5 / 7 / 12 / 4)	7
79	Longest bone of human body is: (humerus / femur / tibia / radius)	femur
80	Acetabulum is part of: (pectoral girdle / pelvic girdle / skull / sternum)	pelvic girdle
81	Knee joint is a: (ball and socket / hinge / pivot / gliding joint)	hinge
82	Osteoporosis is common due to decreased: (insulin / oestrogen / thyroxine / ADH)	oestrogen
83	Myasthenia gravis is: (genetic / auto-immune / infectious / dietary)	auto-immune
84	Hydra has a neural system in the form of: (brain / network of neurons / ganglia / spinal cord)	network of neurons
85	Afferent fibres carry impulses: (from CNS / to CNS / to muscles / to glands)	to CNS
86	Na ⁺ -K ⁺ pump transports: (2 Na ⁺ out, 3 K ⁺ in / 3 Na ⁺ out, 2 K ⁺ in / 3 Na ⁺ in / equal ions)	3 Na⁺ out, 2 K⁺ in
87	At rest the inside of the axon membrane is: (positive / negative / neutral / variable)	negative
88	Electrical synapses are: (common / rare / absent / slow)	rare
89	Hunger and thirst are controlled by: (cerebellum / hypothalamus / medulla / pons)	hypothalamus
90	Cerebral aqueduct passes through: (forebrain / midbrain / hindbrain / spinal cord)	midbrain
91	Thyroid lobes are joined by: (isthmus / stalk / corpus callosum / septum)	isthmus
92	GnRH is secreted by: (pituitary / hypothalamus / gonads / pineal)	hypothalamus
93	Somatostatin inhibits release of: (insulin only / growth hormone / oxytocin / TSH only)	growth hormone
94	Pituitary is located in: (sella turcica / foramen magnum / orbit / cranium roof)	sella turcica
95	Cretinism is due to: (hyperthyroidism / hypothyroidism / low PTH / low GH)	hypothyroidism
96	PTH is a ___ hormone: (hypocalcemic / hypercalcemic / hypoglycemic / diuretic)	hypercalcemic
97	Thymus degenerates in: (children / old age / pregnancy / puberty)	old age
98	Glucagon is secreted by: (alpha cells / beta cells / delta cells / acinar cells)	alpha cells

99	Progesterone is secreted by: (Leydig cells / corpus luteum / growing follicle / pituitary)	corpus luteum
100	Gastrin stimulates secretion of: (bile / HCl and pepsinogen / insulin / bicarbonate)	HCl and pepsinogen
101	Cyclic AMP acts as: (first messenger / second messenger / receptor / enzyme only)	second messenger
102	Hormone receptors for steroid hormones are: (on cell membrane / intracellular / in blood / absent)	intracellular
103	Melatonin regulates: (blood sugar / diurnal rhythm / calcium / growth)	diurnal rhythm

Botany Quick-Revision Sheet

Topic	Must-remember facts
Living World	Defining features: metabolism, cellular organisation, consciousness. Hierarchy K-D-C-O-F-G-S. Linnaeus - binomial; ICBN for plants. Woese - 3 domains.
Classification	Whittaker 1969 - 5 kingdoms. Methanogens (biogas), heterocysts (N_2 fixation), Mycoplasma (no wall). Diatoms (silica), Gonyaulax (red tide), Euglena (pellicle).
Fungi	Chitin wall. Phycomycetes - zygospore (Rhizopus); Ascomycetes - ascospore (yeast, Neurospora); Basidiomycetes - basidiospore (Agaricus, Puccinia); Deuteromycetes - conidia only.
Virus etc.	Ivanowsky (TMV), Beijerinck, Stanley (crystals). Viroid - free RNA (Diener). Lichen = phycobiont + mycobiont; pollution indicator.
Algae	Green: chl a, b, starch. Brown: chl a, c, fucoxanthin, laminarin. Red: chl a, d, phycoerythrin, floridean starch. Agar - Gelidium, Gracilaria.
Bryophytes to gymnosperms	Bryophytes - amphibians, gametophyte dominant, Sphagnum peat. Pteridophytes - first vascular, prothallus, heterospory in Selaginella. Gymnosperms - naked ovules, coralloid roots (Cycas), wind pollination.
Morphology	Potato = stem tuber; sweet potato = root. Aestivation: valvate (Calotropis), twisted (china rose), imbricate (Cassia), vexillary (pea). Placentation: marginal (pea), axile (tomato), parietal (mustard), free central (Dianthus), basal (sunflower).
Solanaceae	$\oplus \varnothing K_{(5)} C_{(5)} A_5 G_{(2)}$; epipetalous; persistent calyx; oblique superior ovary; axile; berry/capsule.
Anatomy	Xylem parenchyma = only living xylem element; phloem fibre = only dead phloem element. Root - radial, exarch; stem - conjoint, endarch. Dicot stem ring, open; monocot scattered, closed. Bulliform cells in grass leaf.
Cell	Virchow - omnis cellula-e cellula. 70S (prokaryote), 80S (eukaryote). Mitochondria and chloroplasts - own DNA. Cilia 9+2; centriole 9+0 triplets. Middle lamella - calcium pectate.
Biomolecules	Peptide, glycosidic, phosphodiester bonds. B-DNA 10 bp/turn, 34 Å. Six enzyme classes OTHLIL. Malonate - competitive inhibitor of succinic dehydrogenase. NAD - niacin; Zn - carboxypeptidase.
Photosynthesis	PS I P700; PS II P680. Non-cyclic: ATP + NADPH + O_2 . Cyclic: ATP only. Calvin: 18 ATP + 12 NADPH per glucose. C_4 : PEP + $CO_2 \rightarrow OAA$; Kranz anatomy. Photorespiration: chloroplast, peroxisome, mitochondria.
Respiration	Glycolysis: net 2 ATP + 2 NADH. Fermentation: 2 ATP. Krebs per turn: 3 NADH, 1 $FADH_2$, 1 ATP. NADH = 3 ATP, $FADH_2$ = 2 ATP; total 38 ATP. RQ: carbohydrate 1, fat 0.7, protein 0.9, anaerobic infinity.
Growth	$L_t = L_0 + rt$ (linear); $W_1 = W_0 e^{rt}$ (sigmoid). Auxin - apical dominance, 2,4-D; GA - bolting, malting; cytokinin - delays senescence; ethylene - ripening, ethephon; ABA - stomatal closure, dormancy.

EXAM-DAY REMINDER

Read every question twice, write definitions first, add a comparison table wherever "distinguish" is asked, and draw at least one neat labelled diagram in every long answer.

PRACTICE & REVISION

Botany · +2 1st Year (Class XI)

Last-Minute Exam Tips

Botany

- Draw neat, labelled diagrams in pencil: they carry marks even in short answers.
- Learn floral formulas and Mendelian ratios (3:1, 9:3:3:1, 1:2:1) by heart.
- Write scientific names in italics or underline them.
- Use difference tables for compare-type questions.

THE NIGHT BEFORE THE EXAM

Revise only formula boxes, name reactions, grammar rules and your own mistake list. Sleep well — a fresh mind solves problems faster than a tired one. Carry admit card, two pens, pencil, scale, eraser and a geometry box. Good luck!