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UPSC CIVIL SERVICES · PRELIMS GENERAL SCIENCE & GS MAINS

General Biology

Complete notes on life science, from the cell to gene editing, written so a beginner can follow every page, with textbook diagrams, Prelims Trap boxes, quick-revision tables and previous year questions. Health data and programmes checked to November 2026.

Compiled by Arvind KrS

27	8	176	148	355
CHAPTERS	UNITS	PRELIMS PYQS 1995–2026	DIAGRAMS AND FIGURES	PAGES

MILESTONES IN BIOLOGY

1665	1859	1866	1928	1953	2003	2025
Hooke names the cell	Darwin's Origin of Species	Mendel's laws	Penicillin found	DNA double helix	Human genome read	Genome-edited rice

IN THIS BOOK

I	Foundations of Life: The Cell and Its Molecules	II	Genetics and Evolution	III	Diversity of the Living World	IV	Plant Biology
V	Human Physiology	VI	Health and Disease	VII	Biotechnology	VIII	Quick Revision

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Updated to November 2026

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General Biology for UPSC

Notes for UPSC Civil Services Preliminary Examination (General Science) and Mains General Studies Papers II and III

2027 Edition · Compiled November 2026 · Compiled by Arvind KrS

Free sample. Two complete chapters with their unit pages. You may share this sample unchanged.

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UNIT I

4 CHAPTERS

Foundations of Life: The Cell and Its Molecules

The cell and its organelles, the molecules of life from sugars and proteins to fats and DNA, enzymes, and how cells grow and divide.

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01 **The Cell: Structure and Organelles**
The Discovery of the Cell and the Cell Theory · Prokaryotic and Eukaryotic Cells · The Plasma Membrane and the Cell Wall · How Substances Cross the Membrane · The Nucleus and the Endomembrane System · Mitochondria and Plastids: The Energy Organelles · The Cytoskeleton, Centrosome, Cilia and Flagella · Cells in the News: Stem Cells and Beyond · Quick Revision Table

02 **Biomolecules I: Carbohydrates, Proteins and Enzymes**
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04 **Cell Cycle and Cell Division**
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GENERAL BIOLOGY
PRELIMS · GS PAPER II & III

The Cell: Structure and Organelles

Every living thing you have ever seen, from the neem tree outside a school to the bacteria in a cup of curd, is built from the same basic unit: the **cell**. A single cell can be a whole organism, as in *Amoeba* or a bacterium. In a human body roughly 37 trillion cells work together, each with a job: red blood cells ferry oxygen, nerve cells carry signals across a metre, and the cells lining the gut are replaced every few days.

Stem-cell therapy, mRNA vaccines, gene editing and "three-parent" IVF all work with the parts of the cell described here, and UPSC has asked about plant and animal cells, organelles with their own DNA, and stem cells.

This chapter covers the discovery of the cell, the main cell types, how substances cross the membrane, and every organelle from the nucleus to the plastids. Biomolecules follow in Chapters 2–3 and cell division in Chapter 4.

SYLLABUS

PRELIMS — General Science

MAINS · GS PAPER III — **Science and Technology – developments and their applications and effects in everyday life**

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01 The Discovery of the Cell and the Cell Theory
02 Prokaryotic and Eukaryotic Cells
03 The Plasma Membrane and the Cell Wall
04 How Substances Cross the Membrane
05 The Nucleus and the Endomembrane System
06 Mitochondria and Plastids: The Energy Organelles
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01 The Discovery of the Cell and the Cell Theory

Cells are far too small to see with the naked eye; most are between **10 and 100 micrometres** across (a micrometre, µm, is a thousandth of a millimetre). So the story of the cell is really the story of the microscope.

- In **1665** the English scientist **Robert Hooke** looked at a thin slice of cork through a microscope he had built himself. He saw tiny empty compartments that reminded him of the small rooms (cells) of a monastery, and named them **cells**. What he saw were only the dead cell walls of cork tissue, published in his book *Micrographia*.
- A few years later the Dutch lens-maker **Antonie van Leeuwenhoek** became the first to see **living cells**: protozoa in pond water (1674), and then bacteria scraped from teeth (1683). He called them "animalcules".
- **Robert Brown**, a Scottish botanist, described the **nucleus** in orchid cells in **1831**.
- The Czech physiologist **Jan Evangelista Purkinje** used the word **protoplasm** (1839) for the living substance of the cell.
- The German botanist **Matthias Schleiden** (1838) concluded that all plants are made of cells, and the zoologist **Theodor Schwann** (1839) reached the same conclusion for animals. Together they gave the **cell theory**.
- **Rudolf Virchow** (1855) completed it with his famous line *omnis cellula e cellula*: every cell comes from a pre-existing cell.

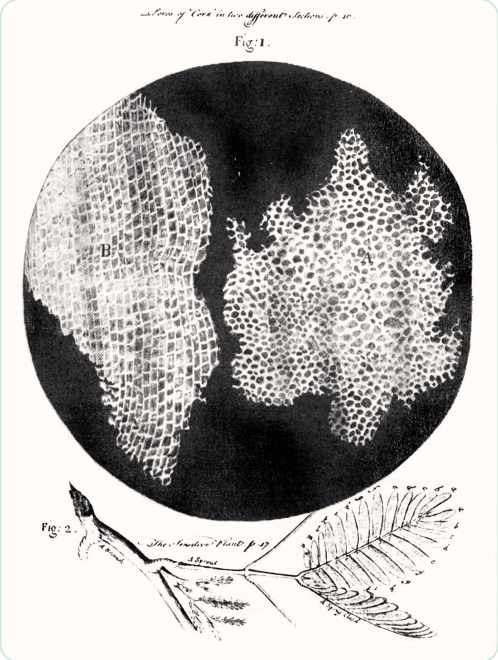


Fig. 1.1 Hooke's 1665 drawing of thin slices of cork: the empty boxes he called "cells".

REMEMBER **The modern cell theory in three lines**

- All living organisms are made of one or more cells and the products of cells.
- The cell is the basic unit of structure and function of life.
- All cells arise from pre-existing cells (Virchow's addition).

Viruses are the great exception to cell-based life: they are not cells at all and show signs of life only inside a host cell (Chapter 8).

Microscopes and the Scale of Cells

An ordinary **light microscope** uses glass lenses and visible light. It magnifies up to about 1,000–1,500 times and can separate two points about **0.2 µm** apart; that is enough to see the nucleus, the cell wall, chloroplasts and large vacuoles. The **electron microscope**, built by Max Knoll and Ernst Ruska in Germany in **1931**, uses a beam of electrons instead of light and magnets instead of glass lenses. It can resolve detail a thousand times finer and was used on cells from the 1940s. Almost everything known about mitochondria, ribosomes, the endoplasmic reticulum and the plasma membrane comes from it.

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- **Transmission electron microscope (TEM)**: electrons pass through a very thin section; shows internal structure.
- **Scanning electron microscope (SEM)**: electrons bounce off the surface; gives three-dimensional pictures of surfaces (the bacteria photograph in Section 02 was taken this way).
- Electron microscopes need a vacuum, so specimens are dead and specially prepared. **Cryo-electron microscopy**, which freezes molecules quickly and images them, won the Nobel Prize in Chemistry in 2017 and is now used to map proteins and viruses.

CELL	APPROXIMATE SIZE	WHAT TO REMEMBER
Mycoplasma (PPLO)	0.1–0.3 µm	Smallest known free-living cell; has no cell wall
Typical bacterium	1–2 µm	Prokaryotic
Human red blood cell	about 7 µm	No nucleus when mature
Human egg (ovum)	about 0.1 mm	Largest human cell, just visible to the eye
Nerve cell (neuron)	up to about 1 m long	Longest cell in the human body
Ostrich egg	about 15 cm	Largest single cell

Units used in cell biology: 1 millimetre (mm) = 1,000 micrometres (µm); 1 µm = 1,000 nanometres (nm). A cell membrane is about **7–8 nm** thick, and a ribosome about 20–25 nm across.

Why Cells Stay Small

As a cell grows, its volume increases faster than its surface area. Food, oxygen and wastes must pass through the surface, so a very large cell could not supply its own interior. That is why large organisms are made of many small cells rather than a few giant ones, and why cells divide once they reach a certain size. Long, thin shapes (nerve cells) and folded surfaces (the microvilli of intestinal cells) are ways of getting more surface for the same volume.

02 Prokaryotic and Eukaryotic Cells

All cells share three things: a **plasma membrane** around them, **cytoplasm** inside, and **DNA** as the genetic material, along with ribosomes to make proteins. Beyond this, living things fall into two great groups depending on whether their DNA is enclosed in a nucleus.

- **Prokaryotes** (*pro* = before, *karyon* = nucleus): cells without a membrane-bound nucleus and without membrane-bound organelles. Their DNA lies in an irregular region of the cytoplasm called the **nucleoid**. Bacteria, cyanobacteria (blue-green algae), mycoplasma and archaea are prokaryotes. They were the first cells on Earth; fossil evidence takes them back about 3.5 billion years.
- **Eukaryotes** (*eu* = true): cells with a true nucleus bounded by a double membrane, and with membrane-bound organelles such as mitochondria, the endoplasmic reticulum and the Golgi apparatus. Protists, fungi, plants and animals are eukaryotes.

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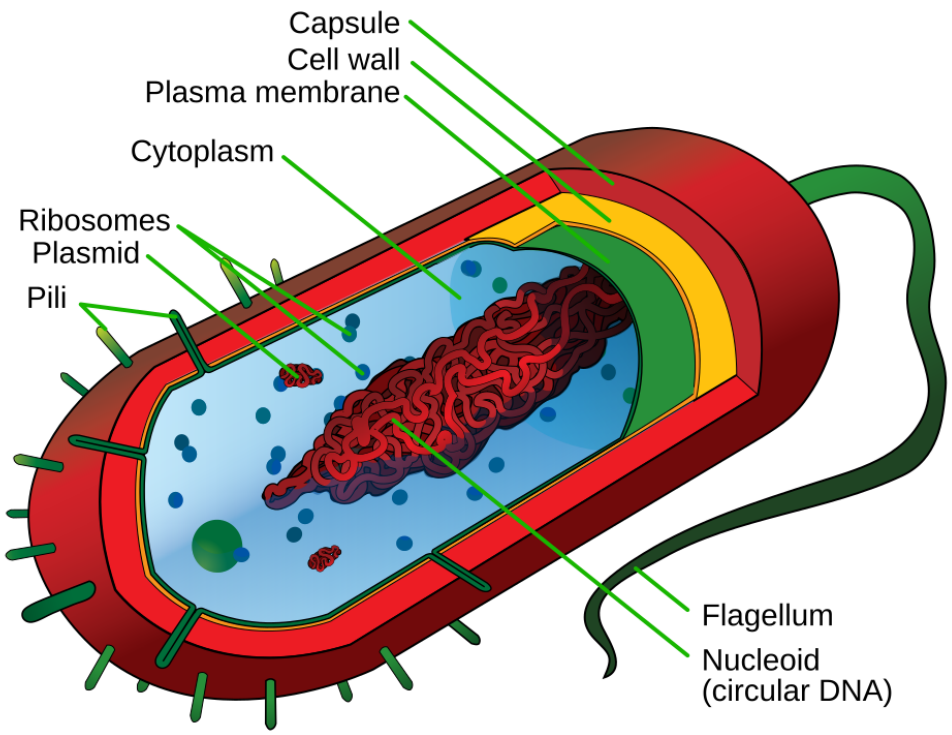


Fig. 1.2 A bacterial cell. Plasmids, the small extra rings of DNA, are the tools of genetic engineering (Chapter 25).

FEATURE	PROKARYOTIC CELL	EUKARYOTIC CELL
Nucleus	No nuclear membrane; DNA in a nucleoid	True nucleus with a double membrane and nucleolus
DNA	Usually one circular chromosome, not wrapped on histone proteins; extra DNA in plasmids	Several linear chromosomes wound on histones
Membrane-bound organelles	Absent	Present (mitochondria, ER, Golgi, lysosomes; plastids in plants)
Ribosomes	70S	80S in the cytoplasm; 70S inside mitochondria and chloroplasts
Cell wall	Usually present; made of peptidoglycan (murein) in bacteria	Cellulose in plants, chitin in fungi; absent in animals
Size	Usually 1–10 µm	Usually 10–100 µm
Cell division	Binary fission; no mitosis	Mitosis and meiosis with a spindle
Examples	Bacteria, cyanobacteria, mycoplasma, archaea	Amoeba, yeast, fungi, plants, animals

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Photosynthetic prokaryotes such as cyanobacteria have chlorophyll, but it sits on infoldings of the membrane, not inside chloroplasts. In some bacteria the membrane folds inwards into structures called **mesosomes**, once thought to help in respiration and cell-wall formation. Many bacteria also have a sticky outer **capsule** or slime layer, hair-like **pili** for sticking to surfaces and for passing DNA to another bacterium, and whip-like **flagella** for swimming.

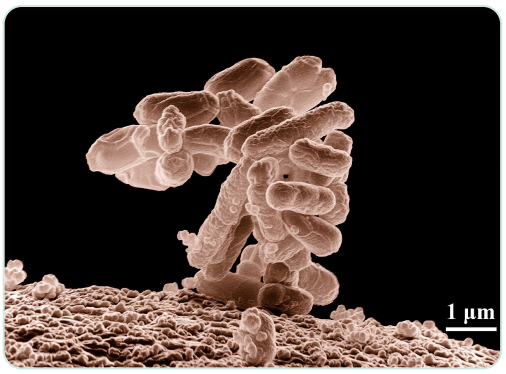


Fig. 1.3 Rod-shaped *E. coli* bacteria seen with a scanning electron microscope (coloured). Each cell is about 2 µm long.

PRELIMS TRAP **The "S" in 70S is not a size in nanometres**

"S" stands for the **Svedberg unit**, a measure of how fast a particle settles when spun in a centrifuge. It depends on both mass and shape, so the numbers do not add up: the 50S and 30S subunits make a **70S** ribosome, and the 60S and 40S subunits make an **80S** ribosome, **not** 80S and 100S.

Plant Cells and Animal Cells

Plant and animal cells are both eukaryotic and share most organelles. The differences come from their ways of life: plants make their own food and cannot move, so their cells have chloroplasts for photosynthesis and a rigid wall for support; animals must move to find food, so their cells are flexible and have no wall.

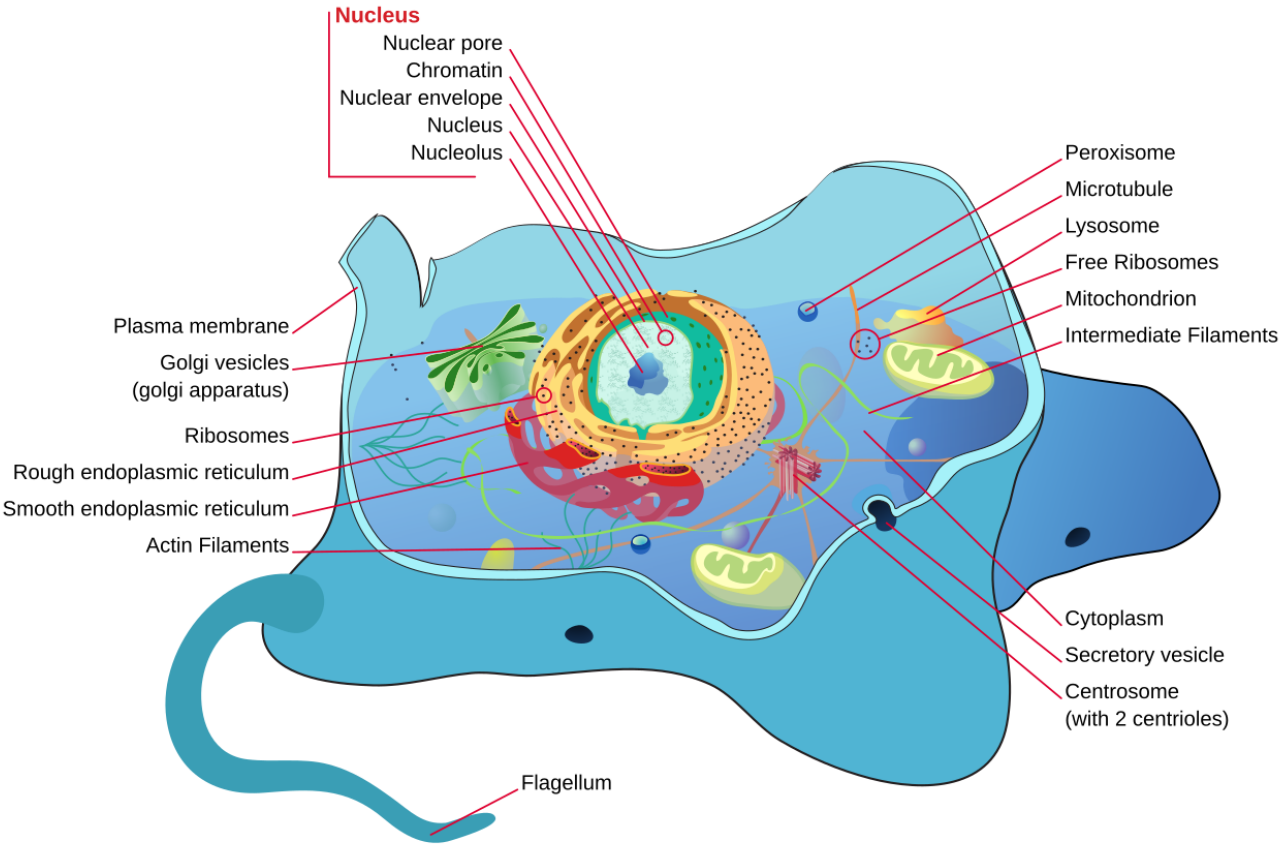


Fig. 1.4 The parts of an animal cell. Each organelle is a compartment with its own job, kept apart from the others by membranes.

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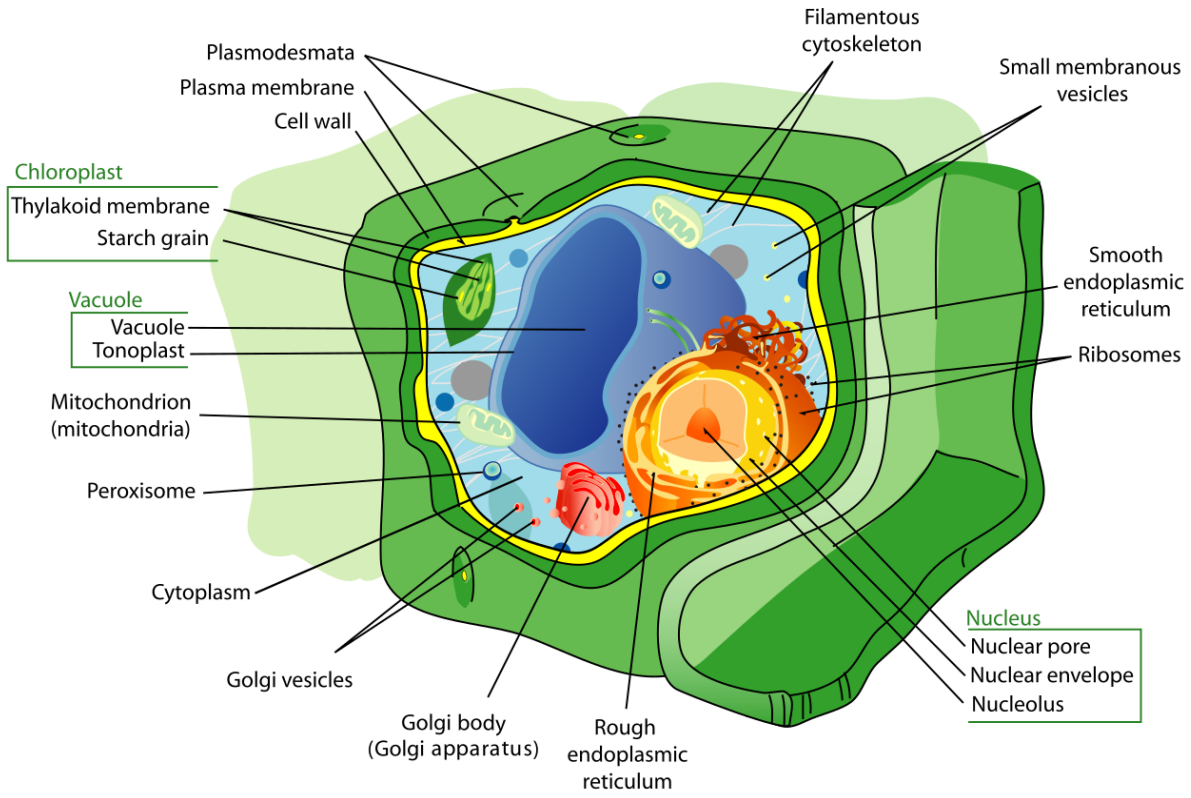
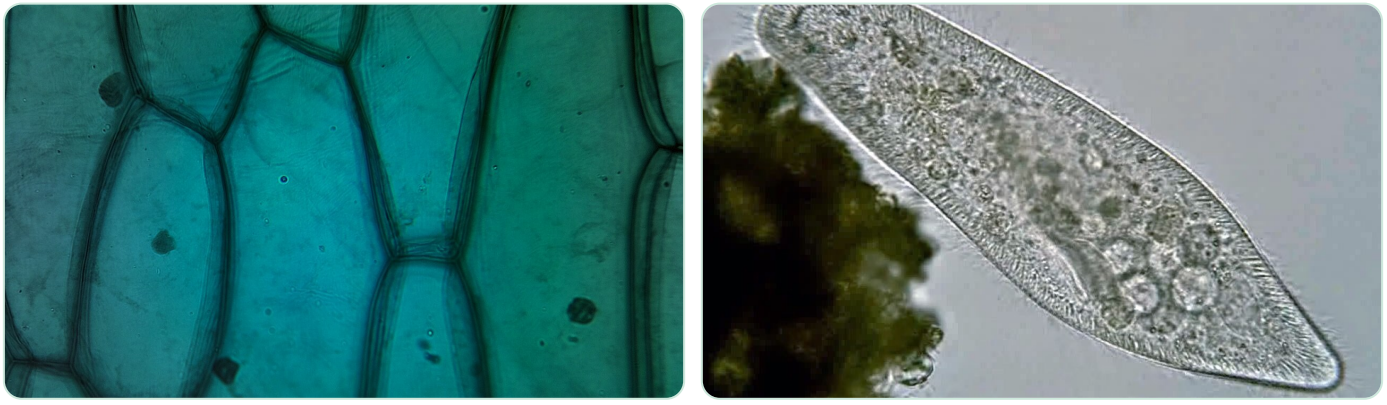


Fig. 1.5 The parts of a plant cell. The large central vacuole pushes the cytoplasm into a thin layer against the wall.



Onion peel cells | Paramecium

Fig. 1.6 Under a school microscope: brick-like onion cells with clear walls, and a single-celled Paramecium, a complete organism in one cell.

FEATURE	PLANT CELL	ANIMAL CELL
Cell wall	Present, made of cellulose	Absent
Plasma membrane	Present, inside the wall	Present; it is the outer boundary
Plastids	Present (chloroplasts, chromoplasts, leucoplasts)	Absent
Vacuole	Usually one large central vacuole (up to about 90% of the volume)	Small and often many, or absent

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FEATURE	PLANT CELL	ANIMAL CELL
Centrioles	Absent in most higher plants	Present
Lysosomes	Rare; the vacuole does much of their work	Common
Stored food	Starch	Glycogen
Shape	Fixed, often rectangular	Flexible, often rounded
Cytokinesis (division of cytoplasm)	By a cell plate built from the centre	By a furrow pinching in from outside

03 The Plasma Membrane and the Cell Wall

The Plasma Membrane

The **plasma membrane** (cell membrane) is the outermost covering of an animal cell and lies just inside the wall in a plant cell. It is so thin that it can be seen properly only with an electron microscope. It separates the cell's contents from the outside and decides what enters and leaves.

The membrane is made mainly of **lipids** (chiefly phospholipids, plus cholesterol in animal cells) and **proteins**, with some carbohydrates attached to them on the outer surface. In the human red blood cell membrane, proteins make up about 52% and lipids about 40%. Each phospholipid has a water-loving (hydrophilic) head and two water-fearing (hydrophobic) fatty-acid tails. In water they line up in two layers, heads facing outwards and tails hidden inside: the **lipid bilayer**.

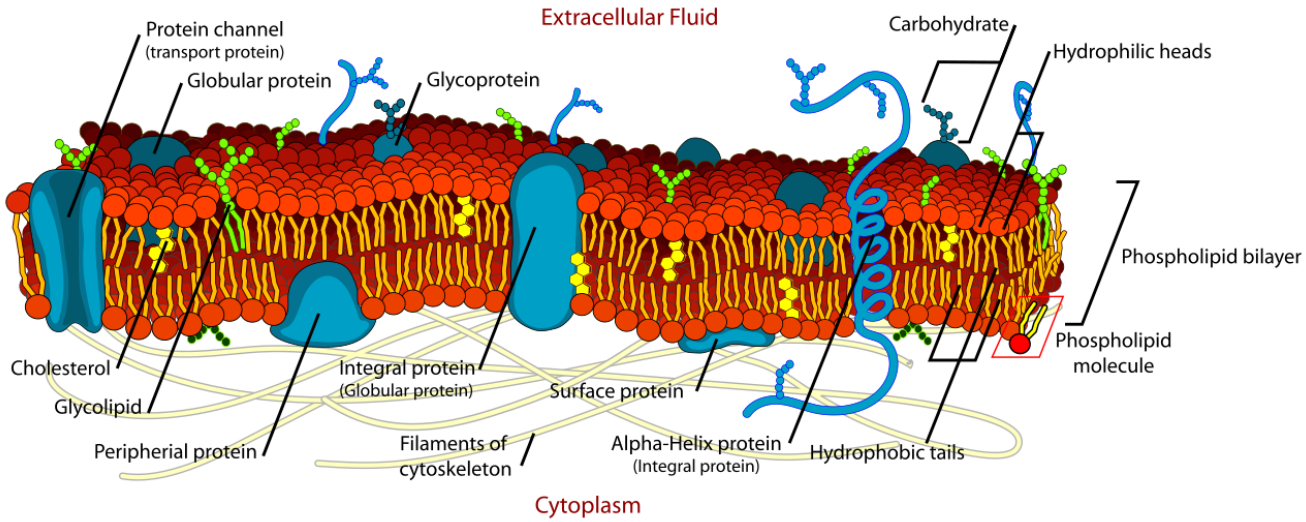


Fig. 1.7 The fluid mosaic model. The lipids and many proteins can move sideways within the layer, which is why the membrane is called "fluid".

The accepted picture of the membrane is the **fluid mosaic model** of **S.J. Singer and G.L. Nicolson (1972)**. Proteins are scattered through the lipid bilayer like a mosaic, and the whole sheet behaves like a thick fluid rather than a rigid wall:

- **Integral proteins** pass through the bilayer and act as channels and carriers; **peripheral proteins** sit on one surface.

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- Sugar chains attached to proteins (**glycoproteins**) and lipids (**glycolipids**) act as identity tags. They let cells recognise one another, and the ABO blood group antigens on red blood cells are of this kind.
- The fluidity lets the membrane bend, heal small tears, fuse with vesicles, and let the cell divide, grow and engulf food.

The plasma membrane is **selectively permeable**: it lets some substances through freely (water, oxygen, carbon dioxide), lets others through only with help, and keeps out most large molecules.

The Cell Wall

Plants, fungi, most bacteria and many algae have a non-living, rigid **cell wall** outside the plasma membrane. It gives the cell its shape, protects it, and stops it from bursting when it takes in water.

ORGANISM	MAIN MATERIAL OF THE CELL WALL
Plants	Cellulose, with hemicellulose, pectin and proteins; woody cells add lignin
Fungi	Chitin (the same material as in insect shells)
Bacteria	Peptidoglycan (murein)
Algae	Cellulose, galactans, mannans and minerals such as calcium carbonate; silica in diatoms
Animals	No cell wall

A young plant cell first lays down a thin **primary wall** that can stretch as the cell grows. Mature cells often add a thicker **secondary wall** on the inside. Neighbouring plant cells are glued together by the **middle lamella**, made mainly of **calcium pectate**; when fruits ripen, enzymes dissolve it, which is why ripe fruit turns soft. Fine strands of cytoplasm called **plasmodesmata** pass through the walls and connect the cytoplasm of neighbouring cells.

PRELIMS FACT **Why antibiotics spare our cells**

Penicillin works by blocking the building of the bacterial peptidoglycan wall. Human cells have no cell wall at all, so the drug harms the bacterium and not the patient. Mycoplasma, which has no wall, is naturally resistant to penicillin.

04 How Substances Cross the Membrane

A living cell must constantly take in food, water, oxygen and salts and throw out carbon dioxide and wastes. This happens in two ways: **passive transport**, which needs no energy from the cell, and **active transport**, which uses energy in the form of ATP.

Diffusion

Diffusion is the natural spreading of a substance from where it is crowded (high concentration) to where it is sparse (low concentration), until it is evenly spread. The smell of incense spreading through a room is

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diffusion. Oxygen and carbon dioxide, which are small and dissolve in lipids, diffuse straight across the bilayer. Gas exchange in the lungs and in plant leaves depends entirely on diffusion.

Some substances such as glucose and ions cannot pass through the lipid layer by themselves. They move down their concentration gradient through special channel or carrier proteins, still without using energy. This is **facilitated diffusion**. Water itself moves quickly through channel proteins called **aquaporins**.

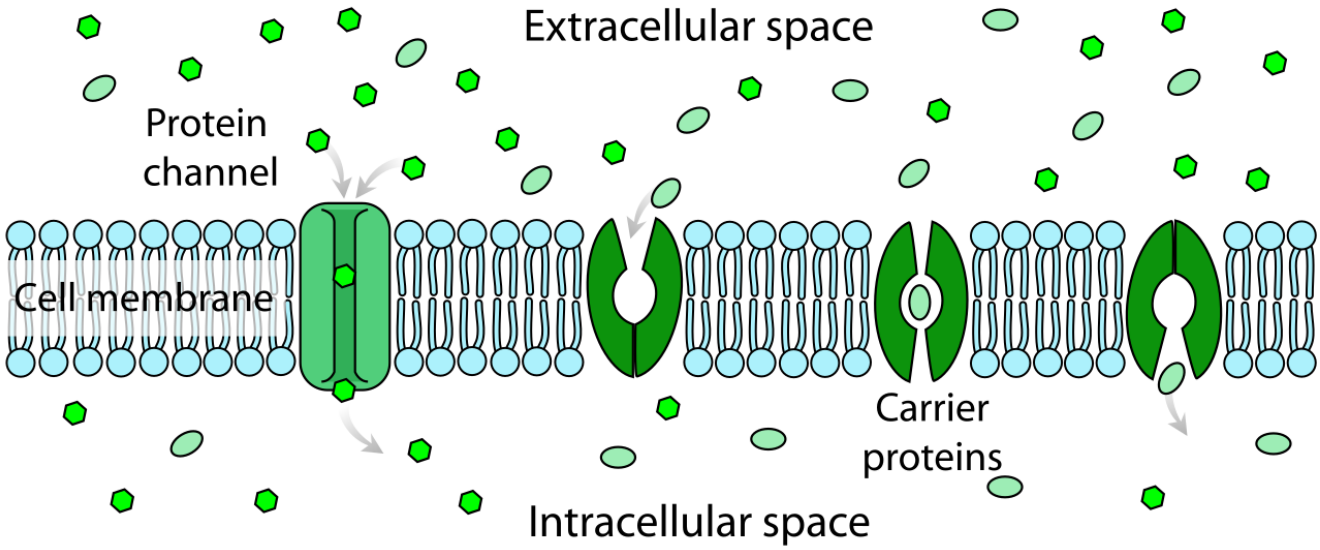


Fig. 1.8 Facilitated diffusion: channel proteins and carrier proteins let ions and sugars cross the membrane down their gradient, without using energy.

Osmosis

Osmosis is the movement of **water** through a selectively permeable membrane from a region of higher water concentration (a dilute solution) to a region of lower water concentration (a concentrated solution). It is a special case of diffusion. The pressure that would have to be applied to stop this flow of water is called **osmotic pressure**.

What happens to a cell depends on the solution around it:

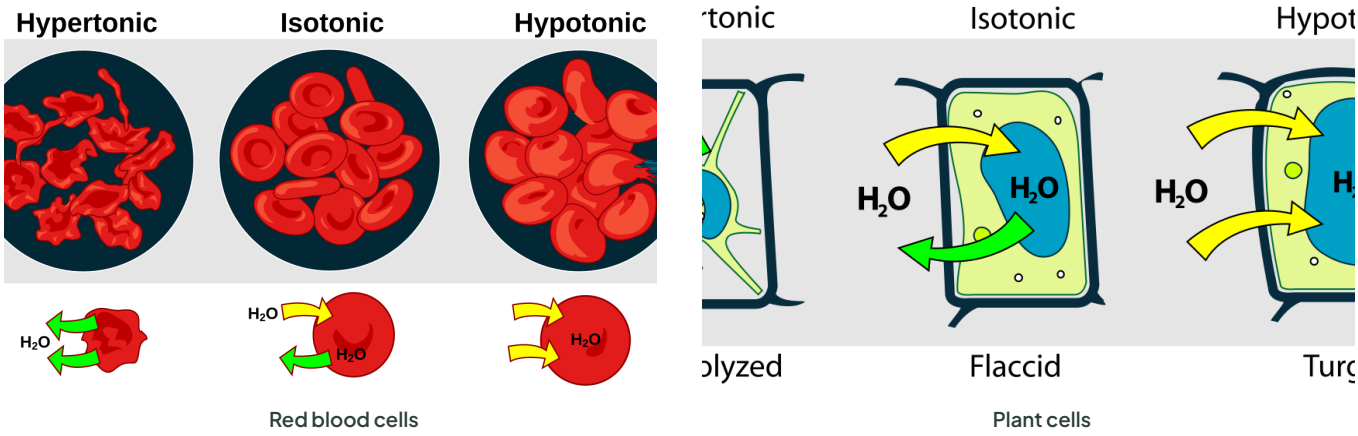


Fig. 1.9 Animal and plant cells in three kinds of solution. The plant cell wall resists the pressure of the swelling cell; this turgor pressure keeps leaves and young stems firm.

- **Hypotonic solution** (outside more dilute than the cell): water enters the cell, which swells. An animal cell, with no wall, may burst; for red blood cells this is called **haemolysis**. A plant cell swells until its contents press hard against the wall and it becomes **turgid**; the wall stops it from bursting.

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- **Isotonic solution** (same concentration): no net movement of water; the cell keeps its shape. A saline drip in hospitals (**0.9% sodium chloride**) is isotonic with blood for this reason.
- **Hypertonic solution** (outside more concentrated): water leaves the cell. Red blood cells shrink and become spiky (**crenation**). In a plant cell the protoplasm shrinks away from the wall: **plasmolysis**.

A plasmolysed cell recovers if it is placed back in water: **deplasmolysis**. Only living cells can be plasmolysed, because a dead cell's membrane is no longer selectively permeable. Osmosis explains many everyday events:

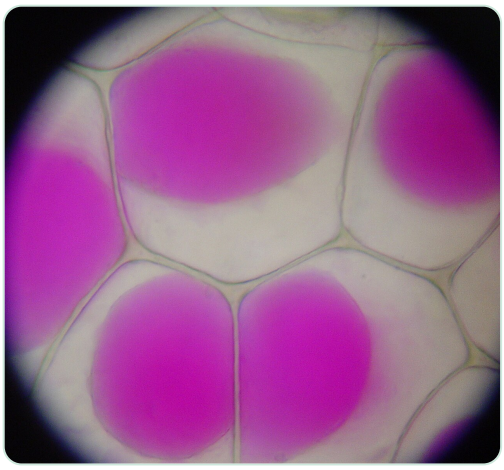


Fig. 1.10 Plasmolysed plant cells: the coloured protoplasm has pulled away from the cell walls in a strong salt solution.

- Plant roots absorb water from the soil by osmosis, because root-hair cells contain more dissolved substances than soil water.
- Too much fertiliser near the roots makes the soil solution hypertonic, so water leaves the roots and the plant wilts ("fertiliser burn"). Salinity damages crops in the same way.
- Salting and sugaring preserve food (pickles, jams): any bacteria or fungi that land on it lose water by osmosis and cannot grow.
- Raisins swell when soaked in water; vegetables kept in salt water shrivel.
- Freshwater single-celled organisms such as *Amoeba* and *Paramecium* constantly gain water by osmosis and pump it out with a **contractile vacuole**.

CONCEPT **Reverse osmosis: how an RO water purifier works**

If pressure greater than the osmotic pressure is applied on the concentrated side, water is forced to flow the other way: from the concentrated solution, through the membrane, to the dilute side. This is **reverse osmosis** (RO). Household RO purifiers and seawater desalination plants push water through a very fine membrane that holds back dissolved salts, heavy metals such as arsenic and lead, and most microbes. The cost: a large share of the water is rejected as brine, and useful minerals such as calcium and magnesium are removed too, which is why many purifiers add minerals back.

Active Transport

Cells often need to collect substances against the gradient: from where they are scarce to where they are already plentiful. This uphill movement uses **carrier proteins called pumps** and costs energy in the form of **ATP**. Examples:

- The **sodium–potassium pump** in animal cells pushes **3 sodium ions out** and brings **2 potassium ions in** for every ATP used. It keeps the inside of the cell rich in potassium and makes nerve impulses possible (Chapter 18).
- Root cells take in mineral ions from the soil even when the soil has fewer of them than the root.
- The cells lining the small intestine absorb glucose and amino acids actively.

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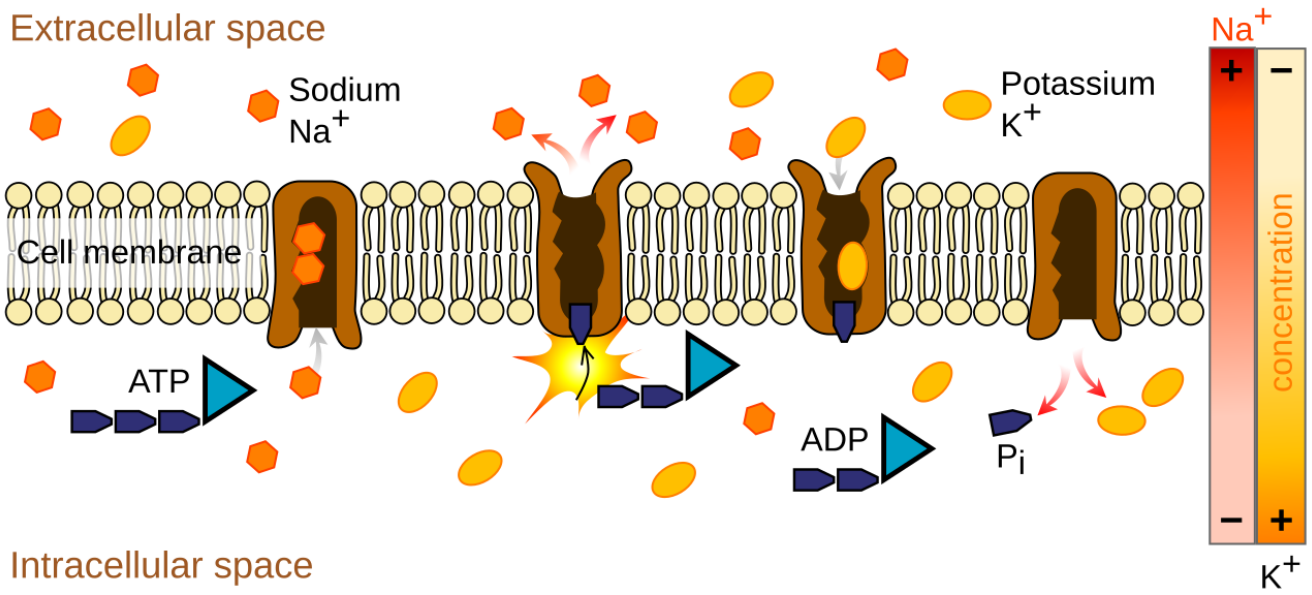


Fig. 1.11 The sodium–potassium pump: each cycle uses one ATP to push three Na^+ ions out and bring two K^+ ions in.

Moving Bulk Material: Endocytosis and Exocytosis

Large particles and droplets are moved in packets wrapped in membrane, which also needs energy.

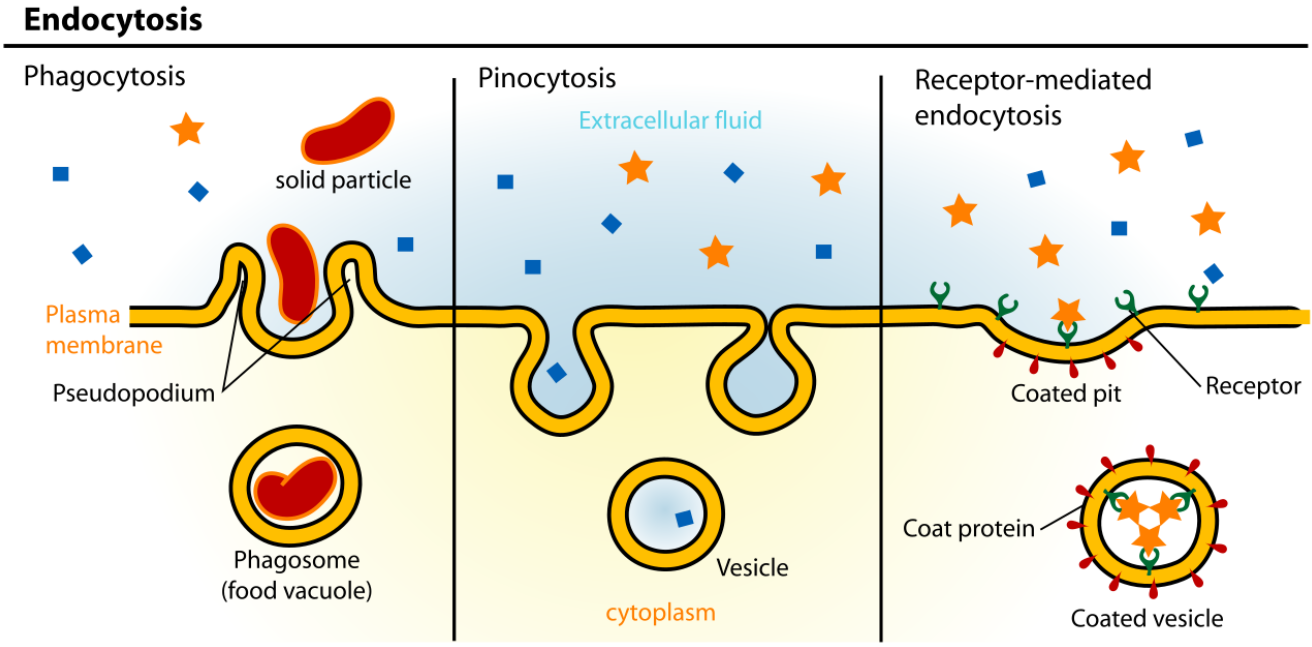


Fig. 1.12 Three kinds of endocytosis: phagocytosis (solid particles), pinocytosis (fluid droplets) and receptor-mediated endocytosis (specific molecules).

- **Endocytosis** (taking in): the membrane folds around the material and pinches off as a vesicle inside the cell. Taking in solid particles is **phagocytosis** ("cell eating"): *Amoeba* feeds this way, and white blood cells swallow bacteria. Taking in droplets of fluid is **pinocytosis** ("cell drinking").
- **Exocytosis** (sending out): a vesicle from inside fuses with the membrane and empties its contents outside. Hormones such as insulin, digestive enzymes, and the chemical messengers released by nerve endings leave cells this way.

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PROCESS	DIRECTION	ENERGY (ATP)?	HELPER PROTEIN?
Simple diffusion	High to low concentration	No	No
Facilitated diffusion	High to low	No	Yes, channel or carrier
Osmosis	Water: dilute to concentrated solution	No	Partly (aquaporins)
Active transport	Low to high (against the gradient)	Yes	Yes, pump
Endocytosis and exocytosis	Bulk, in vesicles	Yes	Membrane itself

05 The Nucleus and the Endomembrane System

The jelly-like material between the plasma membrane and the nucleus is the **cytoplasm**. Its fluid part, the **cytosol**, is mostly water with dissolved salts, sugars, amino acids and enzymes, and it is where many chemical reactions of the cell take place. The organelles float in it. The cytoplasm and the nucleus together make up the **protoplasm**, which the physiologist T.H. Huxley called "the physical basis of life".

The Nucleus: The Control Centre

The **nucleus** is usually the largest and most visible organelle, often spherical and near the centre of an animal cell (pushed to one side by the vacuole in a plant cell). Most cells have one nucleus, but some have none and some have many:

- **No nucleus**: mature mammalian red blood cells and the sieve-tube cells of plant phloem lose their nucleus as they mature.
- **Many nuclei**: skeletal muscle fibres, some fungi and the slime moulds.

Its parts:

- **Nuclear envelope**: a **double membrane** with a narrow space between the two layers. It is pierced by thousands of **nuclear pores** through which RNA and proteins move between the nucleus and the cytoplasm. The outer membrane is continuous with the endoplasmic reticulum.
- **Nucleoplasm**: the fluid inside.
- **Chromatin**: a loose network of threads made of DNA wound around proteins called **histones**. Just before division, the chromatin coils tightly into rod-shaped **chromosomes**, which is why chromosomes are seen only in dividing cells. The working stretches of DNA that code for products are the **genes**; they carry the information for inheritance and for the working of the cell (Chapters 3 and 5).

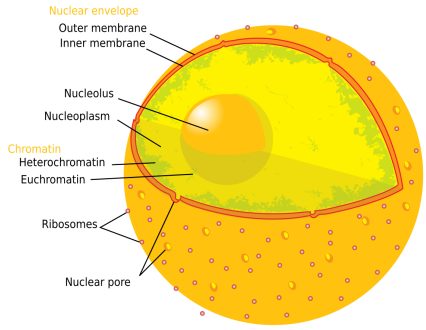


Fig. 1.13 The nucleus: double envelope with pores, chromatin and the nucleolus.

- **Nucleolus** (one or more): a dense, round body with no membrane around it. It makes ribosomal RNA and assembles the subunits of ribosomes, so cells that make a lot of protein have large nucleoli.

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The nucleus has two main roles: it holds the hereditary material that is passed on when the cell divides, and it directs the chemical activities of the cell by deciding which proteins are made. A classic experiment with the large single-celled alga *Acetabularia*, in which nuclei were swapped between species, showed that the shape of the regenerated cap followed the nucleus, not the cytoplasm.

The Endoplasmic Reticulum (ER)

The **endoplasmic reticulum** is a branching maze of membrane-lined tubules and flat sacs running through the cytoplasm and connected to the nuclear envelope. It divides the cytoplasm into compartments and acts as the cell's internal transport system. There are two kinds:

- **Rough ER (RER)**: studded with ribosomes, which give it a rough look under the electron microscope. It makes proteins, especially those meant to be exported from the cell or placed in membranes. It is extensive in cells that secrete proteins, such as the cells of the pancreas that make digestive enzymes.
- **Smooth ER (SER)**: has no ribosomes. It makes **lipids**, including steroid hormones (in the adrenal glands and gonads), and in liver cells it helps to **detoxify** drugs and poisons. In muscle cells a special smooth ER (the sarcoplasmic reticulum) stores the calcium needed for contraction.

The proteins and lipids made by the ER are also used to build new membranes for the cell: **membrane biogenesis**.

Ribosomes: The Protein Factories

Ribosomes are tiny granules of RNA and protein, first described by **George Palade** in the mid-1950s (they were once called "Palade granules"). They are the only organelles found in every cell, prokaryotic or eukaryotic, because every cell needs to make proteins. They have **no** membrane around them. Ribosomes read the instructions carried by messenger RNA and join amino acids into proteins (Chapter 3). Some are free in the cytosol and make proteins used in the cell itself; others are attached to the rough ER. A string of ribosomes working on one mRNA is a **polysome**.

The Golgi Apparatus

Described by the Italian scientist **Camillo Golgi** in **1898**, the **Golgi apparatus** is a stack of flattened, curved membrane sacs (cisternae) with small vesicles around them. In plant cells it is broken up into separate units called **dictyosomes**. It is the cell's packing and dispatch department:

- It receives proteins and lipids from the ER, modifies them (for instance by attaching sugar chains to make glycoproteins), sorts them, and packs them into vesicles for different destinations.
- It sends material out of the cell by exocytosis, which is why it is large in secretory cells.
- It makes some complex sugars from simple sugars; in plant cells it supplies material for the new cell wall during division.
- It forms **lysosomes**.

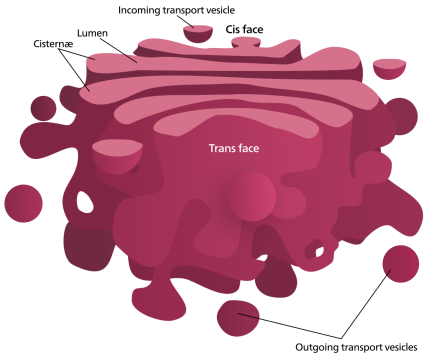


Fig. 1.14 The Golgi apparatus: material enters at the cis face and leaves in vesicles from the trans face.

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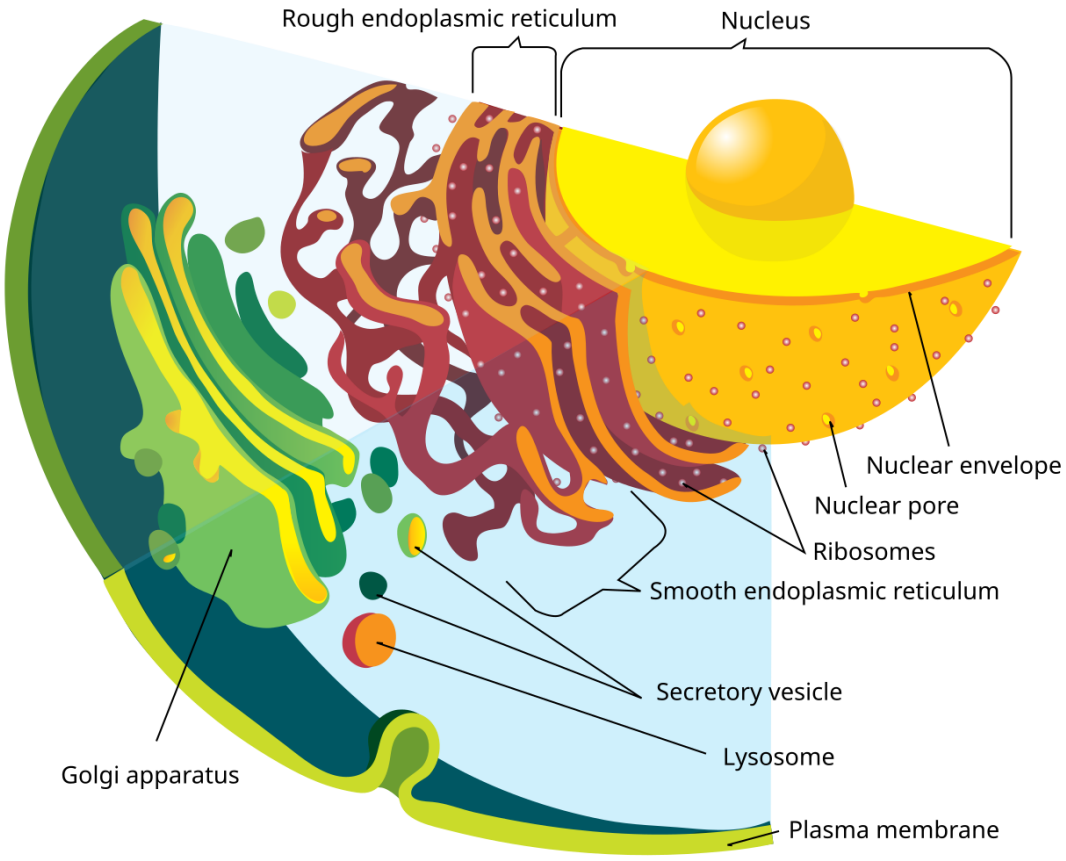


Fig. 1.15 The endomembrane system: nucleus, rough and smooth ER, Golgi apparatus, vesicles and lysosomes work as one connected network.

How a Cell Makes and Exports a Protein

The endomembrane system works like a factory line: instructions, assembly, finishing, packing and dispatch.

1 Nucleus	2 Rough ER	3 Transport vesicle	4 Golgi apparatus	5 Secretory vesicle
DNA → mRNA (instructions)	ribosomes make the protein; it folds inside	carries it onward	modifies (adds sugars), sorts, packs	fuses with membrane: exocytosis

Some Golgi vesicles become lysosomes and stay in the cell; enzymes such as digestive enzymes and hormones such as insulin leave by this route.

Fig. 1.16 The route of a secreted protein through the endomembrane system. The ER, Golgi apparatus, lysosomes and vacuoles work as one coordinated system.

Lysosomes: The Suicide Bags

Lysosomes, discovered by **Christian de Duve** in **1955**, are small, round sacs bounded by a single membrane and filled with powerful **digestive (hydrolytic) enzymes** that can break down almost every organic material: proteins, fats, carbohydrates and nucleic acids. These enzymes work best in acidic conditions (about pH 5), and the inside of the lysosome is kept acidic.

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- They are the cell's waste-disposal system: they digest food brought in by endocytosis, bacteria swallowed by white blood cells, and old, worn-out organelles (a recycling process called **autophagy**, for which Yoshinori Ohsumi received the Nobel Prize in 2016).
- When a cell is badly damaged, its lysosomes may burst and the enzymes digest the cell itself. This is why they are called the **"suicide bags"** of the cell.
- In tadpoles turning into frogs, lysosomes help to absorb the tail.
- Inherited lack of a single lysosomal enzyme leads to **lysosomal storage disorders** such as Tay–Sachs disease and Gaucher disease, in which undigested material piles up in cells.

Vacuoles

Vacuoles are membrane-bound sacs that store water, food, salts and wastes. In a mature plant cell one large **central vacuole**, bounded by a membrane called the **tonoplast**, can fill **50 to 90 per cent** of the cell. It is filled with **cell sap** (water with sugars, amino acids, organic acids, salts and pigments) and pushes the cytoplasm against the wall, keeping the cell **turgid** and firm. The red and purple colour of beetroot and many flowers comes from pigments (anthocyanins) dissolved in the vacuole. Animal cells have only small vacuoles, if any. In protists, **food vacuoles** digest food and **contractile vacuoles** pump out excess water.

Peroxisomes and Glyoxysomes

Peroxisomes are small single-membrane sacs that break down fatty acids and toxic substances. Several of these reactions produce hydrogen peroxide, which is itself harmful, so peroxisomes carry the enzyme **catalase** to break it into water and oxygen. They are plentiful in liver and kidney cells and, in plants, take part in photorespiration. **Glyoxysomes** are a related kind found in germinating oil-rich seeds, where they turn stored fat into sugar for the growing seedling.

06 Mitochondria and Plastids: The Energy Organelles

Mitochondria: The Powerhouses

Mitochondria (singular *mitochondrion*) are rod-shaped or oval organelles, usually 0.5–1 µm wide and a few micrometres long. They carry out **aerobic respiration**: they use oxygen to break down food molecules completely and store the energy released in **ATP (adenosine triphosphate)**. ATP is called the **energy currency** of the cell, because the cell "spends" it on everything from building proteins to contracting muscles and pumping ions. If the mitochondrion is the power station, ATP is the electricity.

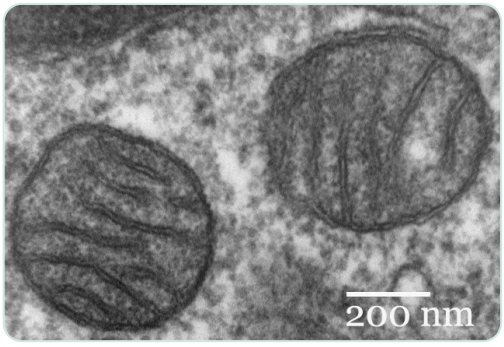
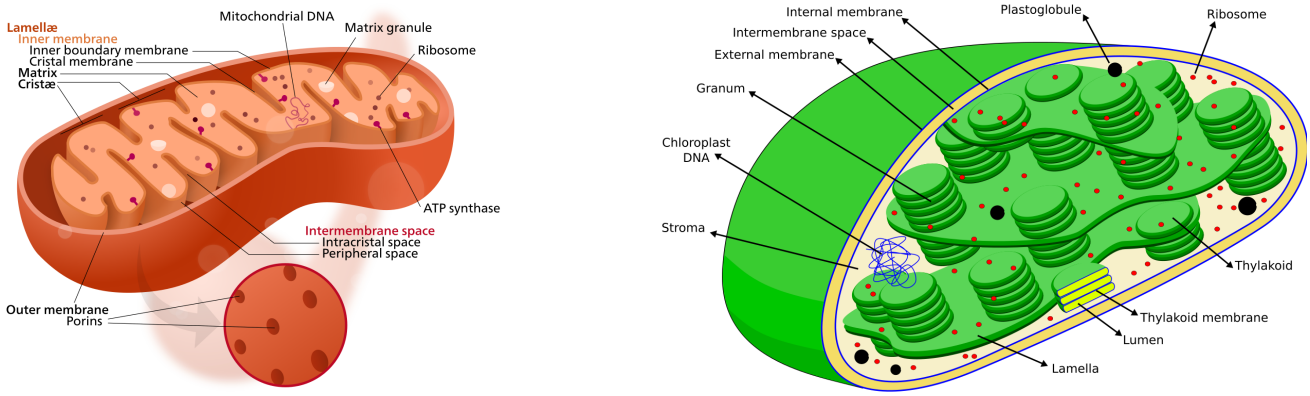


Fig. 1.17 Two mitochondria in a lung cell, seen with a transmission electron microscope. The folded inner membrane (cristae) is clearly visible.

- A mitochondrion has **two membranes**. The outer one is smooth; the inner one is folded into finger-like **cristae**, which give a very large surface for the enzymes that make ATP.
- The space inside the inner membrane is the **matrix**, which contains the enzymes of the Krebs cycle.

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- Mitochondria contain their own **circular DNA** and their own **70S ribosomes**, so they can make some of their own proteins. They also multiply by dividing in two, rather like bacteria.
- Their number reflects the cell's energy needs: heart-muscle and liver cells have hundreds to thousands; mature red blood cells have none.



Mitochondrion Chloroplast

Fig. 1.18 Mitochondrion and chloroplast compared. One releases energy from food; the other traps the energy of sunlight to make food.

IN THE NEWS

Mitochondrial DNA and "three-parent" babies

A baby gets its mitochondria almost only from the **mother's egg**; the sperm's mitochondria are destroyed after fertilisation. So mitochondrial DNA is **inherited through the mother**, and it is used to trace maternal ancestry and human migrations. Human mitochondrial DNA is small, about **16,500 base pairs** carrying 37 genes. Faults in it cause serious inherited mitochondrial diseases. **Mitochondrial replacement therapy** places the nucleus of the mother's egg into a donor egg that has healthy mitochondria, so the child carries DNA from three people. The United Kingdom legalised it in 2015, and in 2025 its doctors reported eight babies born with this method. The genetics of such disorders is taken up in Chapter 6.

Plastids

Plastids are found only in plant cells and some algae. Like mitochondria, they have a double membrane, their own DNA and 70S ribosomes. They are of three kinds:

- **Chloroplasts** (green plastids) contain the green pigment **chlorophyll** along with yellow and orange carotenoids. They are the sites of **photosynthesis** (Chapter 12). Inside, flat membrane sacs called **thylakoids** are stacked like coins into **grana**, which trap light; the surrounding fluid, the **stroma**, contains the enzymes that build sugar.
- **Chromoplasts** (coloured plastids) contain carotenoid pigments that give yellow, orange and red colours to flowers, fruits and roots: carotene in carrots, lycopene in tomatoes, capsanthin in red chillies. Green tomatoes turning red is chloroplasts changing into chromoplasts.
- **Leucoplasts** (white plastids) are colourless and store food: **amyloplasts** store starch (potato tubers), **elaioplasts** store oils and fats, and **aleuroplasts** store proteins.

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CONCEPT **The endosymbiotic theory**

Why do mitochondria and chloroplasts carry their own DNA? The **endosymbiotic theory**, developed by the American biologist Lynn Margulis in the 1960s, holds that they were once free-living bacteria that were swallowed by an ancestral cell about two billion years ago and, instead of being digested, stayed on as partners. Mitochondria came from oxygen-using bacteria and chloroplasts from cyanobacteria. The evidence: both have two membranes, circular DNA like bacteria, 70S ribosomes like bacteria, and divide by splitting in two.

07 The Cytoskeleton, Centrosome, Cilia and Flagella

The cytoplasm is not a shapeless soup. It is criss-crossed by a network of protein fibres, the **cytoskeleton**, which gives the cell its shape, anchors organelles, moves vesicles about and helps the cell move and divide. It has three kinds of fibres: thin **microfilaments** (made of actin), **intermediate filaments**, and hollow **microtubules** (made of tubulin).

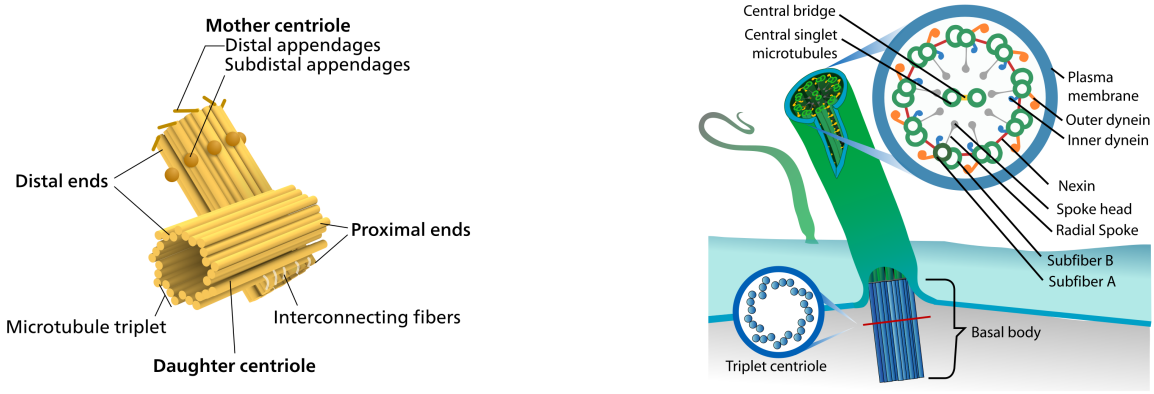


Fig. 1.19 Centrioles are built from nine microtubule triplets; a cilium has the "9 + 2" core of nine doublets around a central pair, growing from a basal body.

- **Centrosome**: found in animal cells near the nucleus. It contains two **centrioles** lying at right angles to each other. Each centriole is a cylinder of nine sets of three microtubules arranged like the spokes of a cartwheel (a "9 + 0" pattern). During cell division the centrosome organises the **spindle** that separates the chromosomes (Chapter 4). Most higher plant cells have no centrioles yet still form a spindle.
- **Cilia** (short and many) and **flagella** (long and few) are hair-like extensions of the cell used for movement. In eukaryotes their core has nine pairs of microtubules around a central pair: the **"9 + 2" arrangement**. Each grows from a **basal body** similar to a centriole. *Paramecium* swims with cilia; sperm cells swim with a flagellum; cilia lining the windpipe sweep mucus and dust out of the airways, which is why smoking, by damaging them, leads to a "smoker's cough".
- Bacterial flagella are built quite differently, from a protein called flagellin, and turn like a propeller.

ORGANELLE	MEMBRANES AROUND IT
Nucleus, mitochondrion, chloroplast	Double membrane

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ORGANELLE	MEMBRANES AROUND IT
ER, Golgi, lysosome, vacuole, peroxisome	Single membrane
Ribosome, centriole, nucleolus, cytoskeleton	No membrane

08 Cells in the News: Stem Cells and Beyond

Stem Cells

Stem cells are unspecialised cells that can do two things other cells cannot: they can divide again and again to renew themselves, and they can turn into (differentiate into) specialised cells such as blood, muscle or nerve cells. They are classified by how many kinds of cell they can form:

- **Totipotent**: can form every cell of the body and the placenta. The fertilised egg (zygote) and the cells of the first few divisions are totipotent.
- **Pluripotent**: can form any cell of the body, but not the placenta. **Embryonic stem cells**, taken from the inner cell mass of an early embryo (blastocyst), are pluripotent.
- **Multipotent**: can form a limited family of related cells. **Adult stem cells** are of this kind; for example, the haematopoietic stem cells of the bone marrow form all the types of blood cell. Umbilical-cord blood is another rich source of blood-forming stem cells.
- **Induced pluripotent stem cells (iPSCs)**: ordinary adult cells, such as skin cells, reprogrammed back to a pluripotent state by switching on a handful of genes. **Shinya Yamanaka** did this with mouse cells in 2006, and shared the 2012 Nobel Prize in Physiology or Medicine with John Gurdon. iPSCs avoid the ethical problem of destroying embryos, and a patient's own iPSCs are not rejected by the immune system.

Plants have stem cells too: the **meristems** at the tips of roots and shoots keep dividing throughout the plant's life (Chapter 11).

Uses of stem cells include replacing damaged tissue (regenerative medicine), testing new drugs on lab-grown human tissue, and studying how diseases develop. In India, the **National Guidelines for Stem Cell Research (2017)** of the ICMR and the Department of Biotechnology allow stem-cell treatment as a standard therapy only for blood disorders treated by **haematopoietic stem-cell (bone-marrow) transplantation**, such as leukaemia and thalassaemia. Any other use must be done only as an approved clinical trial, and the commercial sale of unproven "stem-cell therapy" is not allowed.

COMMON CONFUSION **Stem cells are not only from embryos or from mammals**

Adult tissues (bone marrow, fat, cord blood) are a major source, reprogrammed skin cells give iPSCs, and plants have their own stem cells in meristems. Statements that limit stem cells to embryos or to mammals are false.

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Other Cell Topics in the News

- **HeLa cells**: the first human cells to keep growing indefinitely in the laboratory, taken in 1951 from the cervical cancer of Henrietta Lacks, an American woman, without her consent. They were used to develop the polio vaccine and in thousands of studies, and raised lasting questions about consent and the ownership of human tissue.
- **Synthetic cells**: in 2010 the J. Craig Venter Institute put a chemically made genome into a bacterial cell ("Synthia"); in 2016 it built a bacterium with a minimal genome of only **473 genes**, to find the smallest set of genes needed for life.
- **Organoids**: tiny, simplified organs (mini-brains, mini-guts, mini-kidneys) grown from stem cells in the laboratory, used to study disease and test drugs without animals.

09 Quick Revision Table

ORGANELLE OR PART	MAIN JOB	POINT TO REMEMBER
Plasma membrane	Controls entry and exit	Fluid mosaic model (Singer and Nicolson, 1972); selectively permeable
Cell wall	Shape, support, protection	Cellulose in plants, chitin in fungi, peptidoglycan in bacteria; none in animals
Nucleus	Heredity and control	Double membrane with pores; Robert Brown (1831)
Nucleolus	Makes rRNA and ribosome subunits	No membrane
Rough ER	Makes proteins for export and membranes	Carries ribosomes
Smooth ER	Makes lipids and steroids; detoxifies	Large in liver cells
Ribosome	Protein synthesis	No membrane; 70S in prokaryotes, 80S in eukaryotes; in every cell
Golgi apparatus	Modifies, packs and secretes	Camillo Golgi (1898); dictyosomes in plants; forms lysosomes
Lysosome	Intracellular digestion	"Suicide bags"; de Duve (1955)
Vacuole	Storage, turgidity	Large central vacuole in plants; tonoplast membrane
Peroxisome	Breaks down hydrogen peroxide and fatty acids	Contains catalase
Mitochondrion	Aerobic respiration, ATP	"Powerhouse"; own DNA and 70S ribosomes; maternally inherited
Chloroplast	Photosynthesis	Grana and stroma; own DNA; only in plants and algae
Chromoplast and leucoplast	Colour; storage	Lycopene in tomato; amyloplasts store starch

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ORGANELLE OR PART	MAIN JOB	POINT TO REMEMBER
Centrosome	Forms spindle in animal cells	Two centrioles, 9 + 0 triplets; absent in most higher plants
Cilia and flagella	Movement	9 + 2 microtubules in eukaryotes

Previous Year Questions

2020 Which of the following statements are correct regarding the general difference between plant and animal cells ?
1. Plant cells have cellulose cell walls whilst animal cells do not.
2. Plant cells do not have plasma membrane unlike animal cells which do.
3. Mature plant cell has one large vacuole whilst animal cell has many small vacuoles.
Select the correct answer using the code given below :

a 1 and 2 only | b 2 and 3 only | **c 1 and 3 only** | d 1, 2 and 3

Answer: (c). Both plant and animal cells have a plasma membrane; the cellulose wall and the single large central vacuole are the plant-cell features (Sections 02 and 05).

2012 With reference to 'stem cells', frequently in the news, which of the following statements is/ are correct?
1. Stem cells can be derived from mammals only.
2. Stem cells can be used for screening new drugs.
3. Stem cells can be used for medical therapies.
Select the correct answer using the codes given below :

a 1 and 2 only | **b 2 and 3 only** | c 3 only | d 1, 2 and 3

Answer: (b). Stem cells occur in plants too (meristems), so statement 1 is wrong; they are used both to screen drugs and in therapy (Section 08).

2001 Which organelle in the cell, other than nucleus, contains DNA?

a Centriole | b Golgi apparatus | c Lysosome | **d Mitochondrion**

Answer: (d). Mitochondria (and chloroplasts in plants) carry their own circular DNA and ribosomes (Section 06).

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2001 Which of the following cell organelles play the most significant role in protein synthesis?

a Lysosome and Centrosome

b **Endoplasmic reticulum and Ribosome**

c Golgi apparatus and Mitochondria

d Lysosome and Mitochondria

Answer: (b). Ribosomes assemble proteins and the rough ER carries ribosomes and channels the new proteins (Section 05).

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UNIT VI
5 CHAPTERS

Health and Disease

Immunity and vaccines, infectious diseases from bacteria to emerging viruses, antimicrobial resistance, non-communicable diseases, cancer and substance abuse, and microbes in human welfare.

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TOPICS COVERED IN THIS UNIT

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Immunity and Innate Defences · The Immune System and Acquired Immunity · Active and Passive Immunity · Vaccines and Immunisation · Disorders of the Immune System and Antibody Therapies · HIV and AIDS · Quick Revision Table

21 Infectious Diseases I: Bacteria, Protozoa, Fungi and Worms
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GENERAL BIOLOGY
PRELIMS · GS PAPER II & III

Immunity and the Immune System

Every day we breathe in, swallow and touch countless bacteria, viruses and fungi, yet we fall ill only occasionally. The body's defence force, the **immune system**, recognises invaders, destroys them and often remembers them for life. This memory is what vaccines exploit, and its failures explain allergies, autoimmune diseases, transplant rejection and AIDS.

This chapter covers innate and acquired immunity, antibodies and the cells and organs of the immune system, active and passive immunity, vaccines and India's immunisation programme, disorders of immunity and new antibody-based therapies, and HIV/AIDS.

SYLLABUS

PRELIMS — General Science

MAINS · GS PAPER II & III — **Issues relating to development and management of Social Sector/ Services relating to Health · Science and Technology – developments and their applications and effects in everyday life**

CONTENTS

01 Immunity and Innate Defences
02 The Immune System and Acquired Immunity
03 Active and Passive Immunity
04 Vaccines and Immunisation
05 Disorders of the Immune System and Antibody Therapies
06 HIV and AIDS
07 Quick Revision Table
08 Previous Year Questions

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01 Immunity and Innate Defences

Immunity is the body's ability to resist disease-causing organisms (**pathogens**) and their toxins. It is of two broad kinds: **innate immunity**, present from birth and acting against all invaders alike, and **acquired (adaptive) immunity**, developed during life against specific pathogens.

Innate (non-specific) immunity works through several barriers:

- **Physical barriers**: the unbroken **skin**, and the **mucus** lining the airways, gut and urinogenital tract, which traps microbes; cilia sweep the mucus out of the airways.
- **Physiological barriers**: **acid in the stomach**, saliva and **tears** (which contain the bacteria-killing enzyme **lysozyme**), and the slightly acidic skin surface.
- **Cellular barriers**: white blood cells that engulf and digest microbes (**phagocytosis**), namely **neutrophils**, **monocytes** and tissue **macrophages**, and **natural killer (NK) cells**, which destroy virus-infected and cancer cells.
- **Cytokine barriers**: cells infected by viruses release proteins called **interferons**, which warn neighbouring cells and help them resist the virus.

Inflammation (redness, heat, swelling and pain at the site of injury or infection) is part of innate defence: damaged tissue and mast cells release **histamine**, which widens and leaks blood vessels so that more white cells and fluid reach the spot. **Fever** also helps, by slowing the growth of many microbes. A group of blood proteins, the **complement system**, punches holes in bacteria and marks them for destruction.

02 The Immune System and Acquired Immunity

Lymphoid Organs

The immune system consists of lymphoid organs, white blood cells and molecules such as antibodies and cytokines.

- **Primary lymphoid organs**, where lymphocytes are made and mature:
  - the **bone marrow**, which produces all blood cells, including lymphocytes, in the red marrow of bones such as the long bones, ribs and pelvis; **B cells** mature here;
  - the **thymus**, where **T cells** mature. It is large at birth and shrinks after puberty.
- **Secondary lymphoid organs**, where lymphocytes meet antigens and multiply:
  - the **spleen**, which filters germs from the blood and also destroys old red cells;

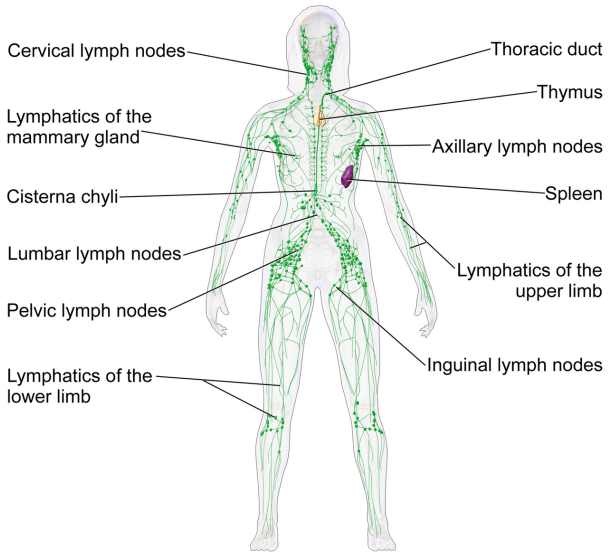


Fig. 20.1 The lymphatic system, with lymph nodes, thymus and spleen.

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- the **lymph nodes**, which filter lymph;
- the tonsils and the **Peyer's patches** of the small intestine;
- the **mucosa-associated lymphoid tissue (MALT)** lining the gut, airways and urinogenital tract, which makes up about half of all lymphoid tissue.

Antigens and Antibodies

An **antigen** is any substance, usually a protein or polysaccharide on the surface of a microbe, toxin or foreign cell, that the body recognises as "non-self" and that **triggers an immune response** and the formation of specific **antibodies**. The immune system normally learns to tolerate the body's own molecules ("self").

Antibodies (immunoglobulins, Ig) are Y-shaped proteins made by **B lymphocytes** (more precisely by their descendants, plasma cells). Each has four polypeptide chains, two long **heavy chains** and two short **light chains**, written H_2L_2. The tips of the "Y" form the antigen-binding sites, which fit one particular antigen like a lock and key. Antibodies neutralise toxins and viruses, clump bacteria together, and mark them for phagocytes and complement. There are five classes:

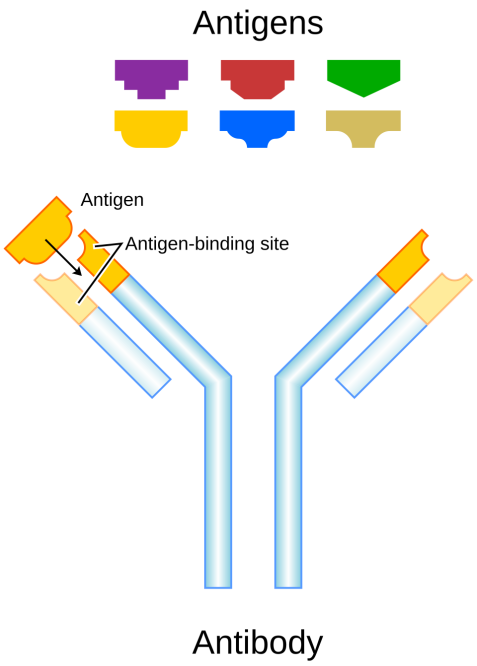


Fig. 20.2 An antibody binds only the antigen whose shape fits its binding sites.

CLASS	KEY FEATURES
IgG	Most abundant in blood (about 75 per cent); the only one that **crosses the placenta**, protecting the newborn; main antibody of the secondary response
IgA	In secretions: tears, saliva, mucus and **breast milk (colostrum)**; guards the gut and airways
IgM	The largest (five Y units joined); **first antibody made** in an infection; its presence signals a recent infection
IgE	Binds to mast cells; causes **allergies**; fights parasitic worms
IgD	On the surface of B cells; helps activate them

Two Arms of Acquired Immunity

- **Humoral (antibody-mediated) immunity**, carried out by **B cells**: when a B cell meets its matching antigen (usually with help from T cells), it multiplies into plasma cells that pour out antibodies into the blood and lymph (the "humours"). It mainly defends against bacteria and toxins in body fluids.

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- **Cell-mediated immunity (CMI)**, carried out by **T cells**:
  - **Helper T cells (CD4 cells)** act as the "commanders", releasing cytokines that activate B cells, killer T cells and macrophages;
  - **cytotoxic (killer) T cells** directly destroy body cells infected by viruses, and cancer cells;
  - regulatory T cells calm the response once the threat is over.

  Cell-mediated immunity is also responsible for **rejecting transplanted organs**.

Two features distinguish acquired immunity: **specificity**, since each B and T cell recognises one antigen, and **memory**. On first contact with a pathogen, the **primary response** is slow and weak. Some B and T cells then remain as long-lived **memory cells**, so that a second encounter brings a much faster and stronger **secondary response**, often stopping the infection before symptoms appear. This is why people rarely get measles or chickenpox twice, and why vaccines work.

CONCEPT **Why transplanted organs are rejected**

Every person's cells carry a set of surface proteins, the **human leucocyte antigens (HLA)** or major histocompatibility complex, that mark them as "self". T cells attack a donated organ whose HLA differs. So doctors match blood groups and HLA (tissue typing), prefer related donors, and give patients **immunosuppressant drugs** such as cyclosporine for life, which in turn increases their risk of infections. Pig organs gene-edited to be less likely to be rejected have been transplanted into a few patients since 2022 (xenotransplantation).

03 Active and Passive Immunity

- **Active immunity**: the body makes its own antibodies and memory cells after exposure to an antigen. It develops slowly (one to two weeks) but lasts long, often for life.
  - Natural active: after recovering from an infection.
  - Artificial active: after **vaccination**.
- **Passive immunity**: **ready-made antibodies** are received from outside. It acts immediately but is short-lived (weeks to months), because no memory cells are formed.
  - Natural passive: IgG antibodies crossing the **placenta** from mother to foetus, and IgA in **colostrum** and breast milk (Chapter 19).
  - Artificial passive: injection of preformed antibodies, used when protection is needed at once, as with **anti-tetanus serum**, **anti-rabies immunoglobulin** for severe dog bites, anti-diphtheria serum, and **antivenom** for snakebite. Antivenoms in India are made by injecting small doses of venom from the "Big Four" snakes (cobra, common krait, Russell's viper and saw-scaled viper) into horses and purifying the antibodies from their blood. Monoclonal antibodies (Section 05) also give passive protection.

When a large enough share of a population is immune, a pathogen cannot spread easily, so even those who are not immune (newborns, the very sick) are protected: **herd immunity**. The share needed depends on how contagious the disease is, about 95 per cent for measles.

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04 Vaccines and Immunisation

A **vaccine** is a preparation of a killed or weakened pathogen, or of some of its antigens, that trains the immune system without causing the disease, producing memory cells and antibodies. In 1796 the English doctor **Edward Jenner** showed that material from cowpox sores protected people against smallpox; the word vaccine comes from *vacca*, Latin for cow. Louis Pasteur later made vaccines against chicken cholera, anthrax and rabies (1885). Smallpox became the first human disease to be eradicated worldwide (declared in **1980**).

TYPE	WHAT IT CONTAINS	EXAMPLES
Live attenuated	Weakened live pathogen; strong, long immunity; not for people with weak immunity	BCG (tuberculosis), oral polio vaccine, measles-rubella, rotavirus, yellow fever, chickenpox
Inactivated (killed)	Whole pathogen killed by heat or chemicals; often needs boosters	Injectable polio (IPV), rabies, hepatitis A, Covaxin
Toxoid	Inactivated bacterial toxin	Tetanus, diphtheria
Subunit / recombinant	A purified antigen, often made by genetically engineered yeast or bacteria	Hepatitis B (from yeast), HPV, acellular pertussis, Covovax
Conjugate	A weak sugar antigen joined to a carrier protein so infants respond to it	Hib, pneumococcal (PCV), typhoid conjugate, meningococcal
Viral vector	A harmless virus engineered to carry a gene for the pathogen's antigen	Covishield (chimpanzee adenovirus), Sputnik V (human adenovirus), Ebola vaccine
Nucleic acid	mRNA or DNA instructions; body cells make the antigen	mRNA: Pfizer-BioNTech, Moderna, India's Gennova vaccine; DNA: ZyCoV-D

mRNA vaccines, whose underlying research won **Katalin Karikó** and Drew Weissman the 2023 Nobel Prize in Medicine, can be designed and made very quickly but need very cold storage. India's **ZyCoV-D** (Zydus, 2021) was the world's first DNA vaccine approved for humans, given without a needle; Bharat Biotech's **iNCOVACC** (2022) was the world's first intranasal COVID-19 vaccine approved for primary doses. **Recombinant vector vaccines** use genetic engineering to insert an antigen's gene into a harmless virus or bacterium.

India's Universal Immunisation Programme

India's **Universal Immunisation Programme (UIP)**, begun in 1985, is among the largest in the world, giving free vaccines to about 2.6 crore newborns and 2.9 crore pregnant women every year. It protects against **12 diseases**:

- diphtheria, pertussis (whooping cough) and tetanus;
- polio, measles and rubella;
- severe childhood tuberculosis and hepatitis B;
- meningitis and pneumonia due to *Haemophilus influenzae* type b;
- rotavirus diarrhoea and pneumococcal pneumonia;
- Japanese encephalitis, in endemic districts.

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Mission Indradhanush (2014) and its intensified rounds target children missed by routine immunisation. The **eVIN** system tracks vaccine stocks and cold-chain temperatures, and the **U-WIN** portal digitally records every vaccination. India was certified **polio-free in 2014** and eliminated maternal and neonatal tetanus in 2015.

> IN THE NEWS **HPV vaccination campaign, 2026**
>
> On **28 February 2026** India launched a nationwide campaign of free, single-dose **HPV vaccination for girls aged 14** (about 1.2 crore girls a year) to prevent **cervical cancer**, the second most common cancer among Indian women. The programme uses the quadrivalent Gardasil-4 vaccine, protecting against HPV types 16 and 18 (which cause most cervical cancers) and 6 and 11; India's own vaccine, Cervavac by the Serum Institute, was approved in 2022. By September 2026 over 80 lakh doses had been given, with registration on U-WIN.

05 Disorders of the Immune System and Antibody Therapies

Allergy

An **allergy** is an exaggerated immune response to a harmless substance (an **allergen**), such as pollen (including *Parthenium*, Chapter 13), house-dust mites, animal dander, mould spores, certain foods (peanuts, shellfish, milk, eggs) or drugs (penicillin). The body makes **IgE** antibodies, which attach to **mast cells**; on later exposure the mast cells release **histamine** and serotonin, causing sneezing, a runny nose, watery eyes, itching, rashes and wheezing (**asthma**). A severe whole-body reaction, **anaphylaxis**, can close the airways and drop blood pressure and needs an immediate injection of **adrenaline**. Allergies are treated with **antihistamines**, steroids and avoiding the allergen. They are rising in cities; one explanation, the "hygiene hypothesis", is that too little exposure to microbes in early childhood leaves the immune system poorly trained.

Autoimmune Diseases

Sometimes the immune system fails to recognise the body's own cells as "self" and attacks them, causing **autoimmune diseases**:

- **rheumatoid arthritis** (joints);
- **type 1 diabetes** (insulin-making beta cells, Chapter 18);
- **multiple sclerosis** (myelin);
- systemic lupus erythematosus (many organs);
- psoriasis (skin);
- Graves' disease and Hashimoto's thyroiditis (thyroid);
- myasthenia gravis (nerve-muscle junction);
- **coeliac disease** (gut lining, triggered by gluten).

Many are more common in women.

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Immunodeficiency

When part of the immune system is missing or weakened, ordinary infections become dangerous. It may be inherited, as in **severe combined immunodeficiency (SCID)**, the "bubble boy" disease; one form, adenosine deaminase deficiency, was the first disease treated by gene therapy, in 1990 (Chapter 26). More often it is **acquired**: through HIV infection, malnutrition, cancer treatment, immunosuppressant drugs or old age.

Monoclonal Antibodies and Immunotherapy

Antibodies from one clone of B cells, all identical and binding a single target, are **monoclonal antibodies (mAbs)**. In 1975 **Georges Köhler** and César Milstein fused antibody-making B cells with fast-dividing cancer (myeloma) cells to create **hybridomas**, "immortal" cells that make one antibody indefinitely; they shared the 1984 Nobel Prize. Today most mAbs are made by genetically engineered cells. These man-made proteins bind specific antigens and are used:

- in **cancer** treatment, such as trastuzumab for some breast cancers;
- for **autoimmune diseases**, such as rheumatoid arthritis;
- against **viral infections**: m102.4 was used against the Nipah virus in Kerala, and mAb cocktails were used against COVID-19;
- in **diagnosis**: pregnancy tests and rapid kits.

Their drawback is high cost. **Immunotherapy** harnesses the immune system against cancer. In **CAR-T cell therapy**, a patient's own T cells are genetically modified to recognise and kill cancer cells; India's first indigenous CAR-T therapy, **NexCAR19** (developed by IIT Bombay and Tata Memorial Centre), was approved in 2023 for certain blood cancers at a fraction of the cost abroad. Over-reaction of the immune system can also kill: a **cytokine storm**, a flood of inflammatory signals, caused many deaths in severe COVID-19.

06 HIV and AIDS

AIDS (Acquired Immuno Deficiency Syndrome) is a set of illnesses caused by the **human immunodeficiency virus (HIV)**. It is "acquired" during life, not inherited. AIDS was first reported in the USA in 1981; HIV was identified in 1983. India's first case was detected in Chennai in 1986.

The Virus and How It Spreads

HIV is a **retrovirus**: an enveloped virus with an **RNA** genome and the enzyme **reverse transcriptase**, which copies its RNA into DNA. That DNA is then inserted into the host cell's own DNA. Its main target is the **helper T cell (CD4 cell)**, as well as macrophages, which act as a factory for the virus. As the virus multiplies, the number of helper T cells falls steadily, and the whole immune system, which depends on them, collapses.

HIV spreads through:

- unprotected **sexual contact** with an infected person (the commonest route);
- **transfusion of infected blood**;
- **shared needles and syringes**, as among injecting drug users;
- from an infected **mother to her child** during pregnancy, delivery or breastfeeding.

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It does **not** spread by touching, hugging, shaking hands, sharing food or utensils, coughing, swimming pools or mosquito bites.

Course and Symptoms

After infection there may be a brief flu-like illness, followed by years (often 5–10) without symptoms while the virus quietly destroys CD4 cells. When the CD4 count falls very low, AIDS sets in, and the person suffers **opportunistic infections** that a healthy immune system would control, such as tuberculosis, a fungal pneumonia (*Pneumocystis*), oral thrush (*Candida*), toxoplasmosis and certain cancers (Kaposi's sarcoma). Symptoms include **swollen lymph nodes**, **night sweats**, fever, chronic diarrhoea, **weight loss** and, when the brain is affected, **loss of memory** and dementia. **Tuberculosis** is the commonest cause of death among people with HIV in India.

Diagnosis, Treatment and Prevention

- **Diagnosis**: antibodies to HIV are detected by rapid tests and **ELISA** (enzyme-linked immunosorbent assay); viral RNA by **PCR**, especially in infants.
- **Treatment**: there is no cure or vaccine yet. **Antiretroviral therapy (ART)**, a combination of drugs that block reverse transcriptase and other viral steps, keeps the virus suppressed so that infected people can live near-normal lives; a person with an undetectable viral load does not transmit HIV sexually. ART is provided free in India.
- **Prevention**: condom use, screening all donated blood, sterile needles, testing pregnant women, ART during pregnancy to prevent mother-to-child transmission, pre-exposure medicines (PrEP) for high-risk people, and awareness.

INDIA

HIV response

India has about 25 lakh people living with HIV, the third-largest number in the world, though adult prevalence is low (about 0.2 per cent) and new infections have fallen sharply since 2010. The **National AIDS Control Organisation (NACO)** runs the National AIDS and STD Control Programme, now in its fifth phase (2021–26). The **HIV and AIDS (Prevention and Control) Act, 2017** bans discrimination against people with HIV in jobs, education, healthcare and housing, and guarantees confidentiality. India's cheap generic antiretroviral drugs supply much of the developing world. The global target is "95-95-95" by 2025: 95 per cent of people with HIV knowing their status, 95 per cent of them on treatment, and 95 per cent of those having suppressed virus. World AIDS Day is **1 December**; the red ribbon is its symbol.

07 Quick Revision Table

TOPIC	KEY FACT
Innate immunity	From birth, non-specific: skin, mucus, stomach acid, lysozyme, phagocytes, NK cells, interferons

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TOPIC	KEY FACT
Interferons	Proteins from virus-infected cells that protect neighbouring cells
Primary lymphoid organs	Bone marrow (B cells mature) and thymus (T cells mature)
Secondary lymphoid organs	Spleen, lymph nodes, tonsils, Peyer's patches, MALT
Antigen	Substance that triggers an immune response and antibody formation
Antibody	Y-shaped; H_2L_2; made by B cells (plasma cells)
IgG / IgA / IgM / IgE	Crosses placenta / in colostrum and secretions / first made, largest / allergy
Humoral / cell-mediated	B cells and antibodies / T cells; CMI rejects grafts
Helper T cells	CD4 cells; targeted by HIV
Memory	Secondary response faster and stronger; basis of vaccination
Active / passive	Own antibodies, slow, long-lasting / ready-made antibodies, immediate, short-lived
Natural passive	Placenta (IgG), colostrum (IgA)
Antivenom	Horse antibodies against the "Big Four" snakes
Herd immunity	About 95% immunity needed for measles
Jenner / Pasteur	Smallpox vaccine 1796 / rabies vaccine 1885
Smallpox / polio	Eradicated 1980 / India polio-free 2014
Vaccine types	Live (BCG, OPV), inactivated (IPV, Covaxin), toxoid (tetanus), recombinant (hepatitis B), conjugate (PCV, Hib), vector (Covishield, Sputnik V), mRNA, DNA (ZyCoV-D)
UIP	1985; free vaccines against 12 diseases; Mission Indradhanush; eVIN; U-WIN
HPV campaign	28 Feb 2026; single dose for girls aged 14; cervical cancer
Allergy	IgE, mast cells, histamine; antihistamines; anaphylaxis needs adrenaline
Autoimmune diseases	Rheumatoid arthritis, type 1 diabetes, multiple sclerosis, lupus, psoriasis, coeliac
Monoclonal antibodies	Hybridoma (Köhler and Milstein, 1975); cancer, Nipah, COVID-19, diagnostics
CAR-T	Engineered T cells; India's NexCAR19 (2023)
HIV	Retrovirus; RNA; reverse transcriptase; destroys helper T cells
AIDS symptoms	Swollen lymph nodes, night sweats, weight loss, memory loss; TB commonest killer
HIV tests / treatment	ELISA, PCR / antiretroviral therapy (free in India)

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TOPIC	KEY FACT
HIV law	HIV and AIDS (Prevention and Control) Act, 2017; NACO

Previous Year Questions

2025

With reference to monoclonal antibodies, often mentioned in news, consider the following statements:
I. They are man-made proteins.
II. They stimulate immunological function due to their ability to bind to specific antigens.
III. They are used in treating viral infections like that of Nipah virus.
Which of the statements given above are correct?

a. I and II only
b. II and III only
c. I and III only
d. I, II and III

Answer: (d). Monoclonal antibodies are laboratory-made copies of a single antibody that bind one specific antigen; m102.4 has been used for Nipah, and others for COVID-19, cancers and autoimmune diseases (Section 05).

2022

Which one of the following statements best describes the role of B cells and T cells in the human body?

a. They protect the body from environmental allergens.
b. They alleviate the body's pain and inflammation.
c. They act as immunosuppressants in the body.
d. They protect the body from the diseases caused by pathogens.

Answer: (d). B cells make antibodies and T cells kill infected cells and direct the response; together they give specific (adaptive) immunity against pathogens (Section 02).

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2022 In the context of vaccines manufactured to prevent COVID-19 pandemic, consider the following statements:
1. The Serum Institute of India produced COVID-19 vaccine named Covishield using mRNA platform.
2. Sputnik V vaccine is manufactured using vector based platform.
3. COVAXIN is an inactivated pathogen based vaccine.
Which of the statements given above are correct?

a 1 and 2 only | **b 2 and 3 only** | c 1 and 3 only | d 1, 2 and 3

Answer: (b). Covishield uses a chimpanzee adenovirus vector, not mRNA; Sputnik V uses human adenovirus vectors, and Covaxin is a whole inactivated virus vaccine (Section 04).

2021 With reference to recent developments regarding 'Recombinant Vector Vaccines', consider the following statements:
1. Genetic engineering is applied in the development of these vaccines.
2. Bacteria and viruses are used as vectors.
Which of the statements given above is/are correct?

a 1 only | b 2 only | **c Both 1 and 2** | d Neither 1 nor 2

Answer: (c). A gene for a pathogen's antigen is engineered into a harmless virus or bacterium, which then carries it into the body (Section 04).

2020 What is the importance of using Pneumococcal Conjugate Vaccines in India?
1. These vaccines are effective against pneumonia as well as meningitis and sepsis.
2. Dependence on antibiotics that are not effective against drug-resistant bacteria can be reduced.
3. These vaccines have no side effects and cause no allergic reactions.
Select the correct answer using the code given below:

a 1 only | **b 1 and 2 only** | c 3 only | d 1, 2 and 3

Answer: (b). PCV protects against pneumococcal pneumonia, meningitis and sepsis and so cuts antibiotic use, but like every vaccine it can have side effects (Section 04).

2004 In which organ of the human body are the lymphocyte cells formed?

a Liver | **b Long bone** | c Pancreas | d Spleen

Answer: (b). Lymphocytes, like all blood cells, arise from stem cells in the red bone marrow of bones such as the long bones (Section 02).

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2003 Consider the following conditions of sick human body:

1. Swollen lymph nodes
2. Sweating at night
3. Loss of memory
4. Loss of weight

Which of these are the symptoms of AIDS?

a 1 and 2 | b 2, 3 and 4 | c 1, 2 and 3 | **d 1, 2, 3 and 4**

Answer: (d). Advanced HIV infection causes swollen lymph nodes, night sweats, weight loss and, when the brain is affected, memory loss (Section 06).

2001 Antigen is a substance which:

a Destroys harmful bacteria | b Is used to treat poisoning

c Lowers body-temperature | **d Stimulates formation of antibody**

Answer: (d). An antigen is any molecule the immune system recognises as foreign, which stimulates the formation of specific antibodies (Section 02).

1997 Antigen is a substance which:

a Lowers body temperature | b Destroys harmful bacteria

c Triggers the immune system | d Is used as an antidote to poison

Answer: (c). Antigens, such as proteins on the surface of microbes, trigger an immune response (Section 02).

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