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HIGHLIGHTED HANDOUT

BIO5105

Cell Biology

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BIO5105

Cell Biology

Lecture-Wise Study Handout
Virtual University of Pakistan

13 lectures • prepared for exam study 

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About This Course

Cell biology is the study of the cell — the basic structural and functional unit of all living organisms. Every process of life, from a muscle contracting to a plant capturing sunlight, happens inside or between cells, so understanding cells is understanding life itself.

This handout moves from the discovery of cells and microscopy, through cell chemistry and membranes, to each organelle's structure and function, then to energy, the cell cycle, cell communication and modern cell-biology techniques. Definitions, labelled-structure descriptions, examples and exam pointers accompany every lecture. 

Lecture 1: The Cell Theory and the Discovery of Cells

Learning Objectives

- State the cell theory
- Describe the history of cell discovery

The cell theory — one of biology's great unifying ideas — states three things: all living organisms are composed of cells, the cell is the basic unit of structure and function, and all cells arise from pre-existing cells. Formulated by Schleiden and Schwann in 1838–39 and completed by Virchow's *omnis cellula e cellula* (1855), it ended the idea of spontaneous generation.

The theory rests on microscopy. Robert Hooke (1665) coined the term cell after seeing cork compartments; Antonie van Leeuwenhoek's simple microscopes first revealed living cells — bacteria, protozoa, sperm. Modern light microscopy resolves about 0.2 micrometres; electron microscopy (TEM for internal ultrastructure, SEM for surfaces) reaches nanometres, revealing the organelles this course studies.

Cell biology matters because disease is cellular malfunction: cancer is uncontrolled cell division, cystic fibrosis a faulty membrane channel, mitochondrial disorders are energy failures. Every medical advance traces back to understanding cells — which is why this course underpins all of biotechnology.

Key Definitions

Cell theory is defined as the theory that all organisms consist of cells, the cell is life's basic unit, and all cells come from pre-existing cells

Resolution limit (light microscopy) is defined as the resolving power limit of the light microscope, about 0.2 micrometres

Key Points — very important for exams

Cell theory: all life is cellular; cells are the basic unit; cells come from cells.

Hooke named cells (1665); Leeuwenhoek saw living cells; EM revealed ultrastructure.

Disease = cellular malfunction — cell biology underpins all biotechnology.

Review Questions

- ? Who contributed what to the cell theory?
- ? Compare light and electron microscopy.

Section Summary

Cells were discovered through microscopes and unified by the cell theory — biology's central idea.

Exam Pointers

- State the cell theory and trace the microscopic discoveries behind it.

Lecture 2: Prokaryotic versus Eukaryotic Cells

Learning Objectives

- Compare the two cell types
- Explain size constraints on cells

Cells divide into two great types. Prokaryotic cells (bacteria, archaea) lack a membrane-bound nucleus and organelles: their DNA lies in a nucleoid region, they are typically 0.5–5 micrometres, and they divide by binary fission. Eukaryotic cells (animals, plants, fungi, protists) keep DNA in a true nucleus, contain membrane-bound organelles, are typically 10–100 micrometres, and divide by mitosis/meiosis.

Size constrains design through the surface-area-to-volume ratio: as a cell grows, volume rises faster than surface area, so nutrient uptake and waste removal across the membrane cannot keep up. Cells stay small, or evolve adaptations — long thin nerve cells, folded membranes, the flattened red blood cell — to raise surface area.

Model organisms make cell biology experimental: E. coli (prokaryotic genetics), yeast (eukaryotic cell cycle), and HeLa cells (human cell culture). Very important for exams: the prokaryote/eukaryote comparison table is among the most frequently asked questions in cell biology.

Key Definitions

Prokaryotic cells is defined as cells lacking a membrane-bound nucleus, with DNA in a nucleoid region

Surface-area-to-volume ratio is defined as the geometric constraint forcing cells to stay small or develop high-surface-area shapes

Key Points — very important for exams

Prokaryotes: no nucleus/organelles, nucleoid DNA, small, binary fission.

Eukaryotes: true nucleus, organelles, larger, mitosis/meiosis.

Surface-area-to-volume ratio limits cell size — a favourite exam explanation.

Review Questions

- ? Tabulate six differences between prokaryotes and eukaryotes.
- ? Why can't cells simply grow very large?

Section Summary

Two cell architectures — simple prokaryotic and complex eukaryotic — both obey the geometry of surface and volume.

Exam Pointers

- Compare prokaryotic and eukaryotic cells across six features; explain the surface-area constraint.

Lecture 3: The Chemistry of Cells: Biomolecules

Learning Objectives

- Describe cellular biomolecules
- Explain protein structure and enzyme function

Cells are chemical systems: about 70 percent water, plus macromolecules. Carbohydrates (monosaccharides, polysaccharides like starch, glycogen, cellulose) provide energy and structure; lipids (fats, phospholipids, steroids) store energy and build membranes; proteins (polymers of 20 amino acids) do the work — enzymes, motors, signals; nucleic acids (DNA, RNA) store and transmit information.

Protein structure has four levels: primary (amino acid sequence), secondary (alpha-helices, beta-sheets held by hydrogen bonds), tertiary (3D folding driven by hydrophobic interactions), quaternary (multiple polypeptides, e.g. haemoglobin). Shape determines function — denaturation (by heat or pH) destroys function by unfolding the protein.

Enzymes are protein catalysts: they lower activation energy, are specific (lock-and-key or induced-fit), and are regulated — by temperature, pH, inhibitors and allosteric modulators. Almost every cellular process is enzyme-driven, so enzyme logic (specificity, regulation) reappears throughout this course.

Key Definitions

Protein structure (primary–quaternary) is defined as the four levels of protein organization: sequence, helices/sheets, 3D folding, multi-subunit assembly

Enzymes is defined as biological catalysts, usually proteins, that lower activation energy and are highly specific

Key Points — very important for exams

Four macromolecules: carbohydrates, lipids, proteins, nucleic acids — each with roles.

Protein: primary → secondary → tertiary → quaternary; shape = function; denaturation kills function.

Enzymes: specific catalysts, regulated by conditions and inhibitors.

Review Questions

- ? What happens during denaturation?
- ? How is enzyme specificity explained?

Section Summary

Cells are built of four macromolecule families; proteins do the work, and their shape is their function.

Exam Pointers

- Describe the four biomolecule classes and protein structure levels; explain enzyme action.

Lecture 4: The Plasma Membrane and Transport

Learning Objectives

- Describe membrane structure
- Compare transport mechanisms

The plasma membrane is a phospholipid bilayer with embedded proteins — the fluid mosaic model (Singer and Nicolson, 1972): a fluid lipid sea in which proteins float, carrying out transport, signalling and recognition. Cholesterol tunes fluidity; surface carbohydrates (glycolipids, glycoproteins) form the glycocalyx for cell recognition and immunity.

The membrane is selectively permeable. Passive transport needs no energy: diffusion, facilitated diffusion (through channel and carrier proteins) and osmosis (water across semipermeable membranes). Active transport uses ATP to pump substances against gradients — the sodium–potassium pump (3 Na⁺ out, 2 K⁺ in) maintains the electrochemical gradients behind nerve impulses. Bulk transport moves large cargo: endocytosis in, exocytosis out, phagocytosis for particles.

Osmosis has medical consequences: red blood cells burst (haemolysis) in pure water and shrivel (crenation) in concentrated salt — which is why intravenous fluids must be isotonic. Exam favourite: predict cell behaviour in hypotonic, isotonic and hypertonic solutions.

Key Definitions

Fluid mosaic model is defined as the model describing membranes as a fluid lipid bilayer with embedded, mobile proteins

Key Points — very important for exams

Fluid mosaic: phospholipid bilayer + floating proteins + cholesterol + glycocalyx.

Passive: diffusion, facilitated diffusion, osmosis (no ATP); active: pumps like Na⁺/K⁺ ATPase (needs ATP).

Bulk: endocytosis/exocytosis/phagocytosis; tonicity predicts cell swelling or shrinking.

Review Questions

- ? What does selective permeability mean?
- ? Predict a red cell's fate in distilled water vs concentrated saline.

Section Summary

The fluid-mosaic membrane controls all traffic — passively down gradients, actively against them.

Exam Pointers

- Describe membrane structure and compare passive vs active transport with examples.

Lecture 5: The Nucleus: Genome Storage and Control

Learning Objectives

- Describe nuclear structure
- Explain DNA packaging levels

The nucleus is the cell's control centre: it stores the genome, directs protein synthesis and controls division. It is bounded by a double nuclear envelope perforated by nuclear pores — selective gates for mRNA export and protein import — and contains chromatin (DNA + histones), which condenses into chromosomes during division, and the nucleolus, where ribosomal RNA is made.

DNA packaging is hierarchical: DNA wraps histones to form nucleosomes (beads on a string), which coil into the 30-nm fibre and loop into chromosomes — compressing two metres of human DNA into a micrometre-scale nucleus. Euchromatin is loosely packed and transcriptionally active; heterochromatin is dense and silent.

The nucleolus manufactures rRNA and assembles ribosomal subunits — fitting, since ribosomes then translate the nucleus's messages. Nuclear abnormalities (abnormal chromosome numbers, misshapen nuclei) are diagnostic in cancer pathology, linking this lecture to medicine.

Key Definitions

Nucleosomes is defined as DNA–histone beads-on-a-string, the first level of chromosome packaging

Nucleolus is defined as the nuclear subdomain where ribosomal RNA is synthesized and ribosomal subunits assembled

Key Points — very important for exams

Double envelope + nuclear pores (selective transport); chromatin; nucleolus makes rRNA.

Packaging: DNA → nucleosomes → 30-nm fibre → loops → chromosomes.

Euchromatin active, heterochromatin silent; nuclear changes diagnose cancer.

Review Questions

- ? How does the cell fit 2 metres of DNA into the nucleus?
- ? What passes through nuclear pores, and in which directions?

Section Summary

The nucleus stores, packages and expresses the genome through a gated double membrane.

Exam Pointers

- Describe nuclear structure and the hierarchy of DNA packaging.

Lecture 6: The Endomembrane System: ER, Golgi and Lysosomes

Learning Objectives

- Describe endomembrane organelles

- Trace protein trafficking

The endomembrane system is a coordinated set of membranes: rough endoplasmic reticulum (RER, studded with ribosomes — synthesizes secretory and membrane proteins), smooth ER (lipid synthesis, detoxification, calcium storage), Golgi apparatus (stacks of cisternae that modify, sort and package proteins into vesicles), lysosomes (digestive-enzyme sacs recycling waste) and vacuoles.

Protein trafficking follows the secretory pathway: RER → transport vesicle → Golgi (modification, e.g. glycosylation; sorting) → secretory vesicle → plasma membrane or outside. Signal sequences act as address labels; mis-sorting causes disease (e.g. inclusion-cell disease). This directional flow is a favourite exam diagram. 

Lysosomes digest worn organelles (autophagy), engulfed particles and, in programmed contexts, whole cells during development; Tay–Sachs disease results from a missing lysosomal enzyme. Plant central vacuoles store water, pigments and toxins and maintain turgor pressure — the basis of plant rigidity.

Key Definitions

Autophagy is defined as lysosomal digestion of the cell's own worn-out organelles

Secretory pathway is defined as the RER → Golgi → vesicle route delivering proteins to membranes or secretion

Key Points — very important for exams

RER: protein synthesis; SER: lipids/detox/calcium; Golgi: modify, sort, package.

Secretory pathway: RER → vesicle → Golgi → vesicle → membrane/outside; signals are address labels.

Lysosomes recycle via autophagy; defects cause storage diseases (Tay–Sachs).

Review Questions

- ? Draw and label the secretory pathway.
- ? What goes wrong in lysosomal storage diseases?

Section Summary

The endomembrane system manufactures, addresses and delivers proteins — and recycles the cell's waste.

Exam Pointers

- Trace the secretory pathway and explain the functions of ER, Golgi and lysosomes.

Lecture 7: Mitochondria, Chloroplasts and Energy

Learning Objectives

- Describe mitochondrial and chloroplast structure
- Explain respiration and photosynthesis

Mitochondria generate ATP by aerobic respiration and are called the powerhouse of the cell — though they also regulate apoptosis and calcium. Their double membrane, infolded cristae (housing the electron transport chain) and small circular DNA reflect their origin as engulfed bacteria — the endosymbiotic theory, supported by their own ribosomes and binary-fission-like division.

Cellular respiration has three stages: glycolysis (cytoplasm; glucose → pyruvate; net 2 ATP), the Krebs cycle (mitochondrial matrix; acetyl-CoA oxidized, NADH/FADH₂ produced) and oxidative phosphorylation (inner membrane; electron transport chain pumps protons; ATP synthase makes ~34 ATP as protons flow back — chemiosmosis). Total: about 36–38 ATP per glucose.

Chloroplasts, the plant counterpart, capture light: thylakoid membranes hold chlorophyll; the light reactions split water, releasing O₂ and making ATP/NADPH; the Calvin cycle (stroma) fixes CO₂ into sugar. Photosynthesis and respiration are mirror processes — very important: one stores solar energy in glucose, the other releases it as ATP.

Key Definitions

Chemiosmosis is defined as ATP synthesis driven by proton flow through ATP synthase down an electrochemical gradient

Endosymbiotic theory is defined as the theory that mitochondria and chloroplasts originated as engulfed free-living bacteria

Key Points — very important for exams

Mitochondria: double membrane, cristae, own DNA — endosymbiotic origin; make ATP aerobically.

Respiration: glycolysis (2 ATP) → Krebs → oxidative phosphorylation (~34 ATP via chemiosmosis).

Chloroplasts: light reactions + Calvin cycle; photosynthesis mirrors respiration.

Review Questions

- ? Where does each stage of respiration occur?
- ? What evidence supports the endosymbiotic theory?

Section Summary

Mitochondria release energy from food; chloroplasts capture it from sunlight — the cell's energy economy.

Exam Pointers

- Describe the three stages of respiration; explain chemiosmosis and the endosymbiotic theory.

Lecture 8: Cytoskeleton, Cell Junctions and the Cell Surface

Learning Objectives

- Describe cytoskeletal components
- Explain cell–cell and cell–environment connections

The cytoskeleton — microtubules, microfilaments and intermediate filaments — gives the cell shape, organizes organelles and drives movement. Microtubules (tubulin) form the mitotic spindle, move vesicles along tracks and build cilia and flagella (9+2 microtubule arrangement); microfilaments (actin) power muscle contraction and amoeboid movement; intermediate filaments (keratin) provide mechanical strength.

Cilia and flagella beat to move cells (sperm) or fluids (respiratory tract mucus); their coordinated beating depends on dynein motor proteins walking along microtubules — defects cause primary ciliary dyskinesia. Cell junctions bind tissues: tight junctions seal, desmosomes anchor, gap junctions communicate (plasmodesmata in plants).

The extracellular matrix (animal) and cell wall (plant: cellulose; fungi: chitin; bacteria: peptidoglycan) lie outside the membrane, providing support and signalling context. Integrins link the matrix to the cytoskeleton — the cell senses and grips its environment, important in development and cancer metastasis.

Key Definitions

Microtubules is defined as hollow tubulin polymers forming the spindle, tracks and the 9+2 core of cilia/flagella

Gap junctions is defined as channels directly connecting animal cells for ion and small-molecule exchange

Key Points — very important for exams

Microtubules: spindle, transport tracks, cilia/flagella; microfilaments: movement; intermediate filaments: strength.

Junctions: tight (seal), desmosomes (anchor), gap junctions (communicate).

Outside: ECM/cell walls; integrins link environment to cytoskeleton.

Review Questions

- ? What is the 9+2 arrangement?
- ? How do cells attach to each other and to the matrix?

Section Summary

The cytoskeleton shapes and moves the cell; junctions and walls connect it to neighbours and environment.

Exam Pointers

- Compare the three cytoskeletal elements; describe junctions and extracellular structures.

Lecture 9: The Cell Cycle and Mitosis

Learning Objectives

- Describe the cell cycle and mitosis
- Explain checkpoint control

The cell cycle — interphase (G1, S, G2) plus mitosis and cytokinesis — is the cell's reproductive program. G1: growth; S: DNA replication (each chromosome duplicated into sister chromatids); G2: preparation; then mitosis: prophase (chromosomes condense, spindle forms), metaphase (chromosomes align at the equator), anaphase (sister chromatids separate), telophase (nuclei re-form), followed by cytokinesis (cytoplasm divides).

Checkpoints guard the cycle: G1 (is DNA undamaged? is the cell big enough?), G2 (is DNA fully replicated?), and the spindle checkpoint (are all chromosomes attached?). Cyclins and cyclin-dependent kinases (Cdks) drive transitions; p53, the guardian of the genome, arrests or kills cells with damaged DNA.

When checkpoints fail, cancer results: uncontrolled division from accumulated mutations in proto-oncogenes and tumour suppressor genes. This is why the cell cycle is medically central — many chemotherapy drugs target dividing cells, and modern oncology targets checkpoint proteins.

Key Definitions

Cell-cycle checkpoints is defined as the surveillance mechanisms (G1, G2, spindle) that halt the cycle until conditions are correct

p53 is defined as the tumour suppressor protein that arrests or kills cells with damaged DNA

Key Points — very important for exams

Interphase (G1, S, G2) → mitosis (prophase, metaphase, anaphase, telophase) → cytokinesis.

Checkpoints (G1, G2, spindle) + cyclins/Cdks + p53 guard fidelity.

Checkpoint failure → cancer; chemo and targeted drugs exploit cycle biology.

Review Questions

- ? What happens in each mitotic phase?
- ? How does p53 prevent cancer?

Section Summary

The cell cycle duplicates and divides with checkpoint-guarded precision — failures cause cancer.

Exam Pointers

- Describe mitosis stage by stage; explain checkpoints and their link to cancer.

Lecture 10: Meiosis and Genetic Diversity

Learning Objectives

- Describe meiotic stages
- Explain genetic diversity and errors

Meiosis produces haploid gametes through two divisions: meiosis I separates homologous chromosomes (reducing chromosome number), meiosis II separates sister chromatids. Prophase I is the signature stage — homologous chromosomes pair (synapsis) and exchange segments (crossing over), generating new allele combinations.

Meiosis creates genetic diversity three ways: crossing over, independent assortment of homologues (2^{23} combinations in humans), and random fertilization. Errors cause aneuploidy: nondisjunction (chromosomes failing to separate) produces trisomies such as Down syndrome (trisomy 21), risk rising with maternal age.

Compare with mitosis — very important exam table: mitosis gives two diploid identical cells for growth/repair; meiosis gives four haploid diverse cells for reproduction. Spermatogenesis yields four sperm per meiosis; oogenesis yields one ovum plus polar bodies, with unequal cytoplasmic division.

Key Definitions

Crossing over is defined as exchange of segments between homologous chromosomes in prophase I, creating new allele combinations

Nondisjunction is defined as failure of chromosomes to separate in meiosis, causing trisomy/monosomy

Key Points — very important for exams

Meiosis I: homologues separate (reduction); meiosis II: chromatids separate; prophase I: crossing over.

Diversity: crossing over + independent assortment + random fertilization.

Nondisjunction → aneuploidy (e.g. trisomy 21); compare mitosis vs meiosis in a table.

Review Questions

- ? What are the three sources of meiotic diversity?
- ? Contrast mitosis and meiosis across five features.

Section Summary

Meiosis halves the chromosome number while shuffling genes — the cellular basis of inheritance and diversity.

Exam Pointers

- Describe meiosis and compare it with mitosis; explain sources of genetic diversity.

Lecture 11: Cell Signalling and Communication

Learning Objectives

- Describe signalling modes
- Trace a signalling pathway

Cells communicate constantly. Signalling modes: direct contact (gap junctions), paracrine (local mediators), synaptic (neurons), endocrine (hormones via blood) and autocrine (self). A signal binds a receptor — either intracellular (steroid hormones crossing the membrane) or cell-surface (G-protein-coupled receptors, receptor tyrosine kinases) — triggering transduction cascades that amplify the message.

Second messengers (cAMP, Ca²⁺, IP₃) relay signals inside the cell; phosphorylation cascades (e.g. MAP kinase) amplify and distribute them. Responses include enzyme activation, gene expression changes and cytoskeletal rearrangement. Signal termination — phosphodiesterases degrading cAMP, receptor internalization — is as important as activation; cholera toxin kills by blocking G-protein shutoff.

Defective signalling causes disease: uncontrolled growth-factor signalling drives cancers (many targeted drugs block receptor tyrosine kinases), insulin-signalling failure causes diabetes. The pathway diagram — signal → receptor → transduction → response → termination — organizes every example.

Key Definitions

Second messengers is defined as intracellular relay molecules (cAMP, Ca²⁺) that carry the signal from receptor to response

Key Points — very important for exams

Modes: contact, paracrine, synaptic, endocrine, autocrine.

Pathway: signal → receptor (GPCR/RTK) → second messengers/cascades → response → termination.

Broken signalling → cancer, diabetes; many drugs target these pathways.

Review Questions

? Compare steroid-hormone and peptide-hormone signalling.

? Why is signal termination essential?

Section Summary

Cells talk through receptors and cascades — amplified, regulated, terminable conversations.

Exam Pointers

→ Describe cell-signalling modes and the receptor → response pathway with an example.

Lecture 12: Cell Death, Apoptosis and Cancer

Learning Objectives

- Compare cell death modes
- Explain apoptosis and cancer biology

Cells die in two ways. Necrosis is accidental death from injury — swelling, rupture, inflammation. Apoptosis is programmed cell death: orderly, energy-requiring, non-inflammatory — the cell shrinks, its DNA fragments, and it is quietly engulfed. Apoptosis sculpts development (removing webbing between fetal fingers), maintains tissues and eliminates damaged cells.

The machinery centres on caspases (protease executioners) activated via the extrinsic pathway (death receptors like Fas) or the intrinsic pathway (mitochondria releasing cytochrome c when Bcl-2-family sensors detect damage; p53 can trigger it). Too little apoptosis → cancer and autoimmunity; too much → neurodegeneration.

Cancer is the cell biology of failed controls: sustained proliferative signalling, evasion of growth suppressors and apoptosis, limitless replication (telomerase), angiogenesis, invasion and metastasis — the hallmarks. Understanding these hallmarks guides therapy: surgery, radiation and chemotherapy attack dividing cells; targeted and immune therapies attack specific hallmarks.

Key Definitions

Apoptosis is defined as orderly, programmed cell death via caspases — non-inflammatory cellular suicide

Key Points — very important for exams

Necrosis: messy accidental death; apoptosis: orderly programmed death (caspases; extrinsic/intrinsic paths).

Apoptosis sculpts development and deletes damaged cells; failures → cancer/autoimmunity/neurodegeneration.

Cancer hallmarks: uncontrolled growth, apoptosis evasion, angiogenesis, metastasis — each a therapy target.

Review Questions

- ? How does the intrinsic apoptotic pathway work?
- ? List four hallmarks of cancer.

Section Summary

Programmed death balances division; when the balance breaks, cancer follows — and therapy targets the breakage.

Exam Pointers

- Compare necrosis and apoptosis; explain apoptotic pathways and cancer hallmarks.

Lecture 13: Studying Cells: Fractionation, Microscopy and Culture

Learning Objectives

- Describe cell-study techniques
- Choose techniques for research questions

Cell fractionation — homogenizing tissue then separating organelles by differential centrifugation — lets biochemists study each organelle: nuclei pellet at low speed, mitochondria next, microsomes (ER fragments) and finally ribosomes at ultra-high speed. Marker enzymes confirm purity (e.g. acid phosphatase for lysosomes).

Microscopy advanced from light to fluorescence (antibodies tagged with fluorophores locate specific proteins), confocal (optical sectioning for 3D), and electron microscopy (TEM ultrastructure, SEM surfaces). Live-cell imaging with GFP-tagged proteins watches processes in real time — mitosis, vesicle trafficking — as they happen.

Cell culture grows cells in dishes: primary cultures (limited divisions) versus immortal cell lines (HeLa).

Applications span drug testing, vaccine production and stem-cell research. Very important: every technique answers what it separates or visualizes — exams ask you to match technique to question.

Key Definitions

Differential centrifugation is defined as separating organelles by spinning homogenates at increasing speeds

Key Points — very important for exams

Differential centrifugation separates organelles by size/density; marker enzymes verify.

Microscopy: fluorescence (protein location), confocal (3D), TEM (ultrastructure), SEM (surfaces), live GFP imaging.

Cell culture: primary vs cell lines — drug testing, vaccines, stem cells.

Review Questions

- ? How would you isolate pure mitochondria?
- ? Which microscopy shows a protein's location in a living cell?

Section Summary

Fractionation, advanced microscopy and culture let us take cells apart, watch them live and grow them at will.

Exam Pointers

- Describe fractionation and microscopy techniques; match each to its use.

Glossary of Key Terms

Cell theory — the theory that all organisms consist of cells, the cell is life's basic unit, and all cells come from pre-existing cells

Resolution limit (light microscopy) — the resolving power limit of the light microscope, about 0.2 micrometres

Prokaryotic cells — cells lacking a membrane-bound nucleus, with DNA in a nucleoid region

Surface-area-to-volume ratio — the geometric constraint forcing cells to stay small or develop high-surface-area shapes

Protein structure (primary–quaternary) — the four levels of protein organization: sequence, helices/sheets, 3D folding, multi-subunit assembly

Enzymes — biological catalysts, usually proteins, that lower activation energy and are highly specific

Fluid mosaic model — the model describing membranes as a fluid lipid bilayer with embedded, mobile proteins

Nucleosomes — DNA–histone beads-on-a-string, the first level of chromosome packaging

Nucleolus — the nuclear subdomain where ribosomal RNA is synthesized and ribosomal subunits assembled

Autophagy — lysosomal digestion of the cell's own worn-out organelles

Secretory pathway — the RER → Golgi → vesicle route delivering proteins to membranes or secretion

Chemiosmosis — ATP synthesis driven by proton flow through ATP synthase down an electrochemical gradient

Endosymbiotic theory — the theory that mitochondria and chloroplasts originated as engulfed free-living bacteria

Microtubules — hollow tubulin polymers forming the spindle, tracks and the 9+2 core of cilia/flagella

Gap junctions — channels directly connecting animal cells for ion and small-molecule exchange

Cell-cycle checkpoints — the surveillance mechanisms (G1, G2, spindle) that halt the cycle until conditions are correct

p53 — the tumour suppressor protein that arrests or kills cells with damaged DNA

Crossing over — exchange of segments between homologous chromosomes in prophase I, creating new allele combinations

Nondisjunction — failure of chromosomes to separate in meiosis, causing trisomy/monosomy

Second messengers — intracellular relay molecules (cAMP, Ca²⁺) that carry the signal from receptor to response

Apoptosis — orderly, programmed cell death via caspases — non-inflammatory cellular suicide

Differential centrifugation — separating organelles by spinning homogenates at increasing speeds